

Impaired Visual Hand Recognition in Preoperative Patients during Brachial Plexus Anesthesia

Importance of Peripheral Neural Input for Mental Representation of the Hand

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ABSTRACT

Background: Perceptual illusions described in healthy subjects undergoing regional anesthesia (RA) are probably related to short-term plastic brain changes. We addressed whether performance on an implicit mental rotation task reflects these RA-induced changes in body schema brain representations. Studying these changes in healthy volunteers may shed light on normal function and the central mechanisms of pain.

Methods: Performance pattern was studied in upper limb-anesthetized subjects on a left/right hand judgment task, which is known to involve motor imagery processes relating to hand posture. Three conditions were used: control (*i.e.*,

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What We Already Know about This Topic

- Perceptual illusions can occur during sensory blockade produced by regional anesthesia
- A better understanding of the central mechanisms for these illusions may also improve our understanding of permanent phantom sensations, including pain

What This Article Tells Us That Is New

- In 20 subjects receiving brachial plexus block for surgery, right/left judgment appears to involve mental simulation of hand movement and induces acute alterations in mental substrates representing the anesthetized limb

absence of deafferentation), RA (*i.e.*, deafferentation), and vision (*i.e.*, deafferentated limb exposed to view). To limit potential bias such as order effect, the control state was recorded in a randomized manner.

Results: All subjects described perceptual illusions of their anesthetized limb. They were slower and less accurate on the task during RA compared with control. Response patterns were similar in all conditions, suggesting sensitivity of performance to arm/hand biomechanical constraints. Vision was associated with an increase in the proportion of correct responses and a reduction of the response times in hand judgment and was accompanied by disappearance of the lat-

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eralization of the underlying mental representations, which was identified during RA.

Conclusions: These results suggest the following: (1) the right/left judgment task involves mental simulation of hand movements, (2) underlying mental representations and their neural substrates are subject to acute alterations after RA, and (3) the proprioceptive deficit induced by RA is influenced by the subject's ability to see the anesthetized limb.

THE amputation of a limb is usually followed by the feeling that the missing limb is still present.¹⁻³ These nonpainful phantom sensations may include perceptual illusions related to size, shape, and posture of the absent body part.^{4,5} In the past decade, evidence has accumulated that the onset of these illusions is related to long-term plastic changes at several levels of the neuraxis and especially the cerebral cortex.⁶⁻⁹ Interestingly, a set of perceptual illusions similar to those identified in amputees has been described in healthy subjects receiving regional anesthesia (RA),¹⁰⁻¹³ suggesting the implication of acute brain plasticity phenomena. Nevertheless, these studies do not make it possible to confirm the existence of such processes because they are based exclusively on an analysis of the subjective descriptions reported by the participants.

The main purpose of this study was an objective assessment of the effects of acute deafferentation produced by RA on central sensorimotor representations. For this purpose, we used a mental rotation task during an RA procedure on the upper limb. The task concerned a visual left/right hand judgment task, implicitly recruiting motor imagery processes and mental rotation of the hand. Mentally rotating the hand is different from rotating neutral visual shapes. The response time (RT) depends on the trajectory that the hand would have followed if it had actually been moved, as if the subjects mentally rotated their own hand into the stimulus orientation for comparison.¹⁴ The RT for comparing two hands is influenced by the angle of rotation between the two hands and by the direction of the rotation. Indeed, although neutral visual shapes can be rotated freely in any direction, the rotation of one's hand is limited by the biomechanical constraints of the arm.¹⁴⁻¹⁷ These psychophysical studies showed that central body representation also appears to be the implicit functional basis of motor activity in the domain of mental simulation. We hypothesized that short-term loss of sensory feedback would cause an impairment in the hand recognition task, with an increase in RTs when the task was executed. This effect should be predominant for the most unnatural postures (*i.e.*, requiring unnatural movements from the subject to reproduce the postures from his or her own point of view) of the stimulus hand because they challenge mental rotation abilities that are sensitive to the biomechanical constraints of the upper limb. Furthermore, the demonstration of a performance difference in relation to the deafferentated side should be consistent with the possibility that subjects favor their dominant upper limb to execute the task mentally. If so, then when the subject's dominant limb is

deafferentated, he or she would need to use motor simulation by the nonanesthetized hand to execute the task. Last, control of the visual information about the deafferentated limb should allow us to assess the influence of heteromodal information in the central alterations induced by RA.

Methods

Participants

In accordance with the requirements of the local ethical committee (Comité de Protection des Personnes, University Teaching Hospital of Toulouse, Toulouse, France), which approved the study, all participants signed informed consent forms before volunteering for this study. According to the Edinburgh inventory (*i.e.*, a hand preference scale asking which hand is used for 10 items of daily living),¹⁸ all were right-handed. None of them had a history of chronic pain or neurologic or psychiatric disorders. Presurgical patients' conditions and surgery did not lead to impairment of either movements or later use of the upper limb. No patient received any sedative or opioid drug before or during the study period. All had normal or corrected-to-normal vision. Ten subjects (six women and four men; mean age, 41 ± 6 yr [mean \pm SD]) received RA of their dominant upper limb, and another 10 subjects (five women and five men; mean age, 38 ± 8 yr) received RA of their nondominant limb. The indication for the RA was independent of the study (scheduled surgery of the upper limb).

Stimuli

Stimuli were pictures of right and left hands. They were two-dimensional pictures that had shadowing to suggest spatial fullness (fig. 1). The size of these pictures was approximately two-thirds of the size of a real hand (Poser.8; Smith Micro Software, Inc., Aliso Viejo, CA). Each picture, corresponding to one view, was presented using a personal computer. Views included two frontal postures (back and palm) and two side views (thumb and pinkie sides). For each view, hands were rotated through 12 different angles (in 30° steps, from an arbitrary starting position with all fingers pointing up; corresponding to $0^\circ/360^\circ$). Six orientations corresponded to postures easily reached during usual movements (right hand, from 30° to 120° counterclockwise; left hand, from 330° to 120° clockwise). The remaining six pictures depicted less natural postures¹⁹ (*i.e.*, requiring unnatural movements from the subject to reproduce the postures from his or her own view).

Peripheral Nerve Blocks and Assessment of Perceptual Illusions

All patients were anesthetized using the same infraclavicular brachial plexus technique.²⁰ After disinfection of the skin and drawing of cutaneous landmarks, a 22-gauge 100-mm insulated needle (Stimuplex B; B. Braun, Boulogne-Billancourt, France) connected to a peripheral nerve stimulator (Stimuplex, HNS 11; B. Braun, Melsungen, Germany) was used to identify each of the following nerves according to its specific motor-evoked

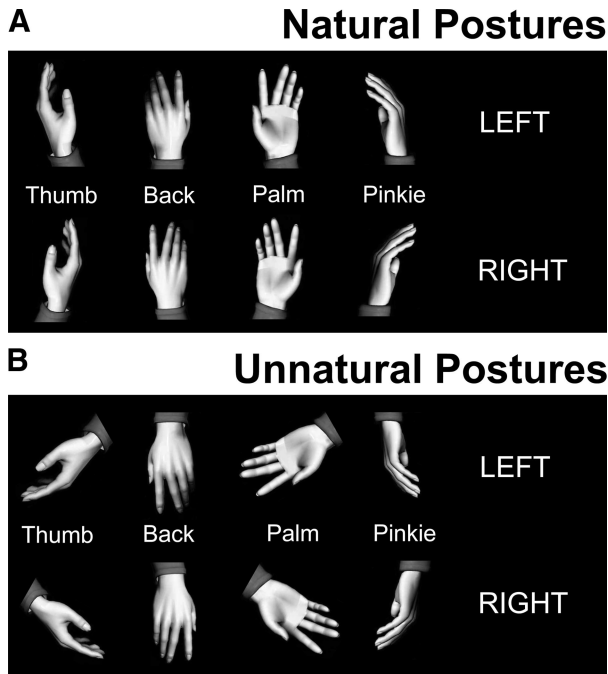


Fig. 1. Stimuli. Examples of pictures of right and left hands used as stimuli. Views included two frontal postures (back and palm) and two side views (thumb and pinkie sides). (A and B) For each view, hands were rotated through 12 different angles (in 30° steps, from 0° to 360°), corresponding to six natural (A) and six unnatural (B) orientations.

responses: median, ulnar, radial, and musculocutaneous nerves. Specific motor responses were sought with the nerve stimulator set at 1-Hz frequency and 100 μ s and a current of 1.5 mA, then progressively reduced to 0.5 mA or fewer when closest to the nerve and before injection of local anesthetic solution (0.75% ropivacaine). A single-injection protocol was used in all cases. The total volume of ropivacaine administered was 30 ml. Immediately after anesthesia, the limb was placed in abduction (arm at 90° with respect to the body) with the elbow in extension (180°) to avoid contact of the studied limb with nonanesthetized parts of the body. The anesthetized limb was hidden from the patient's sight before the block was performed. Then, every 5 min for 60 min, the patients were encouraged to describe their sensations.^{10–13} Finally, the visual mask was removed 60 min after RA, and perceptual distortions were analyzed immediately and then every 5 min for 15 min. Furthermore, sensory (heat-cold, arthrokinesthesia, pallesthesia, and pinprick) and motor functions were also assessed in all of the main distributions of the brachial plexus (musculocutaneous, median, radial, and ulnar nerves) at 15, 45, and 60 min after the end of block placement to evaluate the overall quality of the block before surgery.

Left/Right Hand Judgment Task

The subjects were comfortably installed in a semireclining position. The limb to be anesthetized was positioned at 90° abduction and hidden with the aid of a removable curtain. The contralateral limb stayed in adduction alongside the body. The hand pictures were presented on a personal computer facing the

subject. Subjects were required to look carefully at each stimulus that appeared on the screen and to decide, as rapidly and accurately as possible, whether it was a right or a left hand. The examiner started each trial by pressing a computer key. A fixation cross appeared in the middle of the screen and remained visible for 200 ms. As soon as the previous image disappeared, a new image of one hand appeared in the same location; the picture lasted on the screen until the onset of the verbal response. Participants were asked to answer by responding aloud either *droite* (right) or *gauche* (left). A voice-key microphone recorded response onset and terminated the trial by turning the screen to black. Both time and verbal response to each trial were recorded. RTs were computed as time elapsed between appearance of the stimuli and verbal onset of response. RTs shorter than 300 ms and longer than 15,000 ms were discarded from analyses. As the two response words began by stop consonant in French, the digitized sound file was marked by a sharp increase of the sound intensity of similar value for the two words, and the same threshold could be used to trigger the voice key. The identity of each verbal response was verified and recorded by an experimenter (SS). Six randomized sequences of 96 trials were run. Each sequence comprised 48 pictures of right hands and 48 pictures of left hands, shown from four views (back, palm, thumb, and pinkie) and 12 orientations (six natural and six unnatural) presented randomly. Three conditions were studied in all subjects: control (*i.e.*, absence of deafferentation without visual access to the anesthetized limb), deafferentation (*i.e.*, sensory and motor nerve block without visual access to the anesthetized limb), and vision (*i.e.*, sensory and motor block and the anesthetized limb visible). For each condition, two sessions of 96 pictures, separated by 5 min, were presented. To limit potential biases, such as order effect, the control state was recorded at random either immediately before the RA procedure or 24 h after it (when the nerve block had completely disappeared).

Statistical Analysis

The data are expressed as mean \pm SD. Only RTs and proportions of correct responses corresponding to valid trials were considered for analysis. Accuracy for each participant was computed as the proportion of correct responses from valid trials. This rate was submitted to an arc-sine transformation so that the distribution was normal.¹⁹ Descriptive statistics were reported on the original proportions and not the transformed values. Proportions of correct responses and RTs satisfied the conditions for parametric analysis (Shapiro–Wilk test). To assess whether our paradigm produced results congruent with previous reports, two separate three-way ANOVAs were used for repeated measures (factors included hand [left or right], view [back, palm, thumb, or pinkie], or orientation [natural or unnatural]) and were run on RTs; the proportion of correct responses was determined for all the subjects in the control condition. Then, to assess the effect of peripheral deafferentation, two separate four-way ANOVAs were run on proportion of correct responses and RTs. The

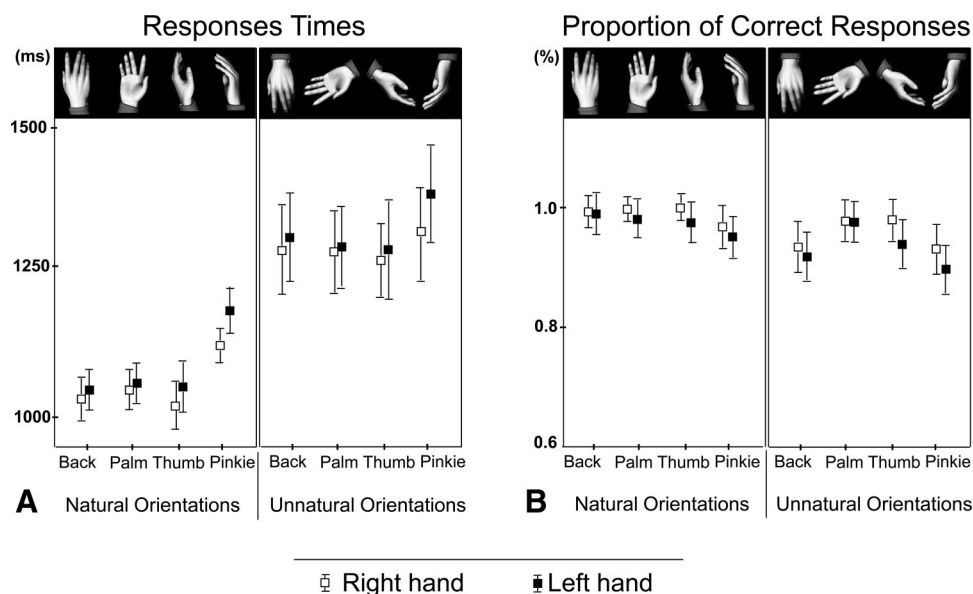


Fig. 2. Control state. (A and B) Response times (A) and corresponding proportion of correct responses (B) reported by subjects in the “control state” before regional anesthesia. White squares correspond to responses given to stimuli depicting right hands (*i.e.*, dominant hands); black squares, left hands (*i.e.*, nondominant hands). The averages for the six natural and six unnatural orientations are presented for each view. Error bars represent SD. The ANOVA main effect of orientation (natural/unnatural) was significantly different for both proportion of correct responses ($F_{1,19} = 20.9$, $P < 0.0001$) and response times ($F_{1,19} = 103.1$, $P < 0.0001$).

between-subjects factor was condition (two levels: control and deafferentation); within-subject factors were the same as in the previous analyses (hand, view, and orientation). The influence of dominance of the deafferented limb was analyzed in terms of between-subjects factor (deafferentation of the dominant limb *vs.* deafferentation of the nondominant limb) during two separate three-factor ANOVAs (factors: hand, view, and orientation) on the RTs and the rate of correct responses from all patients in the “deafferentation” condition. Last, the effect of the visual input from the deafferented limb was studied with two separate four-way ANOVAs on RTs and proportions of correct responses. The between-subject factor was condition (three levels: control, deafferented, and vision), and the within-subject factors were the same as in the previous analyses (hand, view, and orientation). A Newman–Keuls test was used for *post hoc* analysis of the significant interactions.

All P values were two-sided, and $P < 0.05$ was considered significant. The analyses were performed using computer software (Statistica 7.0; StatSoft, Inc., Tulsa, OK).

Results

Perceptual Illusions Associated with RA

Twenty patients were included consecutively in the study (see Supplemental Digital Content 1, which is a table listing main characteristics of the patients, <http://links.lww.com/ALN/A664>). No failure of the anesthetic procedure was identified. All subjects described perceptual alterations of size or shape (S illusion) and of posture (P illusion) of their anesthetized limb. These illusions were rarely recalled spontaneously, but

a detailed description was facilitated by focusing the subject’s attention on the perception of the deafferented limb.^{11,12} No subject except one (5%) described an effect of the view of the hidden limb on the S illusion. However, the same visual information causes a rapid superposition of the position of the phantom limb with the real posture of the anesthetized limb (*i.e.*, “fusion phenomenon”).¹³

Control State

Correct Responses. As expected, a three-way ANOVA (hand, view, and orientation; fig. 2) on the proportion of correct responses revealed a main effect of the stimulus hand, the right hand being more often correctly recognized than the left hand ($F_{1,19} = 4.7$, $P < 0.05$; right hand, 0.98 ± 0.03 ; left hand, 0.97 ± 0.04), of the view used ($F_{3,57} = 4.97$, $P < 0.01$; back, 0.97 ± 0.03 ; palm, 0.98 ± 0.01 ; thumb side, 0.98 ± 0.03 ; pinkie side, 0.96 ± 0.03), and of the orientation of the stimuli ($F_{1,19} = 20.9$, $P < 0.0001$; natural, 0.99 ± 0.03 ; unnatural, 0.96 ± 0.04). In other words, during the control state, the subjects gave significantly more correct responses when a right hand (*i.e.*, their dominant hand) was shown and presented in ecologic orientations. *Post hoc* analyses identified significantly greater difficulty in recognizing a hand from the pinkie side than a hand presented in more commonly adopted postures, such as palm ($P < 0.002$) and thumb side ($P < 0.012$) views.

Response Times. Analysis of RTs provided data congruent with the previously described results. The ANOVA analysis showed main effects of all factors (fig. 2): stimulus hand ($F_{1,19} = 7.78$; $P < 0.01$; right hand, 1177 ± 204 ms; left hand, 1204 ± 210 ms), view ($F_{3,57} = 15.68$, $P < 0.0001$;

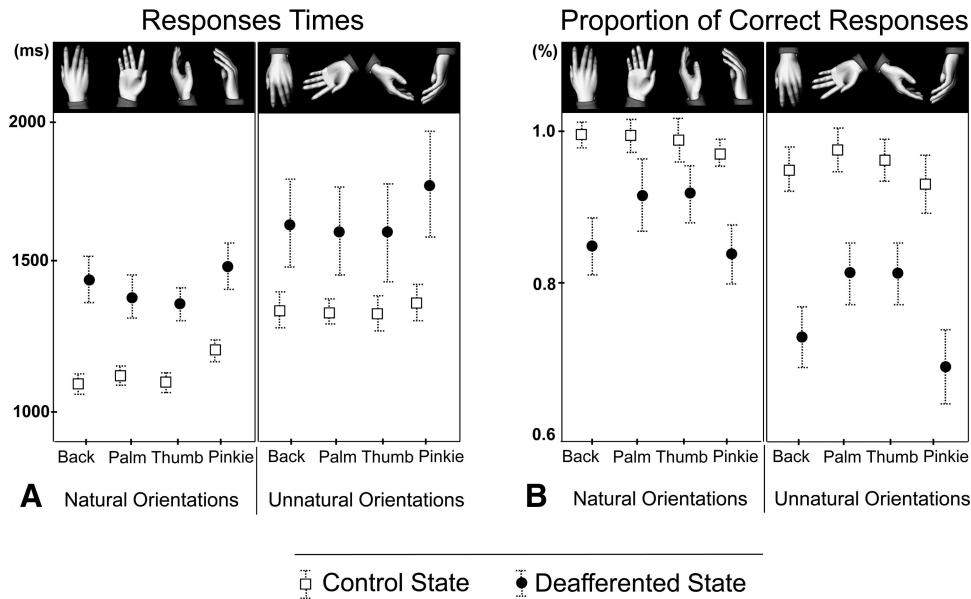


Fig. 3. Effect of acute peripheral deafferentation. (A and B) Response times (A) and corresponding proportion of correct responses (B) given by subjects before (white squares) and after (black circles) upper-limb anesthesia. The averages for the six natural and six unnatural orientations are presented for each view. Error bars represent SD. ANOVA main effect of condition (control/regional anesthesia) was significantly different for both proportion of correct responses ($F_{1,19} = 101.5$, $P < 0.0001$) and responses times ($F_{1,19} = 74.5$, $P < 0.0001$).

back, 1178 ± 169 ms; palm, 1179 ± 162 ms; thumb side, 1167 ± 184 ms; pinkie side, 1240 ± 190 ms), orientation ($F_{1,19} = 47.72$, $P < 0.0001$; natural, 1095 ± 180 ms; unnatural, 1287 ± 200 ms). Indeed, RTs were shorter for recognizing a dominant hand in the most natural orientations and views. As previously described for correct responses, *post hoc* analyses showed that the pinkie side stimuli required significantly longer RTs compared with the back ($P < 0.0001$), palm ($P < 0.0001$), and thumb side ($P < 0.0001$) views. The interaction between view and orientation was significant, pinkie side in unnatural orientation being the most difficult stimulus ($F_{3,57} = 5.71$, $P < 0.002$).

In sum (see fig. 2 and Supplemental Digital Content 2, which is table listing ANOVA's main effects, <http://links.lww.com/ALN/A665>), in agreement with previous studies,^{14–16} healthy subjects produced slower and less accurate responses when they had to recognize a stimulus hand in either a nonecologic unusual orientation or a pinkie side view. Moreover, during the control state, the subjects were faster and more effective when identifying right hands (*i.e.*, dominant hand).

Effect of Acute Peripheral Deafferentation

Correct Responses. To study the effect of RA-induced deafferentation, a four-way ANOVA on proportion of correct responses (fig. 3) showed main effects of the following: condition, stimulus hand, and orientation. The deafferentation condition was associated with poorer performance compared with the control state for all views ($P < 0.0001$). Significant interactions were shown between condition and orientation ($F_{1,19} = 25.9$, $P < 0.0001$) and condition and view ($F_{3,57} = 4.2$, $P < 0.009$). These results were confirmed by *post hoc*

analyses. The number of correct responses was significantly reduced in subjects after deafferentation compared with the control state for all orientations (natural, $P < 0.001$; unnatural, $P < 0.0001$). However, the proportion of correct responses was smaller in the unusual orientations after deafferentation (0.82 ± 0.12 vs. 0.92 ± 0.08 ; $P < 0.0001$).

Response Times. Consistent with the results obtained from the proportions of correct responses, a four-way ANOVA (fig. 3) showed main effects for all the factors. After deafferentation, RTs were longer, particularly for unusual hand postures. In fact, a significant interaction was identified between the condition and orientation ($F_{1,19} = 12.6$, $P < 0.002$). *Post hoc* analyses showed congruent results to the analysis of the proportion of correct responses. Acute deafferentation of the upper limb was associated with longer RTs compared with the control condition, for both unnatural ($P < 0.0001$) and natural ($P < 0.003$) orientations. Nevertheless, after deafferentation, significantly longer RTs were observed for unnatural compared with natural stimuli (1638.2 ± 332 ms vs. 1361.5 ± 324 ms; $P < 0.0001$).

In sum (see fig. 3 and Supplemental Digital Content 2, <http://links.lww.com/ALN/A665>), acute deafferentation was associated with significant reduction in accuracy and lengthening of RTs compared with the control condition. As in the control condition, greater difficulty in recognizing unnatural stimuli was observed after deafferentation through both the accuracy rate and the RT.

Dominant Limb Effect after Deafferentation

Correct Responses. To examine whether deafferentation of the dominant versus the nondominant limb had different

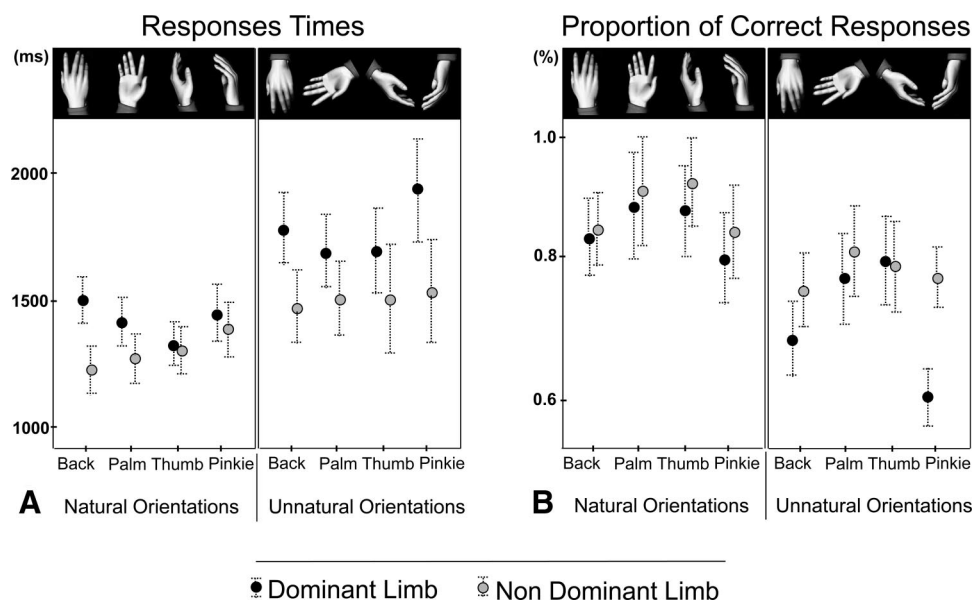


Fig. 4. Effect of dominant limb acute deafferentation. (A and B) Response times (A) and corresponding proportion of correct responses (B) reported by subjects after upper-limb anesthesia of their dominant (black circles) or nondominant (light gray circles) limbs. The averages for the six natural and six unnatural orientations are presented for each view. Error bars represent SD. ANOVA main effect of laterality (dominant/nondominant limb) was significantly different for both proportions of correct responses ($F_{1,18} = 4.6$, $P < 0.01$) and responses times ($F_{1,18} = 10.45$, $P < 0.005$).

effects on the left/right hand judgment task, two subject groups were compared depending on whether they underwent surgery on their right (dominant) or left (nondominant) upper limb (fig. 4). A four-way ANOVA performed on the proportion of correct responses showed main effects of dominance, stimulus hand, view, and orientation. Namely, subjects who had undergone anesthesia of their dominant upper limb gave a lower proportion of correct responses than the group in which deafferentation was performed on the nondominant limb. This effect was significantly greater when subjects were presented a stimulus hand in unusual orientations and from unusual views, as shown by the interactions between dominance and orientation ($F_{1,18} = 16.9$, $P < 0.001$) and between dominance and view ($F_{3,54} = 14.7$, $P < 0.01$). *Post hoc* analyses revealed that this “dominance effect” was mainly related to a change in performance when pictures of unusual orientations were shown ($P < 0.0001$) compared with the usual 1 s ($P < 0.428$). Moreover, we observed an increased proportion of errors induced by deafferentation of the dominant limb compared with that of the nondominant limb, particularly for the pinkie side ($P < 0.0001$) and not in the back, palm, or thumb side views.

Response Times. Analysis of RTs showed the following main effects for all the factors (fig. 4). The subjects who had their dominant upper limb anesthetized presented longer RTs compared with subjects whose deafferentation was on the other side. Significant interactions between dominance and orientation of the stimuli ($F_{1,18} = 7.05$, $P < 0.01$) and between dominance and view were identified ($F_{3,54} = 5.7$, $P < 0.002$). A *post hoc* analysis showed that the effect of

deafferentation of the dominant limb was mainly related to unusual orientations ($P < 0.01$) compared with the usual 1 s ($P < 0.37$). RTs were significantly longer for stimuli presented in the pinkie side ($P < 0.01$) and not in the back, palm, or thumb side views. In sum (see fig. 4 and Supplemental Digital Content 2, <http://links.lww.com/ALN/A665>), deafferentation of the dominant limb was associated with an increased proportion of errors and prolonged RTs compared with deafferentation of the nondominant limb. This dominance effect was particularly important for the unusual orientations or pinkie side view stimuli.

Effect of Visual Information

Correct Responses. We studied the influence of visualization of the anesthetized limb on subjects’ performance. For this purpose, a four-way ANOVA was performed on the proportion of correct responses. The following main effects were identified: dominance, condition, stimulus hand, view, and orientation (fig. 5). Significant interactions were identified between condition and the following factors: dominance ($F_{2,36} = 7.5$, $P < 0.002$), view ($F_{6,108} = 7$, $P < 0.0001$), and orientation ($F_{2,36} = 57.4$, $P < 0.0001$). Interestingly, *post hoc* analyses showed that the dominance effect, observed in the “blind” deafferentation condition ($P < 0.001$), disappeared after the still deafferentated limb ($P < 0.54$) was exposed to view. However, although the accuracy rate improved in the view condition relative to the blind deafferentation condition ($P < 0.0001$), subject’s performance kept showing effects identified in the latter condition. Indeed, during the visual condition, more errors were identified for unusual orientations (natural *vs.* unnatural; $P < 0.0001$) and

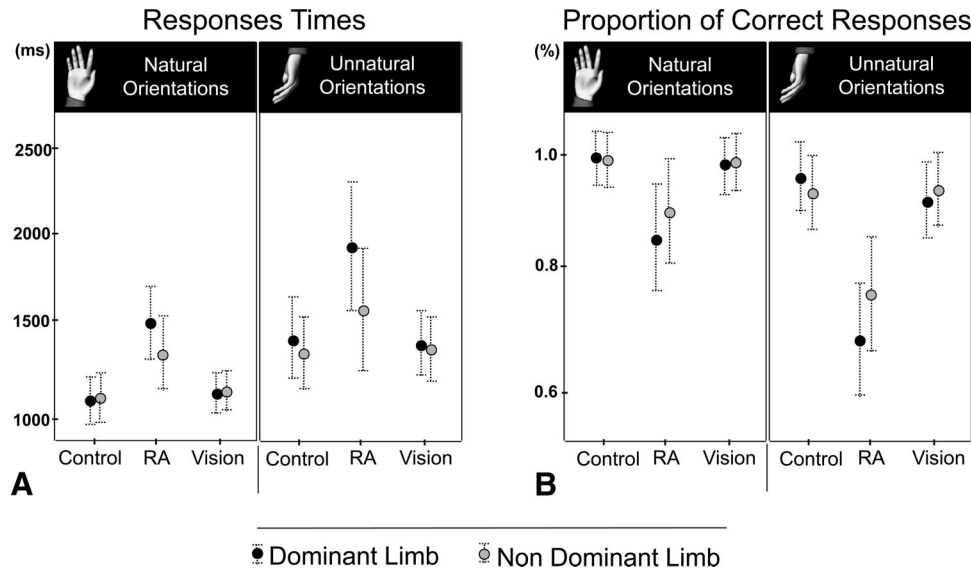


Fig. 5. Effect of visual information. (A and B) Response times (A) and corresponding proportion of correct responses (B) given by subjects before deafferentation (control), during upper limb anesthesia without visual access to the deafferented limb (RA), and during upper limb anesthesia with the deafferented limb visible (vision). The averages for the six natural and six unnatural orientations are presented for each view. Error bars represent SDs. ANOVA main effect of condition (control, RA, or vision) was significantly different for both proportion of correct responses ($F_{2,36} = 102.7$, $P < 0.0001$) and responses times ($F_{2,36} = 118.3$, $P < 0.0001$). RA = regional anesthesia.

when they were shown from the pinkie side view compared with the back ($P < 0.05$), palm ($P < 0.0001$), or thumb ($P < 0.0001$) views. These effects suggest that, despite vision input from the deafferented hand, subjects still have difficulty processing unusual hand representations.

Response Times. Congruent results were obtained from the analysis of RTs using a four-way ANOVA (fig. 5). In agreement with the results of accuracy score, significant interactions were identified between the condition and the following factors: dominance ($F_{2,36} = 16.9$, $P < 0.0001$), view ($F_{6,108} = 2.3$, $P < 0.044$), and orientation ($F_{2,36} = 12.6$, $P < 0.0001$). *Post hoc* analyses showed that the dominance effect had an influence on RTs only during the deafferentation condition ($P < 0.005$) and not after viewing the deafferented limb ($P < 0.90$). In agreement with the analysis of correct responses, subjects, after obtaining visual information from the anesthetized limb, showed longer RTs when the stimuli were presented in an unusual orientation (natural *vs.* unnatural; $P < 0.0001$) or from pinkie side compared with palm ($P < 0.005$) or thumb side ($P < 0.0001$) views. In sum (see fig. 5 and Supplemental Digital Content 2, <http://links.lww.com/ALN/A665>), after deafferentation, seeing the anesthetized limb was associated with a significant increase in the proportion of correct responses and shortening of RTs compared with the blind anesthetized condition. Interestingly, the parallelism between real and imagined movement persists in this condition: lower proportions of correct responses and longer RTs were identified with the presentation of unnatural stimuli or from the pinkie side view. Last, the influence of the laterality of the anesthe-

tized limb observed during the RA condition disappears after the deafferented limb has been exposed to view.

Discussion

RA induces a set of perceptual illusions^{10–13} in healthy subjects that are similar to the phantom limb sensations identified in amputees.^{3–5} This similarity suggests that RA-induced perceptual illusions might be a phenomenon of the central nervous system, related to plastic changes at several levels of the neuraxis and especially the cortex. This hypothesis is supported by the clinical effects of RA observed in patients presenting motor deficits after brain lesions. For example, RA of the healthy hand in patients with chronic stroke was associated with significant motor^{21,22} and sensory²³ improvement of the affected hand, probably because of interhemispheric plasticity processes. Herein, critically, we have extended these findings by demonstrating the existence of alterations of central sensory and motor representations during RA-induced acute deafferentation in healthy subjects, using a motor imagery paradigm.

Contemporary research has revealed the striking parallelism that exists between action imagination and action execution. The time course of mentally simulated movements is highly correlated to their actual execution^{14,24}; and brain networks activated by the same movement, when it is simply imagined or when it is actually executed, seem to overlap broadly.^{25,26} This led Jeannerod²⁷ to propose a concept of functional equivalence between motor imagery and motor execution. Therefore, the theory of neural simulation of action postulates that covert actions are in fact actions, except

that they are not executed, predicting a similarity, in neural terms, between the state in which an action is simulated and the state of its actual execution. According to this theoretical framework, the left/right hand judgment task that we used in this study, and that is known to involve motor imagery processes, appears to be a good way to explore the state of the corresponding neural network during RA. Thus, acute deafferentation associated with absence of visual input from the anesthetized limb alters the somatosensory feedback component of these processes. When the left/right hand judgment task was executed, all the subjects described phantom limb sensations (S and P illusions), the onset of which has been reported to correspond to the alteration of the proprioceptive signals^{12,13} required to generate and update the body image.^{28,29} Therefore, the hand laterality judgment and related motor imagery are likely to imply manipulation of the internal representations of the body^{14–16} and to activate brain regions devoted to body image and body knowledge.^{30,31} Accordingly, the cooccurrence of perceptive illusions and impaired hand recognition performance might result from functional disturbances in such regions as the consequence of the conflicting persistence of feed-forward motor commands in the absence of proprioceptive and visual feedback.

Interestingly, we found that biomechanical constraints of arm movements during hand rotation were preserved after an acute deafferentation by RA: RTs and error rate are increased for the most unusual hand orientations. This finding is compatible with the previously mentioned hypothesis (*i.e.*, at the representation level, the coding of the movements follows the same rules as when they are executed). Furthermore, the fact that RTs are slower and responses are less accurate after deafferentation of the dominant limb compared with the nondominant limb can be explained by the compensatory use of motor representations from the nonanesthetized limb, with less accurate and slower responses when the unaffected limb is the nondominant one. This upper limb preference for motor imagery is consistent with reports that motor asymmetries are present in the mental domain, affecting movement simulation³² and movement attribution.³³

Finally, we found a strong effect of visual input on the performance in our subjects under RA. These findings suggest that brain regions supporting body image representations and responsible for performance impairment under RA are sensitive to heteromodal visual input that can greatly alleviate the cognitive effect of deafferentation. In fact, seeing the anesthetized limb was associated with a significant increase in the proportion of correct responses and shortening of RTs compared with the blind anesthetized condition; likewise, the influence of the laterality of the anesthetized limb observed during the RA condition was no longer observed. Interestingly, several studies have suggested the joint role of visual and proprioceptive information in the production and maintenance of body image. For example, postural illusions can be recreated in amputees using mirrors, allowing the absent limb to be “reconstructed” from sight.³⁴ Recent func-

tional magnetic resonance imaging studies^{29,35} have stressed the functional importance of polymodal cortical regions in inner representations of body image in humans, such as the premotor ventral cortex or the intraparietal sulcus. These two structures form part of the network activated by the left/right hand judgment task.²⁶ Hand laterality recognition studies performed in patients with chronic deafferentation who have not lost their limb (*i.e.*, injury of the brachial plexus)¹⁹ have not shown such a heteromodal effect of vision on subjects' performance. This absence of a facilitating effect of vision might be explained by the fact that, in the long term, the mind/brain integrates the notion of functional loss of the limb. In this way, the chronically deafferentated limb would become a “passive entity” definitely excluded from body image.^{19,36,37} Therefore, seeing it would no longer modulate the neuronal substrates of the body image involved in both execution of hand laterality judgment and phantom limb perception (*i.e.*, fusion phenomenon).

The amount of ropivacaine administered in the short term may induce central effects. A study limitation was that no control group was studied in which intramuscular or subcutaneous local anesthetic was given without neural blockade, to explore these systemic effects. Nevertheless, this possibility would not have been approved by the local ethics committee because the indication for the RA was independent of the study (*i.e.*, scheduled surgery of the upper limb). Furthermore, systemic effects could not explain either subject's performance sensitivity to arm/hand biomechanical constraints, differences of performance identified during deafferentation of the dominant limb compared with the nondominant one, or significant improvement when seeing the arm.

In contrast with previous studies^{19,38} that have explored the relationships between mental movement simulation and the actual state of the body at long-term stages, our results show functional alterations related to acute deafferentation produced a few minutes before the hand laterality task was performed. This might result from acute functional disturbances in brain processing as the consequence of the conflicting activation of efference copies (*i.e.*, representations of the prediction of the consequences of the movement to be executed)^{39,40} in the absence of proprioceptive and visual feedback. Our present results have identified RA-induced alteration of central motor representations, expressed both by the appearance of perceptual illusions and the reduced ability to mentally simulate movement. Future studies are needed to characterize further the changes in neural activity that account for such rapid changes in these representations.

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