Mirror Agnosia and Mirror Ataxia Constitute Different Parietal Lobe Disorders

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We describe two new clinical syndromes, mirror agnosia and mirror ataxia, both characterized by the deficit of reaching for an object through a mirror in association with a lesion of either parietal lobe. Clinical investigation of 13 patients demonstrated that the impairments affected both sides of the body. In mirror agnosia, the patients always reached toward the virtual object in the mirror and they were not capable of changing their behavior even after presentation of the position of the object in real visual space. In mirror ataxia (resembling optic ataxia) although some patients initially tended to reach for the virtual object in the mirror, they soon learned to guide their arms toward the real object, all of them producing many directional errors. Both patient groups performed poorly on mental rotation, but only the patients with mirror agnosia were impaired in line orientation. Only 1 of the patients suffered from neglect and 3 from apraxia. Magnetic resonance imaging showed that in mirror agnosia the common zone of lesion overlap was scattered around the posterior angular gyrus/superior temporal gyrus and in mirror ataxia around the postcentral sulcus. We propose that both these clinical syndromes may represent different types of dissociation of retinotopic space and body scheme, or likewise, of allocentric and egocentric space normally adjusted in the parietal lobe.

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Shaving, combing, or putting on makeup is quite difficult without using a mirror. For such everyday life activities, we make use of a mirror without the need to think about the visuomotor transformations we perform. Young children and animals, who have not had contact with a mirror, have instead gross difficulties dealing with it. Hence, early in our life we learn to use mirror images through our regular contact with them. Because these operations represent high-level performances of spatial abilities requiring complex sensory-motor transformations, only frequently performed and simple tasks are easy to perform under mirror vision. Implementation of more complex tasks such as mirror writing is difficult but can be mastered after regular training. For example, Leonardo da Vinci made his records by mirror writing, to keep them secret from intruders. Moreover, well-learned "mirror transformations" are normally well adapted, so that they can be updated easily for manipulation in extrapersonal space.

The parietal cortex plays a crucial role in the processes linking sensation to action.[1–4] This requires integration of visual and somatic inputs[5,6] for the generation of representations of posture and movement and their spatial relation to external stimuli so that not only the location of an object in space, but also of the potential actions on it, are coded.[1–3,7] To achieve this goal, the parietal lobe participates in directing selective attention to the environment and in establishing the sensorimotor transformations required for on-line organization of motor behavior.[1,8–10]

Neurons in the lateral intraparietal cortex (LIP) and area 7a generate an implicitly distributed representation of stimulus location in head-centered coordinates by combining a signal about the retinal location of the stimuli and a multiplicative gain signal covarying with the orbital position of the eyes.[1] These converging signals also include gain fields covarying with head position and body orientation next to auditory and vestibular inputs. Accordingly, the posterior parietal cortex may generate multiple simultaneous representations in eye-, head-, body-, and world-centered frameworks,[11] rather than a single reference for spatial localization. The multiplicative gain-field interactions between the different processing zones appear to be a powerful and robust mechanism to produce the coordinate transformations that integrate the diverse inputs into a distributed polymodal spatial representation.[1,9,10]

Activation studies in humans provide evidence for

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parietal lobe involvement in visuomotor and tactuomotor performance.[12–14] Conversely, visuomotor dysfunction such as visuomotor ataxia or ideomotor and ideational apraxia with gross derangement of spatial temporal relationships are seen in patients with parietal damage.[15] The disturbance of sensorimotor transformations can be quite circumscribed, as shown by the specific disturbance of prehension movements in anterior intraparietal area lesions[16] and in deaf patients with the inability to produce the movements required for sign language although they can perform flawlessly in visuomotor and tactuomotor activities.[17] A recent activation study showed that mirror and inverse reading activates the superior parietal lobule (SPL), the cortex lining the intraparietal sulcus (IPS), and the latero-occipital area (LO),[18] indicating the prominent role of the posterior parietal lobe for mirror transformation. Another deficit has been recently described for patients with so-called mirror agnosia who were not able to reach toward the object when seen through a mirror but bumped into the mirror.[19] However, their deficit was not specific, as all patients reported so far suffered from hemineglect.

Here, we report on 13 patients with unilateral infarcts of either parietal lobe who presented with a disturbance of visually guided reaching when targets were presented through a mirror. Specifically, the deficit became apparent in the patients lying prone with a mirror positioned over their heads in angulation from the vertical. In all patients, the mirror-induced visuomotor deficit was present on both sides, although more pronounced on the contralesional arm. Because this disturbance of mirror-guided reaching was not associated with spatial hemineglect or spatial disorientation, it appears as a specific syndrome of parietal lobe dysfunction.

Preliminary data were presented in abstract form.[20]

Patients and Methods

Patients

Thirteen patients with lesions of either parietal lobe (mean age, 63.8 years; SD, ± 11.7 years; 6 left parietal, 6 right parietal, and 1 biparietal) of ischemic origin (11 patients), cerebral bleeding (1 patient), or glioma (1 patient) were included in our study. Four patients with lesions of other parts of the brain (mean age, 50.7 years; SD, ± 9.4 years) served as a control group, they also underwent clinical examination and participated in the mirror experiment. Clinical and demographic data of the patients are shown in Table 1.

All but 2 patients were studied in the early chronic stage after regression of acute neurological impairment.

Neuropsychological Testing

All patients were tested for unilateral neglect by means of standard paper and pencil tests, including Visual Neglect,[21] Line Bisection test,[22] and some additional bedside tests (painting a clock, a house, and a flower). They were also screened for apraxia by the Florida Apraxia Screening Test.[23]

Table 1. Clinical Findings at Time of Examination

Patient No.	Age (yr)/Sex	Time of Examination	Lesion Site	Paresis	Hemianopia	Somatosensory Deficit	Apraxia	Neglect
Patients with parietal lesions								
Mirror agnosia								
1	72/M	3 wk	L parietal	+	0	0	+	0
2	72/F	4 wk	L parietal	0	0	0	+	0
3	70/M	4 mo	R parietal	0	0	0	0	0
4	66/M	5 wk	L parietal	0	0	0	++	+
5	75/F	6 wk	R parietal	+	+	++	0	0
Mirror ataxia (severe)								
6	68/M	3 wk	L parietal	0	0	+	++	+
7	77/M	5 wk	R parietal	0	0	++	++	0
8	48/M	12 mo	R parietal	+	+	++	+	+++
9	69/M	3 wk	L parietal	0	0	0	0	0
Mirror ataxia (mild to moderate)								
10	62/M	2 wk	R parietal	0	0	+	0	0
11	56/M	3 wk	L parietal	0	0	+	0	0
12	59/M	5 mo	R parietal	0	0	+	0	0
13	36/M	4 wk	R parietal	0	0	0	0	0
Control patients								
1	45/M	4 wk	R premotor	+	0	0	+	0
2	50/M	3 wk	L premotor	0	0	0	0	0
3	39/M	12 mo	L thalamic	0	0	+++	0	0
4	52/F	3 wk	L frontal	0	0	0	+	+

0 = no deficit; + = slight deficit; ++ = moderate deficit; +++ = severe deficit.

All parietal patients were asked to perform the Mental Rotation Test[24] and the Line Orientation Test.[25]

Eleven patients performed an automated version of the Mirror Drawing Task,[26] where they had to track a star presented to them through a mirror. Because many of the severely affected patients had gross difficulties with completing even one trial of these tasks, based on the normative data from Wilson and colleagues,[26] we defined a normal range for the median time (MT; MT = 75.4 seconds; p90 = 110 seconds) and for the mean number of errors (MNE; MNE = 10; p90 = 20) of the first three trials. Performance of the patients was then classified as normal (within the normal range), poor (outside the normal range), and very poor (no trials completed).

Also, the patients were asked to indicate their subjective body midline by drawing a vertical line in the air with the outstretched arm and and with their eyes closed. The test was repeated after the head was turned passively to the right and to the left. Thereby, we wished to assess whether the subjective midline was related to the midsagittal plane of the patient or was affected by passive turning of the head. Proprioceptive tracking was tested by asking the blindfolded patients to match the position of one forearm to the passively imposed position of the other forearm.

Mirror Experiment

Patients laid comfortably on their backs with their arms outstretched. A bright red object was positioned within reach, approximately 30 cm above the body and at the level of the hips. The object was viewed via a large mirror positioned above the head and tilted 45° from the vertical. The patients were asked to look into the center of the mirror so that they could see the mirror reflection of the object. All patients were fully aware of the experimental situation and recognized the mirror, as they were asked whether the mirror was properly adjusted to see the object well in the center. They were able to see their arms when reaching toward the objects, both directly and through the mirror. The patients were then asked whether they recognized the object and then they were required to reach out and grab for it.

At the beginning of each session, patients were confronted with the object presented through the mirror, and the first 10 measurements were made. Thereafter, the main measurement session began.

In detail, the patients were asked to perform the following tasks: to reach straight toward the object while fixating on the object; to reach toward the object while viewing it through the mirror; to reach toward the object with eyes closed after the hand was guided passively to the object without visual control; to reach toward the object after the hand was guided to the real object passively and under visual control; to reach toward parts of their own bodies with eyes closed; to reach toward parts of their own bodies while viewing them through the mirror; and to adjust a handheld pencil into a subjective vertical position while viewing it through the mirror.

In some patients the following additional control testing was performed: reaching to an object presented through a mirror positioned on the patient's side; and reaching to a light spot presented to the patient directly or through the mirror in darkness. Performance of the patient was recorded by a video camera and evaluated off-line. Ten trials were performed for each condition, to assess the performance and its adaptation quantitatively.

KINEMATIC RECORDINGS. In addition, in 8 patients, the reaching performance was recorded by the optoelectronic system Selspot II (Selcom, Sweden), to demonstrate the dynamic aspects of patient behavior.

Infrared light-emitting diodes (LEDs) were positioned at the index finger and at the styloid process of the radius, the elbow, and the shoulder. LED positions were recorded by two optoelectronic cameras at a sampling rate of 100 Hz. Ten recordings were made for each arm. Both arms were tested. Details about the system and the data processing have been described elsewhere.[16,27]

ANALYSIS OF THE VIDEO RECORDINGS. Detailed analysis of patient performance in the clinical examination and in the reaching tasks was done while examining the video recordings in the slow-motion mode.

The following criteria were used for evaluation of patient performance in the reaching tasks.

Direction of the arm movement during the initial phase of the movement. The patients guided their arms either toward the virtual object in the mirror or toward the real object. The actual direction was expressed as a ratio of percentage toward the mirror to percentage toward the object.

Number of corrections of the movement trajectory during the reaching phase. The patients guided their arms directly to the mirror, to the object, or somewhere in between. Some of them implemented several corrections on their trajectory. The number of turning points in the trajectory was counted. Because the number of corrections could vary from trial to trial we counted the mean number of corrections per 10 trials.

Number of successful trials. This is the number of trials in which the object was successfully grasped by the hand.

Lesion Analysis

High-resolution magnetic resonance images of the entire brain were obtained approximately 1 week before or after investigation using a strongly T1-weighted gradient echo sequence. Images were reoriented parallel to the canthomeatal line, thereby allowing anatomical mapping on corresponding templates of the stereotactic atlas of Talairach and Tournoux.[28] For this purpose, each brain section was proportionally scaled to fit the anteroposterior and transverse dimensions of the atlas brain. Left hemispheric lesions were transferred to the right side so that the lesions of the patients could be superimposed. Common zones of lesion overlap were coded by gray scale (Fig 1).

Results

Reaching to Objects under Direct Visual Control

The patients had no difficulty in reaching to parts of their own bodies while having their eyes closed or

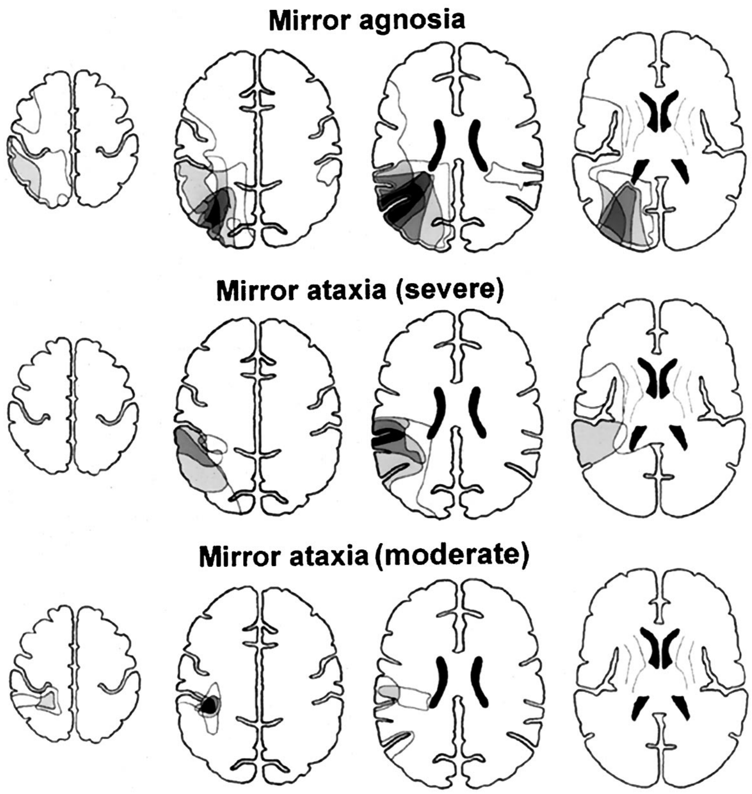

Fig 1. Lesions. Common zone of lesion overlap for patients with mirror agnosia and mirror ataxia (severe and moderate deficits), coded in gray scale and superimposed to corresponding templates derived from the atlas of Talairach and Tournoux.[28] Right hemispheric lesions were transferred to the left side.

while observing through a mirror. Also they were not impaired in grasping the target viewed directly and positioned either in the body midline or in the right or in the left visual field (Fig 2; Table 2). Only 3 patients (Patients 1, 4, and 6) showed mild signs of optic ataxia, misreaching to the target when it was presented in their right visual hemifield and a fixation point was presented centrally. Their optic ataxia was more prominent for the contralesional than for the ipsilesional arm.

Reaching to Objects Presented through a Mirror

When objects were viewed through a mirror, severe reaching deficits became apparent. They could be classified into two subtypes of mirror-induced visuomotor deficits, which were termed *mirror ataxia* and *mirror agnosia.* Some (4 patients) were in between, thus constituting a group with an intermediate type of mirror-induced deficit.

Patients with Mirror Agnosia

One group of patients was unable to distinguish between the real and the mirror space. These patients (Patients 1 through 5) perceived the object as located in or behind the mirror and guided each of their hands directly toward the virtual object image in the mirror. They were not able to reach toward the real object as long as it was presented through a mirror (see Fig 2). Three of these patients (Patients 1, 3, and 4) directed each hand to the mirror in all trials without hesitation and without any attempt to correct the movement path (Figs 3–5; see Fig 2). One patient (Patient 2) initially reached toward the real object two times with the contralesional hand and once with the ipsilesional hand, but after a few corrections (1.8 corrections/trial contralesional and 1 correction/trial ipsilesional) the trajectory was reoriented toward the virtual object in the mirror (see Fig 5). Another patient (Patient 5) directed her arms to the real object in 20% of the trials with the contralesional hand and in 70% of the trials with the ipsilesional hand. This patient was apparently less severely affected and able to correct her movements (3 corrections/trial contralesional and 8.2 corrections/trial ipsilesional). However, she grasped the real object only once with her ipsilesional hand (see Fig 5).

There was no change in the performance of these patients when the position of the target object was changed from trial to trial.

Moreover, common to all these patients was the inability to make use of proprioceptive information provided by passive movements imposed by the experimenter toward the real object, irrespective of whether this was done while the patient watched the procedure or while the patient kept his eyes closed. After this exertion they continued to reach toward the mirror object. Only 1 patient (Patient 5) showed more corrections with the ipsilesional arm.

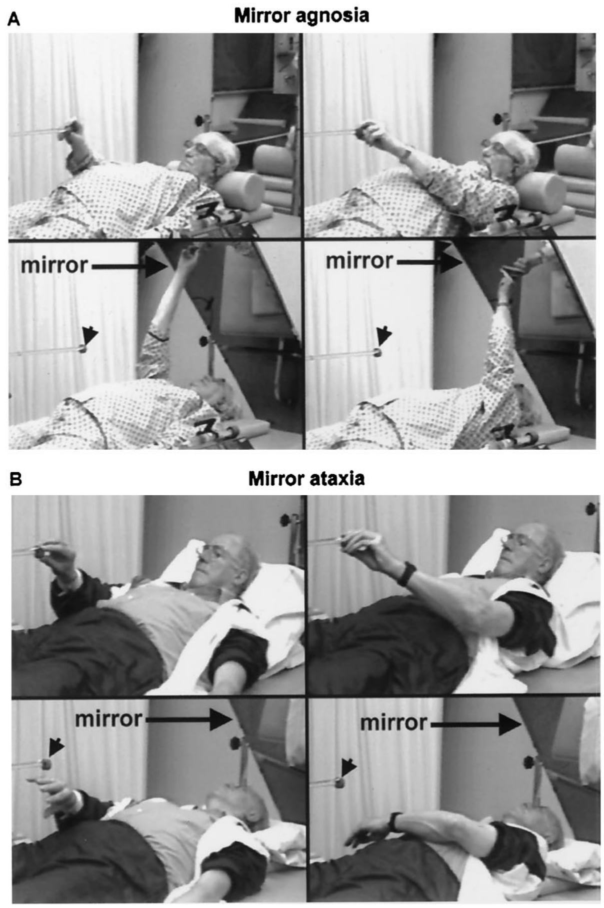

Fig 2. (A) Patient with a left posterior parietal lesion (Patient 1). The patient is able to reach the object correctly with both arms under direct visual control (top panels). When the object is presented through the mirror he directs both arms toward the virtual image in the mirror showing an "agnosic-like" type of behavior (*bottom panels; the mirror is indicated by a* long arrow *and the object by a* short arrow). *(B) Patient with a right lower posterior parietal lesion (Patient 2) with normal reaching under direct visual control (top panels) and an "ataxic-like" behavior with misreaching of the target presented through the mirror with both hands (bottom panels).*

COGNITIVE ASPECTS. All patients were fully aware of the experimental situation and recognized the mirror as they were asked whether the mirror was properly adjusted to see the object well in the center. The patients were then asked whether they recognized the object, and then they were required to reach out and grab the object. When asked where they perceived the position of the object, all these patients reported that they perceived the target as being located in or behind the mirror, thus confusing the real with the virtual image. Even when they watched their arms guided to the object by the experimenter, they could hardly keep their arms on the object. As soon as they looked into the mirror they were so convinced that the object was there that their arms could not be prevented from pointing toward the virtual object as if pulled by a magnet.

To test for the influence of the visual environment on the perception of object position, in 1 patient (Patient 3) the target was presented through a mirror as a dim light in complete darkness. In this new situation (without visual information about the background), the patient continued to direct his arm toward the virtual object in the mirror.

To test whether misreaching also occurred in the horizontal direction, in 2 patients (Patients 1 and 2) the object was presented through a mirror positioned on the patient's side. As long as the direct view of the arm was covered they directed their arm toward the virtual object in the mirror.

A representative example of kinematic recordings of 1 patient with mirror agnosia (Patient 1), while trying to reach an object viewed through the mirror, is presented in Figure 3b. The figures show the different movement paths toward the real object under direct visual control (see Fig 3a[A]) and to the virtual image in the mirror (see Fig 3a[B]). The velocity profiles show that both movements were performed with the same peak velocity and with no additional corrections. All 4 patients from this group, who underwent kinematic recordings, showed the same stereotype features of movement trajectories with a bell-shaped velocity profile and no correction of the movement path.

CLINICAL AND NEUROPSYCHOLOGICAL FEATURES OF PATIENTS WITH MIRROR AGNOSIA. As summarized in Table 1, there were mild signs of contralesional hemiparesis in 2 patients and a moderate sensory loss in the contralesional arm in 1 patient. Three patients exhibited mild or moderate signs of apraxia. In 1 subject there was a mild contralesional hemineglect and 2 patients (Patients 1 and 4) showed mild crossed optic ataxia in the contralesional visual hemifield (see Table 2).

When asked to draw a vertical line in the air with the outstretched forefinger in the subjective midsagittal plane and after passive turning of the head to the right or to the left, all patients reoriented the subjective midsagittal plane in relation to the head (see Table 2).

When asked to match the position of one arm by the other arm with eyes closed all patients exhibited pronounced difficulties (see Table 2).

Also, all patients performed very poor on the Mental Rotation Test[24] ranging between 3 and 8 points. In a similar manner, all patients were impaired in the Benton Line Orientation Test (Version H)[25] (see Table 2).

Four of the 5 patients had difficulties with completing the Mirror Drawing Task.[26] They could not operate their hands on the testboard while viewing it through the mirror. Their hands slid often from the board, as the patients had difficulties with finding even the gross direction for hand orientation (see Table 2).

Table 2. Additional Neuropsychological Abnormalities in the Patients

Patient No.	Grasping Without Mirror		Pointing Toward Own Body Parts		Subjective Body Midline		Proprioceptive Transfer (Bibrachial Position Tracking)		Mirror Drawing Task		MRT (Score Points)	Line Orientation (Score Points)
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left		
Mirror agnosia												
1	VMA to R.				**Head**	**Head**	++	++	+++	++	**3**	**6**
2					**Head**	**Head**	++	++	++	+++	**4**	**7**
3					**Head**	**Head**	++	++	−	−	**6**	**12**
4		VMA to R.		++	**Head**	**Head**	++	++	+++	++	**4**	**16**
5					Body	**Head**	++	++	++	+++	**8**	**11**
Mirror ataxia (severe)												
6	VMA to R.		+	+	Body	Body	++	++	−	−	**3**	**22**
7					Body	Body	++	++	++	++	**1**	25
8					**Head**	**Head**	++	++	++	+++	**7**	25
9					Body	Body		++	++		**12**	27
Mirror ataxia (mild to moderate)												
10					Body	Body	++			++	**16**	26
11					Body	Body			++	++	**6**	29
12					Body	Body					**11**	27
13					Body	Body			++		18	27

Results of additional clinical and neuropsychological testing of patients with parietal lesions.

Displayed are the deficits in performance: + = moderate; ++ = poor; +++ = very poor performance. VMA to R. = visuomotor ataxia to the right; Head = head fixed subjective body midline; Body = head position independent subjective body midline; MRT = Mental Rotation Test;[24] Line orientation = Benton Test of Line Orientation[25] (both tests quantified in score points; pathological performance is emphasized in boldface).

One patient even tried to draw the mirror image on the mirror surface itself.

LESION LOCALIZATION. Three lesions were localized in the left posterior parietal lobe. One ischemic lesion occupied the left posterior parietal lobe down to the parieto-temporo-occipital junction (Patient 1). The second patient had a cystic parieto-occipital lesion after a cerebral bleeding (Patient 2). The third lesion was a grade III astrocytoma with extensive edema covering the entire left parietal lobe extending into the occipital and upper temporal lobe (Patient 2). One patient (Patient 5) had an extensive right parietal infarction occupying the surface of the inferior and posterior parietal lobe and extending into the superior temporal lobe and lower frontal areas. In 1 patient (Patient 3), one lengthy narrow lesion extended from the left lower postcentral sulcus into the superior temporal lobe and another small lesion occupied part of the right supramarginal gyrus.

The common zone of lesion overlap was localized around the posterior part of the angular gyrus and the superior temporal gyrus (see Fig 1).

Patients with Mirror Ataxia

The second group of patients could differentiate the real from the mirror space, but were selectively impaired in the guidance of their movements in mirror space as contrasted by correct visuomotor behavior under direct object view.

MORE SEVERELY AFFECTED PATIENTS. The common feature in the more severely impaired patients (Patients 6 through 9) was that, when confronted with the object through the mirror, they reached spontaneously toward the virtual object in the mirror. They were not able to correct their misreaching in successive trials. However, after external cues were provided, such as demonstrating the movement path through the mirror, they could redirect their movements toward the real object. The crucial feature in these patients was that they were able to learn to operate in the mirror space by external cues.

Nevertheless, they still produced 30 to 40% directional errors with their contralesional arms and 20 to 30% with their ipsilesional arms (see Fig 4), and they did not grasp the object in a considerable number of trials (see Fig 5). A prominent feature of patient per-

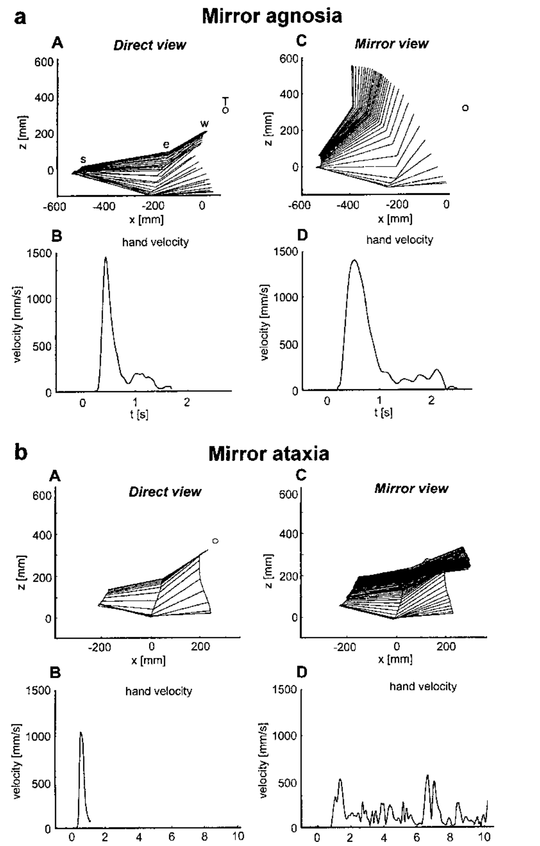

Fig 3. Kinematic recordings of reaching movements of the right arms of patients with mirror agnosia (a) and mirror ataxia (b). (a) The stick figures representing the position of the wrist (w), elbow (e), and shoulder (s) show the different movement paths toward the object (T) under direct visual control (A) and to the mirror when the object is presented through the mirror (C). The velocity profiles show that both movements were performed with the same peak velocity and with no additional corrections (B and D). (b) The stick figures show that the object was reached under direct view (A) and when presented through the mirror (B). However, the movement path shows many corrections as can also be seen on the deranged velocity profile (D) with many velocity peaks.

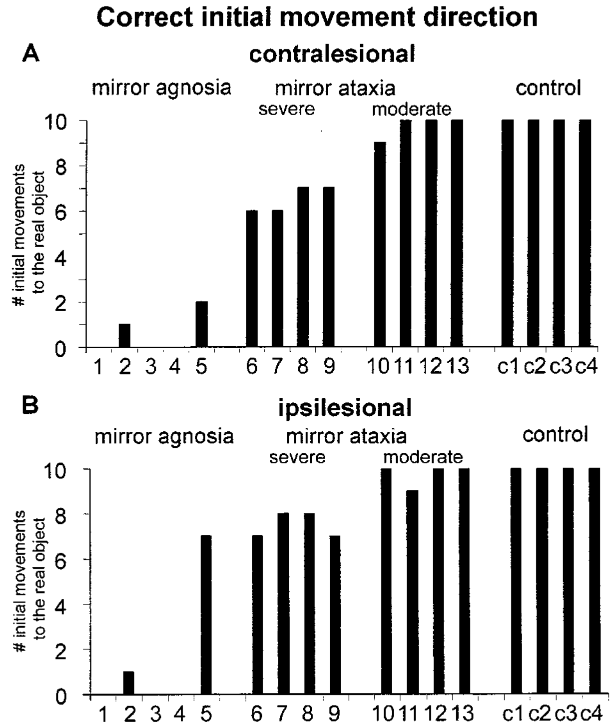

Fig 4. Number of trials with the correct movement direction (toward the real object) for the contralesional arm (A) and for the ipsilesional arm (B).

formances was the large number of corrections they needed to grasp the object. Often, although they could direct their arms away from the mirror and roughly toward the object, they failed to reach it. In these instances they even produced some dystonic-like hand and arm movements (see Fig 2). Otherwise they tried to approach the object by changing their trajectories several times, finally being unable to find a direct way toward the real object (see Figs 2 and 3). They were not able to conceive the direct movement trajectory and therefore looked for other points of reference or approached the target by trial and error.

In 1 patient (Patient 6) the target was presented through a mirror as a dim light in complete darkness. This patient continued to misreach similarly as under normal luminance.

The presentation of the target through the mirror positioned at the side of 3 patients (Patients 6, 7, and 8) provoked a misreaching to the target as in the base condition.

A representative example of a kinematic recording of 1 patient with mirror ataxia (Patient 6) is presented in Figure 3b. Under direct visual control, the target is approached correctly as soon as it becomes visible. The movement shows the normal bell-shaped velocity profile of the hand trajectory. When the object is presented through the mirror, a long searching procedure is induced that can be seen from the stick figure and the deranged velocity profile. Although the details of the movement trajectory varied between the patients of this group, a deranged velocity profile with many corrections of the movement path was the common feature of their reaching behavior.

Clinical and neuropsychological features. One patient (Patient 8) had a slight contralesional paresis, whereas 2 (Patients 7 and 8) had a moderate and 1 (Patient 6) a slight sensory deficit. Two patients (Patients 6 and 7) had a moderate and 1 (Patient 8) a mild apraxia. One patient (Patient 8) presented with a severe contrale-

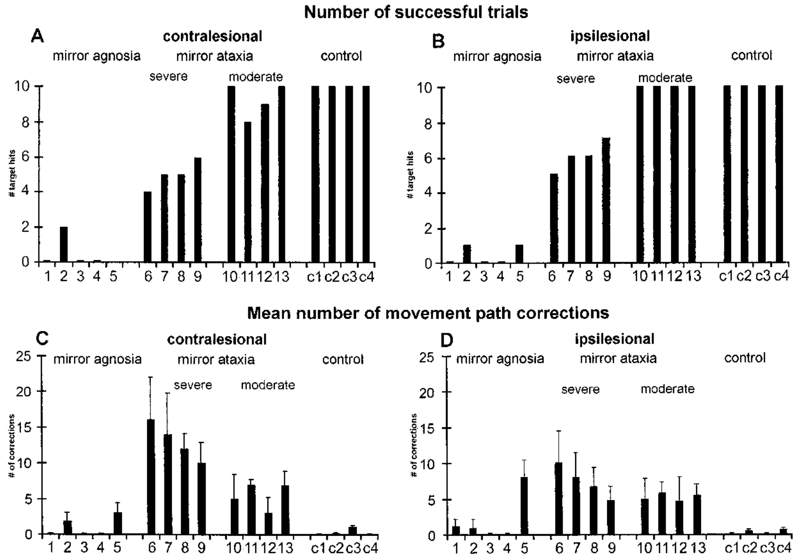

Fig 5. Mean number of corrections of the movement path in 10 trials for the contralesional (A) and ipsilesional (B) arm (with standard deviations). And the number of successful trials (trials in which the target was hit) for the contralesional (C) and ipsilesional (D) arm.

sional visual neglect and 1 patient (Patient 6) with slight contralesional inattention (see Table 1).

One patient (Patient 6) tended to misreach when objects were presented in his right visual field under central fixation of gaze. Only 1 patient (Patient 8) showed a shift of the subjective body midline when his head was passively turned to the left or to the right. The ability to match the position of one arm by the other arm (position tracking) was moderate or poor in this group of patients and affected the contralesional arm more. However, sensory transfer from the ipsilesional arm to the contralesional arm in 1 patient (Patient 9) was not affected (see Table 2).

All patients performed very poorly on the Mental Rotation Test[24] (scores, 1–12), but they performed normally on the Line Orientation Test[25] (scores, 22–27) (see Table 2).

The performance on the Mirror Drawing Task[26] was poor to very poor on both sides in 2 patients (Patients 8 and 7) and poor on the contralesional side in 1 patient (Patient 9) (see Table 2).

Lesion localization. All patients had lesions of ischemic origin of which two affected the right and two the left parietal lobe. One patient (Patient 8) had an extensive lesion occupying the right lower parietal lobe and extending into the right occipital lobe, right upper temporal lobe, and the right frontal opercular area. The other right parietal lesion (in Patient 7) occupied the upper postcentral region, the anterior part of the intraparietal sulcus, and the lower postcentral area extending to the supramarginal gyrus. The larger left parietal lesion (in Patient 9) affected the whole lower posterior parietal lobe down to the parietal operculum. The other left parietal lesion occupied mainly the left supramarginal gyrus and the lower anterior part of the intraparietal sulcus. The zone of common lesion overlap was localized between the posterior part of the lower postcentral gyrus and the supramarginal gyrus (see Fig 1).

LESS SEVERELY AFFECTED PATIENTS. The less severely affected patients (Patients 10 through 13) directed their movements almost always toward the real object, being able to extrapolate the mirror space into real space from the beginning. They always hit the object with the ipsilesional hand, and only 2 patients (Patients 10 and 11) failed to do so in some trials with their contralesional hands (see Fig 4). But, common to these patients, they needed several corrections of their movement path before they finally reached the real object while viewing the object through the mirror (see Fig 5). However, they learned consecutively to direct the movement trajectory to the exact spatial position of the real object.

Clinical and neuropsychological features. The only prominent clinical deficit in this subgroup of patients was a slight contralesional sensory loss in 3 patients (Patients 10, 11, and 12). No paresis, no apraxia, and no neglect was present in these patients. Further, there was no shift of the subjective body midline and no visuomotor ataxia. Only 1 patient (Patient 10) had a slight deficit to match the position of the affected arm by the unaffected arm. Performance on the Mental Rotation Test[24] was, in this patient, either abnormal (11 to 6 points; 12 to 11 points) or in the lower normal range (10 to 16 points; 13 to 18 points). However, all patients in this subgroup performed very well on the Line Orientation Test,[25] scoring between 26 and 29 points. The greatest discrepancy in performance in the two tests was found in a patient (Patient 11) who was severely impaired on the Mental Rotation Test[24] but who performed excellently on Line Orientation Test[25] (see Table 2).

Three of the 4 patients were also impaired on the Mirror Drawing Task.[25]

Lesion localization. All patients from this subgroup had small ischemic lesions localized around the postcentral sulcus and the anterior origin of the intraparietal sulcus, 3 on the right side (Patients 10, 12, and 13) and 1 on the left side (Patient 11). The common zone of lesion overlap was localized in the depth of the anterior intraparietal sulcus (see Fig 1).

Control Group

These patients, who had lesions outside the parietal cortex, including the premotor cortex, the thalamus, and the prefrontal cortex, showed no mirror-induced visuomotor deficit.

Discussion

We observed 13 patients with lesions of right and left parietal lobes who presented with two distinct mirror-induced deficits in visuomotor control.

Five patients, whose presentation was termed mirror agnosia, always reached toward the virtual object in the mirror and were not capable of changing this behavior even after being shown where the object was located in real visual space. More remarkably, the patients were able to see their arms directly and indirectly through the mirror. The characteristic feature in our agnostic patients was their disturbed visual perception such that they were unaware of the mirror-induced disturbance of the spatial relations of objects. However, the more global character of the spatial disorder was illustrated by poor performance on the Benton Line Orientation Test.[25] Although some patients had large parietal lesions in the right hemisphere, they did not present a disturbance of body scheme or visual object agnosia.

Eight of 13 patients presented with mirror ataxia. These patients showed intact cognitive mirror perception, as they could clearly distinguish between the real object and its mirror image, being able to correct the false trajectory to the mirror into one toward the real object. Nevertheless, they produced a number of directional errors.

Patients with mirror ataxia were able to recognize the mirror space but were impaired in the somatosensory-visual integration that is needed for guiding trajectorial movements. Accordingly, the Benton Line Orientation Test[25] was intact in these patients.

Analysis of the imaging data showed that the brain lesions in both groups of patients were localized in either parietal lobe. It is interesting that in both groups of patients the clinical deficit was more pronounced on the contralesional side. This finding may correspond to the observation that the spatial functions are not strongly lateralized[29,30] and that in mirror tracking there is no significant difference for the right or left hemisphere.[31] Plotting the lesions of our patients into common stereotactic space demonstrated that the common zone of lesion overlap in mirror agnosia was located more posteriorly around the temporo-parieto-occipital junction around the superior temporal sulcus, whereas in mirror ataxia the common zone of overlap was located in the anterior and superior posterior parietal cortex (SPL), around the anterior tip of the intraparietal sulcus. Thus, the two clinical syndromes were related to lesions in two different neuronal circuits. Nevertheless, our data suggest that apart from lesion location there was also an effect of lesion size, because the larger infarctions were associated with mirror agnosia and the smaller ones were associated with mirror ataxia. In between, there was a transitional group of patients with large infarctions centered around the intraparietal sulcus. These patients initially did not recognize the mirror space but rapidly adapted to the mirror-induced change of space perception by using external cues and somatosensory feedback information obtained from passive guidance to the objects provided by the investigators.

Our mirror agnostic patients had a disturbance of the transformation of craniotopic into body-centered coordinates that became apparent when they were required to indicate the midline sagittal after turning of the head to one side. In contrast, our mirror atactic patient did not show such a dissociation of craniotopic and body-centered coordinates. A head-centered representation refers to a coordinate system framed with respect to the head. It is formed by relating eye and retinal position information to the head. The body-centered coordinate representation is likewise achieved by relating head, eye, and retinal position information to the body. An even more complicated representation is one in world-centered coordinates, which can be achieved by combining vestibular signals with eye position and retinal position signals. The coordinate systems may vary in different parts of the parietal cortex according to the nature of the activations evoked by the sensory input.[4,32] Evidence from single unit recordings in primates suggests that these representations are continuously updated in the posterior parietal cortex.[33,34] Another way to define relative spatial location of the target and limb would be to converge signals of both onto single cells, as has been observed in the ventral intraparietal cortex (VIP) and area 7b.[35] Parietal neurons related to grasping movements also exhibit interactions between visual inputs and motor functions.[7,36] The convergence of visual- and limb-related inputs might be a means to match attributes of the stimulus, such as target location or object form, with attributes of the appropriate motor response, such as the direction of reach or the general type of grasping action required.[7,36–38] Our data suggest that coding of the different reference coordinate systems involves different parietal modules. In view of the theory of a hierarchical system of space coordination,[11] our agnostic patients showed a dissociation of retinotopic and body-centered coordinates, whereas the mirror-induced visuomotor deficits in the ataxic patients were apparently caused by an inability to update craniotopic coordinates, as suggested by Duhamel and associates.[39] By using a prism adaptation task in a positron emission tomography study, Clower and co-workers[40] found a focal activation in the dorsal parietal cortex (Talairache coordinates −50, −50, 40), concluding that it involved a specific adjustment of representations of the limb and the target used to guide the pointing movements, rather than a global perceptual realignment of visual and proprioceptive reference frames.

A similar inability to distinguish between a real object and its mirror image in 4 patients with right hemispheric lesions and left-sided hemineglect has recently been described by Ramachandran and collaborators,[19] a condition the authors also termed mirror agnosia. It became apparent, when a vertically directed parasagittal mirror was placed on each patient's right side. In this condition these patients reached toward the mirror rather than toward the objects placed in the neglected left hemifield. Because of this arrangement, two interpretations were discussed; ie, mirror agnosia may represent a specific consequence of hemineglect or be caused by a disturbance of spatial abilities after right parietal lobe damage. Because the mentally lucid patients could not "intellectually deduce" that they should search on the left rather than continue to grab the mirror, the deficit was regarded as an example of a "domain-specific tolerance for absurdities." Our investigations make clear that neither hemineglect nor right parietal lesion are necessary conditions for mirror agnosia, so that it constitutes a specific clinical syndrome.

Mirror transformation is learned in early childhood after reaching toward real objects has already been established, having been performed regularly and with increasing frequency during infancy.[41] It should be noted that the only species to show compelling evidence of self-recognition are humans, chimpanzees, and orangutans.[42] One may suggest that the later acquisition of mirror transformation, compared with acting in extrapersonal space by direct viewing, is more vulnerable and therefore is more liable to disruption, and other spatial processing functions subserved by the parietal lobe remain largely undisturbed. The different locations of the lesions in our patients, associated with different expressions of related but clearly differentiable disorders, further support the proposition by Critchley,[43] that the parietal lobes can be parcellated into functional units with different functional properties. As we have recently shown that the described lesions induce a clinical deficit that is the counterpart to a specific activation induced by the corresponding neurological or neuropsychological function,[16] further activation studies are required to clarify whether the disturbed cognitive process resulting in mirror agnosia is parietal in origin or involves occipitotemporal structures that were partly damaged in this group of patients as well.

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