Rehabilitation of Somatic Sensation and Related Deficit of Motor Control in Patients With Pure Sensory Stroke

Nicola Smania, MD, Barbara Montagnana, MD, Silvia Faccioli, MD, Antonio Fiaschi, MD, Salvatore M. Aglioti, MD


Objective: To assess the effectiveness of a rehabilitative training program for deficits in somatic sensation and motor control of the hand in patients with pure sensory stroke.

Design: Multiple baseline and before-after follow-up trial with behavioral analysis of single cases.

Setting: Rehabilitation unit of a university hospital in Italy.

Participants: Four patients were studied: 2 had a unilateral lesion confined to the parietal lobe (patients 1, 2), and 2 had a unilateral lesion of the thalamus (patients 3, 4) that also lapped the posterior limb of the internal capsule. All 4 patients had chronic deficits in somatic sensation and motor control of the contralesional hand.

Intervention: Behavioral training consisting of exercises aimed at improving somatic sensation and motor control of the affected, contralesional hand. Thirty treatment sessions, each lasting 50 minutes, were performed.

Main Outcome Measures: Somatic deficit was evaluated with 5 tests, and motor control deficit was assessed with 4 tests. One functional test estimated the influence of somatic deficit on daily activities. A visual analog scale (VAS) was also submitted to the patients’ relatives to evaluate the amount of use of the affected arm in daily life activities. A baseline was obtained by recording each measure, except for the VAS, 4 times at the first evaluation session. Evaluation sessions were conducted before, after, and 6 months after the end of the experimental treatment.

Results: All patients showed a stable baseline in at least 8 of the outcome measures. Patients 1 and 2 significantly improved in 9 and 7 outcome measures, respectively. Patients 3 and 4 improved in 4 and 7 outcome measures, respectively. With the exception of case 3, all patients considerably increased their use of the affected arm during daily life. The improvement was generally stable over a 6-month period, suggesting that the treatment had a long-term effect.

Conclusions: Results suggest the possible effectiveness of our training program for treating somatic and motor control deficits of the hand in patients with cortical or subcortical pure sensory stroke.

Key Words: Cerebrovascular disorders; Hand; Rehabilitation; Sensation.

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SOMATOSENSORY DEFICIT is among the most frequent outcomes of cerebral lesions.1 According to an epidemiologic survey by Sterzi,2 somatic sensation is impaired in 37% of patients with a lesion to the right hemisphere and in 25% of patients with a lesion to the left hemisphere. The most evident consequences of somatosensory deficit are deficits in tactile recognition and manipulation of objects,3 danger of burns or other injuries to the insensate limb,4 impairment of motor control of the affected limb,5,6 deficits in controlling the level of force of the hand during grasping,7 and poor balance in an upright position and during ambulation. Several studies8-14 have shown that somatosensory deficit has a negative effect on the functional outcome of patients with hemiplegia and prolongs rehabilitative treatment. In the case of the upper limb, the poor functional recovery occurring with sensory loss can be at least in part due to a “learned nonuse” mechanism15 that has been documented in studies with both animal models and human subjects with somatosensory deficit.15-17

The most widely used approaches to stroke rehabilitation—for example, those proposed by Bobath18 and Brunstrom19—typically consider motor deficits as the cardinal impairment and subsequently focus on motor reeducation. To date, despite the clinical relevance of somatosensory deficit, little attention has been given to the rehabilitation of somatosensory function. Nonetheless, both animal and human studies have shown that somatosensory structures in the brain possess a high degree of plasticity20-22 and that rehabilitative training specifically aimed at restoring somatosensory deficit and related disabilities can lead to significant functional improvements.21,23-25

Ruch et al26 performed earlier rehabilitation studies of somatosensory deficit in patients with brain damage. Ruch showed that after a period of training, both monkeys and humans with somatosensory deficit as a result of lesions to the parietal cortex significantly recovered their ability to manipulate objects and discriminate fabric and shapes. These positive results were partially repeated in subsequent studies that nonetheless showed theoretical and methodologic limitations.27-30 More recently, 2 studies24,25 clearly showed the effectiveness of sensory stimulation in reducing somatosensory deficit after brain damage. Carey et al24 tested the effectiveness of a program for rehabilitation of tactile and proprioceptive discrimination in stroke patients by performing 4 AB, single-case experiments31 and 4 multiple baseline experiments. Training consisted of graded discrimination tasks, attentive exploration of stimuli with vision occluded, deliberate anticipation, and quantitative feedback. After treatment, all patients showed clinically significant improvements of trained abilities. Discrimination capabilities of the affected hand became compara-
ble to those of the unaffected hand. Follow-up tests at 3 and 5 months indicated that these therapeutic effects were maintained. Despite their great clinical relevance, the improvements obtained in this study were limited to 2 sensory submodalities: tactile discrimination and proprioception of the elbow joint. Because the stimuli used during rehabilitation were identical to those used in the testing phase, there was no evidence of generalization of acquired abilities to other relevant functions such as hand motor control or daily activities.

Interesting results were obtained also by Yekutiel and Guttman, who assessed 20 patients with chronic hemiplegia and somatic deficits of the hand. These patients received systematic retraining of the sensory function 3 times weekly for 6 weeks. Somatic functions of the plegic hand were tested before and after training in these patients and in 19 untreated control patients. The treated group showed large and significant gains in all sensory tests (tactile location, elbow proprioception, 2-point discrimination, stereognosis). By contrast, no changes were observed in the control group. Unlike in the Carey et al study, a large variety of somatosensory stimuli were used, and training activities differed consistently from those used in the testing phase. Therefore, the Yekutiel and Guttman study showed that comprehensive somatosensory training can lead to significant recovery of somatic sensation, extending to sensory modalities not specifically stimulated during the rehabilitative treatment. As in the Carey study, Yekutiel and Guttman made no attempt either to evaluate or to promote the use of the affected hand in daily life.

Anatomic and physiologic studies show that the neural underpinnings of normal motor performance consist of both somatic and motor systems. Thus, it is no surprise that, as underpinnings of normal motor performance consist of both somatic and motor systems. Thus, it is no surprise that, as

<table>
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<th>Patients No.</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Education (y)</th>
<th>Hand Preference (+24, +24)</th>
<th>Duration of Stroke (mo)</th>
<th>Lesion</th>
<th>Localization</th>
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<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>F</td>
<td>5</td>
<td>+24</td>
<td>20</td>
<td>Ischemic</td>
<td>Right Par (1, 2, 3)</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>F</td>
<td>10</td>
<td>+24</td>
<td>5</td>
<td>Ischemic</td>
<td>Left Par (7, 40)</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>M</td>
<td>5</td>
<td>+24</td>
<td>9</td>
<td>Hemorrhagic</td>
<td>Right Thal, Caps</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>M</td>
<td>3</td>
<td>+24</td>
<td>6</td>
<td>Hemorrhagic</td>
<td>Right Thal, Caps</td>
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</tbody>
</table>

NOTE. 1, 2, 3, 7, 40 are Brodmann’s areas.
Abbreviations: caps, internal capsule; F, female; M, male; par, parietal; thal, thalamus.
etal lesions, whereas patients 3 and 4 had subcortical thalamic lesions that also lapped the posterior limb of the internal capsule. Although the posterior limb of internal capsule normally contains corticospinal motor fibers, patients 3 and 4 (with hemorrhagic thalamic lesions) did not show signs of "pyramidal tract" damage at the clinical examination, likely because the thalamic hematoma did not induce major damage to corticospinal fibers. The sparing of corticospinal fibers was documented in patients 2 and 3 by the absence of degeneration of pyramidal tract, as inferred from the analysis of MRI performed at brainstem levels.45

The topographic distribution of the somatosensory deficit and the anatomic reconstruction of the brain lesions (according to Damasio and Damasio46) of the 4 patients are shown in figure 1.

Clinical examination showed that no patient presented with hypertonus or strength deficit of the intrinsic and extrinsic muscles of the affected hand. Moreover, all patients could
perform slow but coordinated hand movements under visual control. These movements became awkward and imprecise in the absence of visual control.

Under closed-eyes conditions, patients 3 and 4 could not maintain the affected hand in a position aligned with the forearm. In both patients, digits tended to involuntarily and slowly move toward extension while the wrist tended toward flexion, with the hand assuming a dystonic posture.

All patients were informed of the experimental nature of the study and gave their consent for participation. The study followed the guidelines of the Declaration of Helsinki and was approved by the local ethics committee. The patients participating in the study took part in an outpatient regimen.

Testing Procedure

All patients underwent a battery of 10 tests. Five of the tests explored deficits of sensory submodalities involved in the functional use of the hand (tactile discrimination, joint position, pressure sensation, weight discrimination, letters tactile recognition). Four tests examined the impairment of motor control resulting from somatosensory deficit, and 1 test examined the disability deriving from disuse of the insensate hand during daily activities. Complete administration of the battery required about 70 minutes. Patients were blindfolded while being tested.

Each patient was tested before treatment, after treatment, and 6 months after treatment was ceased. For each evaluation session, all tests were repeated 4 times in 4 subsequent days. The scope of multiple repetitions of outcome measures was 2-fold: (1) it provided a pretreatment performance baseline and (2) it reduced variance related to possible spontaneous fluctuations in performance. The training phase started only when the patient achieved a stable baseline in at least 8 of 10 tests. That stability was analyzed by means of the Friedman nonparametric test.

For each test, treatment effects were assessed by comparing the patient’s pretreatment with posttreatment performance and pretreatment with follow-up performance. Averages of the 4 scores obtained in each evaluation session were compared by means of the Wilcoxon nonparametric test. The level of significance for multiple comparisons was adjusted according to the Bonferroni procedure. To ensure that acquired abilities were not restricted to the training stimuli and to test whether generalization of trained ability has been achieved, all the tasks included in the testing protocol differed from those of treatment. Normative data of all tests have been published in a recent report.

Test-retest and interobserver reliability of all outcome measures were evaluated in a sample of 8 patients with pure somatosensory stroke by means of the Kendall τ statistic correlation. Significant and high correlation was observed in the test-retest reliability (τ range, .75–.94; P<.001) and in the interobserver reliability (τ range, .67–1.00; P<.001) in all outcome measures except for the reaching and grasping test, in which there was a relatively smaller statistical correlation in the interobserver reliability (κ = .60, P = .027).

For each patient, an index of use of the affected arm during daily activities was obtained before and after experimental training by asking a patient’s relative to provide his/her subjective judgment on the patient’s use of his/her affected arm during daily life. For this purpose, a visual analog scale (VAS) was used in which higher scores indicated more arm use (range, 0–10). Each patient’s relative was instructed to provide VAS scores by basing their judgments on the amount of use of the arm without taking into account the quality of the patient’s movement performance.

Tactile discrimination (modified version of Carey et al). The stimulus set comprised square-wave gratings cut into the faces of seven 25-mm² plastic blocks. Their spatial periods (combined bar and groove width) were 0.8, 1.6, 2.4, 3.2, 4.0, 4.8, and 5.6mm and were constructed by cutting rectangular (90°) grooves across the face of the blocks. During a test trial, each patient was presented with 3 gratings. Two of them had identical spatial periods (distracting surfaces), whereas the other had different spatial periods (target surface). The patient had to tactually explore the surfaces and recognize the target surface. A forced-choice procedure was used. Each trial requested different levels of tactile discrimination difficulty, depending on the difference between the spatial periods of the target and of distracting surfaces. The test included 12 trials delivered according to a fixed randomization schedule. The score (maximum, 12) was represented by the number of errors.

Joint position sense (Carey’s modified version). This test evaluated subjects’ ability to indicate the wrist or the metacarpophalangeal position after passive movements of these 2 joints. Test stimuli were 36 predetermined wrist or metacarpophalangeal joint positions in the flexion-extension range (22 for the wrist, 14 for the metacarpophalangeal joint).

The testing material consisted of a wooden box (20×40×40cm) that was open at 2 opposite ends. The patient put his/her affected arm inside the box and leaned the proximal segments of the joint to be tested (ie, the forearm in the case of the wrist) against a plank that was vertically fixed inside the box. The distal segments of the arm (hand or fingers) were kept aligned and stable by fixing them to a wood board. Through an opening in the opposite side of the box, the examiner moved the distal segments in various positions within the flexion-extension range according to a fixed randomization schedule. A pointer aligned with the joint’s axis of movement and attached to the top of the box above a protractor scale enabled subjects to provide judgments about joint positions. On each trial, 1 point was assigned for each 15° of discrepancy with respect to the exact joint position. The test score (maximum, 236) corresponded to the sum of points obtained in each trial.

Pressure sensation (modified version of Dannenbaum and Dykes). The testing device consisted of a wooden support with a slide for a plastic tube (1-cm diameter). The tube could move only vertically and ended with a disk at the lower side. A small box was applied at the upper side. The patient, with the hand upright, positioned the tip of her/his third digit under the box that was fixed at the base of the device by means of Velcro strips. During the test, 4 levels of pressure could be applied to the digit by placing 4 different weights (78, 178, 278, 378g) inside the box. Sixteen trials were performed, 8 leaning the tube on the digit without any weight and 8 applying 1 of the weights. Each stimulus was delivered according to a fixed randomization schedule. Subjects were required to report whether weights were applied. The score (maximum, 16) was computed by summing the number of wrong answers.

Weight discrimination. Each patient was required to hold 2 weights simultaneously and to report whether he/she had equal or different weights. In some trials, one of the hands was empty. Six identical cylindrical plastic containers filled with plumbs were used. Three possible weights (100, 300, 500g) were used. A total of 30 trials were performed according to a fixed randomization schedule. The number of wrong answers represented the score (maximum, 30).

Letters tactile recognition. Each patient was required to recognize 12 capital letters (H, V, O, T, F, N, S, C, R, B, Z, A) by means of active tactile exploration. The size of each letter was 0.5×6×8cm (height by width by length). Letters were made of modeling dough and were fixed on a wooden board (12×12cm). The sequence of letter presentation was randomized. The number of wrong answers represented the score (maximum, 12).
Paper manipulation. Each patient was required to crumple a sheet of typing paper into a ball. In a preliminary trial, the task was executed under visual control; in the testing phase, the patient was blindfolded. There were 6 trials. For each trial, the maximum time allowed was 120 seconds. The score (maximum, 120) was represented by the average time used to roll up the sheet of paper.

Motor sequences. Each patient was required to execute 4 movement sequences alternating the first digit of the hand with the other digits. Sequences were as follows: (1) I-II, I-III, I-IV, I-V; (2) I-V, I-IV, I-III, I-II; (3) I-II, I-IV, I-III, I-V; and (4) I-III, I-II, I-IV, I-V. Each trial was preceded by a preliminary practice phase performed under visual control. During the testing phase, each patient was blindfolded. One point was assigned for each opposition movement performed incorrectly (maximum score, 16).

Reaching and grasping. Each patient was asked to reach and grasp 2 or 3 cylinders positioned on a wood board. The board had 64 holes, and the cylinders were fixed to the board by a cog fit in the holes. The cylinders could be positioned according to 12 different predetermined spatial configurations. After 3 practice trials executed under visual control, the testing phase started. Patients were allowed to observe the spatial configuration of the cylinders for 5 seconds, after which they were required to close their eyes and consecutively grab all the cylinders that were present. A maximum of 4 errors were allowed during the trial (hand collisions, grasping failures). The spatial configuration was then changed. The number of errors represented the patient’s score (maximum, 48).

Thumb-index grip force control. The test material was a 10-cm-long cylindrical piston made of Plexiglas, with a diameter of 2 cm. The piston was fitted with a spring that could resist a maximum force of compression of 2500 g. There were 2 red marks on the piston corresponding to the position reached by the piston when compressive forces of 500 or 750 g were applied. Each subject was required to adjust the force of the thumb-index grip to reach the 500- or the 750-g mark. After some practice trials performed under visual control, testing was begun, during which the patient was blindfolded. Both tasks were repeated 10 times according to a fixed randomization schedule. Test score was based on the discrepancies between the expected and the applied force. This comparison was enabled by the presence of other marks on the piston, each mark corresponding to 150 g of compressive force. Zero points were assigned for discrepancies at or below 149 g, 1 point was assigned for discrepancies from 150 to 349 g, 2 points were assigned for discrepancies from 350 to 549 g, and 3 points were assigned for discrepancies from 550 to 750 g. The score (maximum, 30) was obtained by summing the points obtained in each trial.

Functional tests. Each patient was required to perform the following daily activities: (1) closing a zipper; (2) unbuttoning a button; (3) opening and fastening a Velcro strip; (4) fitting a ring on the middle finger of the unaffected hand; (5) using a fork; (6) using a cigarette lighter; (7) sharpening a pencil; (8) pouring water into a glass; (9) putting on and removing a bottle cap; and (10) lacing shoes. For each trial, 0 points were assigned if the task was completed within 15 seconds, 1 point was assigned if the task was concluded between 16 and 30 seconds, 2 points were assigned if the task was concluded between 31 and 45 seconds, 3 points were assigned if the task was concluded between 46 and 60 seconds, and 4 points were assigned if the task was concluded after 60 seconds. The score (maximum, 40) was obtained by summing the points obtained in each trial.

Training Procedure

The treatment protocol consisted of exercises aimed at recovering somatic sensation and motor control of the affected hand. At the beginning of the training session, each patient was asked to perform a series of 25 exercises belonging to 1 of 9 main types of activity. A detailed description of the 9 groups of training activities is provided below. Next, the operator adjusted the protocol to the patient’s specific impairment by choosing exercises that were more challenging for the patient. After this preliminary selection phase, treatment was performed with only the selected exercises. If the patient was unable to perform a given exercise, the operator provided the patient with facilitations. At the end of each trial, the patient was given feedback about her/his performance (eg, number of hits or errors, details about execution, comments). Each patient underwent a total of 30 training sessions. Each patient was required to perform 1 daily hour of exercises at home that were similar to those of the training session. The patient was asked to record in a home diary each day the number and the type of exercises executed, as well as the difficulties encountered.

Tactile discrimination. We used 3 tactile discrimination tasks: sandpaper surfaces of different grains, surfaces made of different materials (eg, rubber, cloth, paper), and grating orientation. All exercises were performed without visual control. In the case of the sandpaper exercises, the operator passively guided tactile exploration to avoid possible skin lesions.

Object recognition. This group included 3 tasks of tactile object recognition. In it, the blindfolded patient was requested to perform these tasks: manipulate a target object and discriminate it visually among 3 objects; manipulate a group of small objects (eg, rice, bolts, stones) and then discriminate visually among the 3 groups of objects; and manipulate 2 objects simultaneously with the affected and unaffected hand and then report whether the 2 objects were the same or different.

Joint position sense. For these training activities, we used the same box as in the testing procedure for the joint position sense testing. This group included 3 tasks of proprioceptive discrimination. The operator moved the patient’s wrist or metacarpophalangeal joints at different angular positions by using the same methods previously described for the joint position test. The patient was required to choose which of 3 suggested positions of the protractor scale above the box corresponded to the real hand position. Using the affected hand, the patient was requested to actively reproduce the position indicated by the operator on the angular scale. The patient was asked to reproduce a gesture shown by the operator with the affected hand (ie, gesture of OK) while keeping her/his arm inside the box.

Weight discrimination. The blindfolded patient was required to weigh an object with the affected hand. Then, he/she was required to weigh 3 objects with the unaffected hand and choose which of them corresponded in weight to the previous object.

Motor sequences. This group included 2 tasks of finger motor sequencing. The blindfolded patient was asked to drum his/her fingers on the table according to a previously shown sequence. The blindfolded patient was required to play a sequence of notes on a piano keyboard.

Reaching and grasping. The blindfolded patient was required to reach and grasp a common object placed on a wood board after having seen its position. The dimensions of the object varied to elicit different kinds of grasping (eg, pinch, whole-hand grasping).

Item grouping. The blindfolded patient was required to separate several small objects (eg, buttons, paper clips) into homogeneous groups.
Grasping strength grading. This group included 4 tasks. First, a cylindrical wood stick was used (70x4cm; 500g). The stick had several marks spaced at 5-cm distances. While holding the stick, the blindfolded patient was required to let the stick slide down, skipping 1 or more marks. Second, the blindfolded patient was required to move a plastic bottle filled from 30% to 60% with water from 1 side of the table to another. During the exercise, patients were asked not to produce any noise that could derive from compression of the plastic. Third, the patient was required to pick up and move objects of different dimensions and frailty (eg, crackers, paper cubes) by using ice piers, without either compressing or breaking them. Last, the patient was required to squeeze a tube containing gel with the affected hand to obtain strips of various lengths.

Daily life activities. This group included 7 tasks: (1) grasping several toothpicks and putting them into a box; (2) stacking up several checker pieces; (3) folding up a sheet of paper and fitting it into an envelope; (4) making a braid with 3 cords made of soft material; (5) hooking up a spring catch to a metal ring while blindfolded; (6) fitting the affected hand into a glove; and (7) picking up several playing cards that had been laid on the table and turning them over while blindfolded.

RESULTS

Patient 1

In the pretreatment baseline battery, patient 1 presented with a fluctuation of performance only in the joint position sense test (χ²=8.89, P=.031). The errors made by this patient in pretreatment, posttreatment, and follow-up sessions in the different outcome measures are shown in figure 2A.

Pretreatment to posttreatment comparisons showed that this patient improved significantly in 9 of 10 tests. Pretreatment to follow-up comparisons showed that the purportedly treatment-related improvement was maintained in 7 tests and that there was a trend toward maintenance of performance in the motor sequence tests (fig 2B). In the pressure sensation test, the patient performed at ceiling levels in all sessions.

Patient 2

Patient 2 did not show any significant fluctuation of performance in the pretreatment baseline battery, except for the thumb-index grip (χ²=19.43, P=.000) and functional (χ²=13.75, P=.003) tests. The errors made by this patient in the pretreatment, posttreatment, and follow-up sessions for each outcome measure are shown in figure 3A.

Pretreatment to posttreatment comparisons showed that performance significantly improved in 7 of 10 tests (fig 3B). Marginal improvement occurred in the weight discrimination and motor sequence tests. Pretreatment to follow-up comparisons showed that all these improvements were maintained at the 6-month follow-up except for the joint position sense test, which showed a worsening. A progression of improvement was seen in the tactile and weight discrimination tests, reaching the level of statistical significance at the 6-month follow-up examination.

Patient 3

This patient was submitted to an initial testing baseline 4 months after his stroke. On this occasion, the analysis with the Friedman test showed that his performance was unstable in 5 of 10 tests (tactile discrimination: χ²=7.69, P=.053; joint position sense: χ²=18.68, P=.000; weight discrimination: χ²=8.64, P=.034; reaching and grasping: χ²=8.05, P=.045; thumb-index grip: χ²=10.57, P=.014). His performance, therefore, exceeded the criterion established for inclusion in the treatment phase. The patient was then submitted to a second baseline testing 9 months after the stroke. A stable performance in all tests was observed. Thus, the second baseline was considered as a pretreatment evaluation, and the patient was admitted to the treatment phase, after which general improvements in performance were seen (fig 4A).

The improvements were statistically significant in 4 tests (weight discrimination, paper sheet twisting, thumb-index grip, functional tests) and were marginally significant in the motor sequences test (fig 4B). The pretreatment to follow-up comparison showed that improvement was maintained in 3 tests and that there was a further significant improvement in the letters tactile recognition test.

Patient 4

The pretreatment baseline in this patient was stable in all the outcome measures. The errors made by patient 4 in pretreatment, posttreatment, and follow-up sessions for each outcome measure are shown in figure 5A.

Pretreatment to posttreatment comparisons showed a significant improvement in 7 tests. A trend toward improvement was also observed in the motor sequences test. The treatment-related improvement tended to diminish in the follow-up sessions. However, pretreatment to follow-up comparisons still showed a statistically significant improvement in 7 tests (fig 5B).
Behavior During Rehabilitative Training

**Patient 1.** The patient was cooperative. In the initial phase, administration of the entire rehabilitative program required 2 training sessions. After this phase, some exercises (grasping bottle, squeezing a tube containing gel, weight estimation, grasping toothpicks, piling up checker pieces, using spring catches) were interrupted because the patient was able to execute them without considerable difficulties. Subsequently, her performance improved, especially in the sandpaper and in the surface discrimination tasks. A progressive improvement was also seen in object recognition, joint position sense, motor sequencing, grouping objects, and daily life tasks. At the end of training, she still had difficulties in the tactile discrimination and in the grasping stick tasks. During the training period, the patient performed the home exercises meticulously and was accurate in the compilation of the home diary. She was satisfied with the results of the training, and she was able to start her work again. The results of the VAS compiled by her sister showed an increase in arm use from 10% to 70%. A further increase in the arm use was seen in the follow-up session (80% by VAS).

**Patient 2.** The patient was compliant. The initial administration of the rehabilitative program required 3 training sessions. After this phase, training was focused on tactile discrimination, motor sequences, item grouping, reaching and grasping, grasping strength grading, and daily life tasks. In particular, 15 minutes of each training session were dedicated to execution of motor sequences on a computer keyboard, taking into account that the patient had worked as a secretary before the stroke. Item grouping as well as reaching and grasping activities were suspended after the first 15 training sessions because the patient successfully executed them. Gradual improvements were seen in motor sequencing and tactile and weight discrimination activities. In the object recognition tasks, the patient showed a slight progression toward improvement. Despite persisting difficulties in tactile discrimination and in object recognition tasks, at the end of training the patient was able to use the computer keyboard. During the training period, the patient performed the home exercises meticulously and was accurate in the compilation of the home diary. She was satisfied with the results of the training, and she was able to start her work again. The results of the VAS compiled by her sister showed an increase in arm use from 10% to 70%. A further increase in the arm use was seen in the follow-up session (80% by VAS).

**Patient 3.** The patient was moderately compliant. The initial phase of the training showed that he had difficulties with all the activities of the training program. During the course of training, the patient slowly but progressively improved in 6 of the proposed activities. No evident effects were found in tactile discrimination, joint position sense, or object recognition tasks. A slight improvement was seen in the movement sequence tasks. At the end of the training, the patient showed clear improvement in daily activities and only minor improvement in the other tasks. It is worth noting that the patient was depressed and thus scarcely motivated to perform the training activities. He did not fill out the home diary, nor did he perform the at-home exercises. The results of the VAS compiled by his wife showed that after training, he still tended to exclusively use the unaffected hand in most daily activities (10% by pretreatment and posttreatment VAS). A slight increase in the use of the arm was seen at the 6-month follow-up session (20% by VAS).

**Patient 4.** The patient was compliant. The first administration of all the training tasks required 3 sessions. After this
The present study showed that patients with pure sensory stroke can achieve significant improvement in somatic sensation and in related deficits of motor control after experimental rehabilitative training. These improvements remained largely stable 6 months after training ended. The effects of treatment cannot be ascribed to spontaneous recovery for at least 2 reasons. First, the performance of all patients was largely stable in the pretreatment baseline session, and, second, all patients were in a chronic stage of illness (stroke had occurred at least 5mo before) at the beginning of treatment.

Our results address a number of issues not considered in previous reports on rehabilitation of somatosensory deficit in patients with stroke. First, our training program was characterized not only by exercise of somatic sensation, but also by exercises aimed at rehabilitation of sensory-related deficits of motor control. Indeed, given the tight links between movement and somatic sensation, motor control exercises could represent a valid integration of training aimed at rehabilitation of somatosensory deficit. The wide number of activities is another important feature of our training program. It enables a precise characterization of the patient’s disability during the first training session, and, consequently, it let us tailor the therapy according to each patient’s specific needs. A further element of distinction from previous studies concerns the assessment procedure. Our testing battery consisted of a large variety of measures that included not only tests of somatic sensation, but also tests aimed at evaluating motor control, functional disability under daily life conditions, and the amount of use of the affected arm. It is relevant that only some of the evaluation tests have affinities with the training activities. In contrast, other activities, such as tactile recognition of letters, rolling up paper, and functional tests, are not similar to the training activities. This strategy enabled us to assess whether treatment-related improvement transferred to untrained sensorimotor activities. Despite the many differences between the tests used in the assessment battery and the training program, most patients showed an improvement that extended to almost all outcome measures, thus showing a generalization of relearned abilities to activities that were not the specific training objectives.

The issue of generalization24 of trained abilities is highly relevant to rehabilitation of somatosensory deficit. In the study of Carey et al.,24 all patients improved their performance considerably, reaching normality in some cases. Nevertheless, their improvement was specifically related to the trained activity. Indeed, when a patient was trained for proprioceptive sensation, the improvement of performance was restricted to proprioception and did not extend to tactile discrimination. Carey’s results suggest that rehabilitation of somatosensory deficit brings about only poor generalization between different somatosensory submodalities. The results of our study, however, show that by using a comprehensive rehabilitative protocol, a considerable degree of generalization of acquired abilities can be attained.

Our results are in agreement with those of Yekutieli and Guttmann,25 who performed a controlled study on a large number of patients with somatosensory deficit. They reported treatment-related improvement in all tests of their battery (location
of touch, sense of elbow position, 2-point discrimination, stereognosis). In the study by Yekutiel and Guttmann, treatment consisted of a wide range of activities that shared only a few aspects with testing activities. Although a poor generalization between somatosensory submodalities has been previously reported, the extensive stimulation offered by a comprehensive rehabilitative treatment of somatosensory deficit may nevertheless lead to improvement in a wider range of somatosensory tasks. It is not surprising that in the present study, all patients significantly improved their performance in many activities, including those involved in daily life that normally require a complex integration between multiple somatosensory submodalities and motor output (eg, active touch, object manipulation, and recognition). Unfortunately, previous studies on rehabilitation of somatosensory deficit do not provide any data about the performance of daily activities.

A further characteristic of our present study involves the level of use of the affected arm. As reported in the VAS examination, all but patient 3 considerably increased their use of the affected arm during daily activities. The nonuse phenomenon is crucial in the rehabilitation of patients with hemiparesis. This phenomenon has been described in detail in nonhuman primates with somatosensory deficit. Taub et al showed that the tendency to underuse the affected arm could be overcome by constraining the unaffected limb with an immobilization device. This procedure has been referred to as constraint-induced movement therapy (CIMT). Some recent studies in patients with stroke hemiparesis showed that the CIMT can lead to significant improvement in the function and use of the affected upper limb. It is relevant that the present study reports, for the first time in pure sensory stroke, increased use of the affected arm contingent on a rehabilitative treatment in which no constraining devices of the intact upper limb were used. A further step of this research could be to assess possible enhancements of treatment effects by combining our rehabilitation program with CIMT.

In the present study, the patients with ischemic parietal lesions were women, whereas the 2 patients with hemorrhagic thalamic lesions were men. The presence of gender differences in somatic sensation has recently been an issue of debate. Relevant to this issue, however, is that no gender- or handedness-related difference was found in a study that collected normative data for the testing battery we used in the present study. It is unlikely that gender-related variables influenced the patients’ performance in the present research. Although handedness per se does not seem to play any significant role in performance of somatosensory tasks, this factor may in principle influence the use of the hand affected by somatosensory deficit and thus influence functional recovery. In the present study, the affected hand was nondominant (left) in patients 1, 3, and 4 and was dominant (right) in patient 2, who, moreover, was also younger than the other patients and was highly motivated to relearn use of the computer for professional reasons. Functional recovery in patient 2, however, did not apparently differ from that observed in the other parietal patient. Studies suggest that functional recovery in the acute poststroke phase may be higher after hemorrhagic than ischemic lesions. Because differential recovery related to the nature (ischemic or hemorrhagic) of the lesions is no longer observed in chronic stages of illness, it is unlikely that the nature of the lesion influenced the patients’ performance in the present study. Another point deserving discussion is the longer lesion-test interval in patient 1 than in patients 2, 3, and 4 (5, 2, and 6 mo, respectively). Although the potential for recovery should be less in the chronic stages of illness, patient 1 remarkably improved in all somatosensory functions tested, thus suggesting the important practical implication that significant recovery may occur long after a stroke lesion.

Patients affected by pure sensory stroke are typically able to perform even selective movements of the finger with reasonable accuracy when the use of vision is allowed. By contrast, when blindfolded, these patients are clearly impaired in their motor performance of the insensate hand in the absence of any paraparesis. It is worth noting that the varied training activities used in the present study brought about amelioration of both somatosensory functions and motor control. This result points to the importance of devoting more attention to rehabilitating somatic sensation, especially in patients in whom somatosensory deficit is associated with a hemiparesis. Indeed, although patients with both sensory and motor deficits constitute the majority of patients with somatosensory deficit after stroke, most classic rehabilitative programs for hemiparetic patients do not provide any rehabilitative approaches for somatosensory deficit.

A final point deserving discussion concerns the relationship between treatment-related improvements and lesional loci. Carey et al reported that the pattern of recovery of patients with somatosensory deficit was not clearly influenced by lesion site. However, no distinction between cortical and subcortical lesions was made because patients were not selected on the basis of the location of the lesion. This issue should be raised because, in principle, organizational redundancy is higher at the cortical than subcortical levels. A considerable degree of functional recovery was observed in 3 of 4 patients in the present study. On the other hand, the efficacy of treatment appears lower in patient 3, who had a subcortical lesion. However, it is important to note that patient 3 was less motivated than the other patients. Indeed, this patient did not perform home activities. Although the results indicate that patients with somatosensory deficit have almost similar recovery potentials after cortical or subcortical lesions, the conclusion based on these results must be confirmed in studies with larger samples of patients with pure sensory stroke lesions. These studies will help researchers to understand the role of lesion location in the recovery of somatosensory deficit after stroke.

CONCLUSION

These 4 cases provide interesting clues for developing rehabilitative procedures in stroke patients with somatosensory and motor disorders. Training programs that include exercises stimulating a wide range of somatosensory modalities and tapping motor control may be most adept for rehabilitation of somatosensory deficit. Training activities should be tailored to the individual, considering the specific pattern of disabilities present in each patient.

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