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Unconscious activation of motor responses in a hemiplegic patient with anosognosia and neglect

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Abstract Unconscious processing of environmental stimuli has been convincingly demonstrated for a large number of neuropsychological syndromes. However, only few studies have successfully recorded on-line the activation of the autonomous or the motoric nervous systems. The activation of the motor system by unconscious stimuli would be a strong argument that information processing in the brain is not organized into two serial steps (stimulus identification first, response selection second). This would argue for parallel processes of stimuli identification routines and response selection mechanisms on the basis of only provisionally worked out stimulus features. Investigating an anosognostic patient we found electrodermal activity (EDA) and electromyographic responses (EMG) to bimanual tasks, mental imagery, and to the request to execute specific actions. But overt behavior remained hemiplegic and the patient was unable to feel any kind of control of her paralyzed left arm and hand. Generally, the data can be interpreted along the lines of a theory of two different routes to action, leaving the unconscious selection of action patterns intact, whereas the intentional triggering of overt behavior with the left hand and arm was impossible for the patient.

Key words Anosognosia · Continuous information transition · Neglect response selection

Introduction

Unconscious processing of environmental stimuli has been convincingly demonstrated for a large number of

neuropsychological syndromes [1]. Most of these studies relied on forcing the patients to choose between different alternatives and calculating the probability of right and wrong answers. However, there are only few studies that have attempted to ascertain unconscious reactions of patients directly [2, 3]. For neglect patients Vallar et al. [4, 5] documented the existence of visual evoked potentials and electrodermal reactions for unconscious stimuli, but we are not aware of any studies that have measured muscle responses in patients with neglect.

A priori, there is no definite prediction of what kind of results such an experiment would uncover. On the one hand, it has been shown that neglect patients process unconscious information up to a categorical analysis of stimuli [6]. On the other hand, the overt behavior of such patients seems to be limited to reactions to stimuli located in the non-neglected hemi-space. Processing of stimuli therefore might gain no access to motor neurons and might be unable to release reactions [7]. Such findings would endorse a view of consciousness which argues that access to consciousness for perceptual stimuli depends on the action selection of the organism [8].

The alternative possibility would be that the innervations remain subliminal and do not result in overt behavior. This would parallel the situation of information uptake when the information is processed but does not reach consciousness. In this case the information would be processed through the whole perception action cycle and without direct reference to consciousness. Which of the triggered action patterns becomes dominant depends on multiple and interactive inhibitions and conscious selection. The model of Shallice [9] on supervisory attentional control where the contention scheduling works in such a manner that "winner takes all" (after the activation of different patterns of possible actions) would be in line with such an observation. Though the supervisory attentional control system is a central system for response selection, the contention scheduling is done automatically and in parallel. Therefore, the preactivation of action patterns by contention scheduling is independent of the conscious experience and decision to act. Given such a model, in

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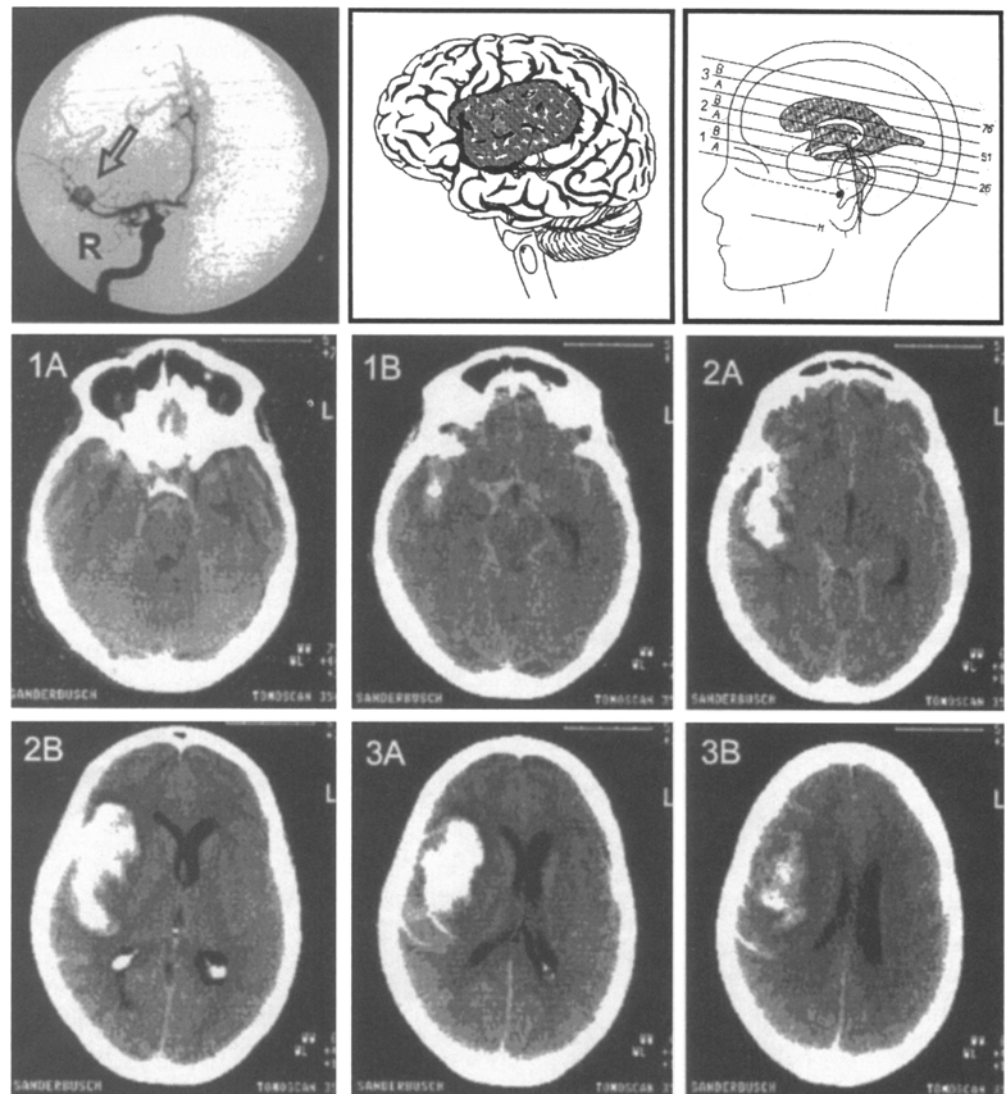
principle it should be possible to demonstrate a disconnection of processes of contention scheduling from attentional supervisory control after brain damages. In order to analyze unconscious processing in neglect, we investigated a woman who was hemiplegic and had a dense anosognosia for her left body side especially for her left hand. Her anosognosia comprised also a visual neglect and an anesthesia for her left body half. Moreover, she did not always acknowledge her left hand as her own. She talked about her left hand from a third-person perspective and she developed several explanations for why this foreign hand was attached to her body and why it was impossible to get rid of it [10]. Our hypothesis was that unconscious and subliminal activation of the left hand was possible, but out of conscious control and willed intention. This hypothesis was supported by the patient's reports about reflex-like actions of the left hand, which we have not yet had the opportunity to observe. All we can say in this regard is that during our neurological, neuropsychological, and behavioral investigations her left hand

and arm always remained hemiplegic. To test our hypothesis we decided to measure the electrodermal response by skin conductance response (SCR) and the muscle tonus pattern by surface electromyography (EMG).

Case report

The patient, 59 years old, was admitted to the neurosurgical department because of an intracerebral huge hemorrhage at the right fissura sylvii (see Fig. 1). The mass bleeding was caused by an aneurysmal malformation of the right cerebral media artery, detected earlier by cerebral angiography. After neurosurgical evacuation of the hemorrhage and aneurysmal clipping, the patient remained in a deep coma for approximately 10 days. A follow-up CT, carried out 57 days after the operation, showed a low density area in the right cerebral hemisphere extending from the fronto-temporal to the parietal lobe. The neurological investigation documented left-sided hemiplegia, abnormal reflexes of the left leg, and a dense anesthesia of the left body side. Sometimes the patient also reported alloaesthesia for tactile stimulation. In these situations the touching of the left side of the body was localized at the right side. Stimuli which caused serious pain sensations (i.e., pinching) were

Fig. 1 Patient HMU: computertomographic angiographic findings. *First row, left picture:* angiography of the right-sided carotis artery revealed a big saccular aneurysma of the right media artery; picture in the middle: lateral schematic overview on the extension of the right intracerebral mass bleeding; right picture: lateral view of the computertomographic scan slice levels of the total investigation. The slice thickness was 6.0 cm. *Second row and third row:* axial computertomographic scan slices from the basal level (1A) up to the high parietal level (3B): the mass bleeding extended from the basal parts of the right sylvian fissura up to the (fronto-)temporo-parietal areas of the right cerebral hemisphere, disconnecting intra- and intercortical association fibers. The computer-assisted planimetric volume evaluation revealed a bleeding size from about 424 ccm. Note the compression of the right side-ventricle, the temporal part of the right side-ventricle, and the small shift of mid-line structures such as the cerebral pedicle from right to left. Shift and compression were caused by perifocal brain edema, and by mass effect of the bleeding



commonly perceived correctly in the left side of the body, but not exactly at the place to which they were applied.

A neuropsychological examination with the WAIS (Wechsler Adult Intelligence Scale), carried out 5 or 6 weeks after the evacuation of the hematoma, showed a normal verbal IQ, but a percentage of zero in the performance tasks (see Table 1). The Benton test (for identifying visually perceived patterns) yielded only random results, because the patient always had chosen the items given at the right side of the answer sheet. Drawings and writing probes showed that she had no constructional apraxia because line orientation and composition of the figures were not disturbed. On the other hand, the drawings and writing probes documented the neglect of the left part of the egocentric space (see Fig. 2).

Neuropsychological assessment of neglect

Because of the clinical status of the patient, the testing was restricted to bedside diagnostics. Our behavioral observations included the typical features of patients with unremediated neglect. The patient's head was always oriented toward the right side, and generally she did not react to voices from the left side of her bed. When talking to people whom she knew were standing on the left

Table 1 Patient's results in the WAIS

Subtest	Scaled score
Information	7
Comprehension	10
Digit span	8
Arithmetic	9
Similarities	10
Vocabulary	11
Digit symbol	0
Picture arrangement	2
Picture completion	0
Block design	2
Object assembly	0

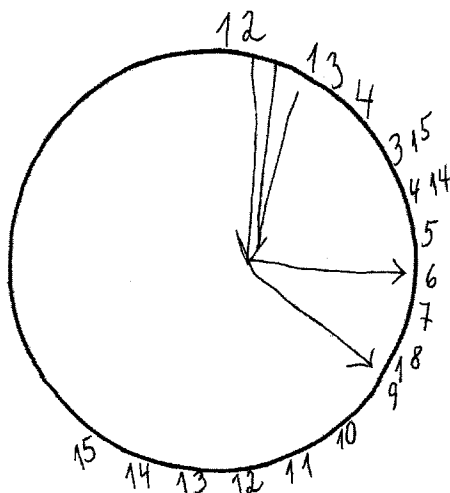


Fig. 2 Writings of the hours of a clock around a circle by the patient. After noticing that something was incorrect, the patient wrote the numbers at the outer circuit (1, 15, 14). The first sweep hand pointing to number "12" and the one pointing to number "6" were drawn as three o'clock. The first sweep hand and the one pointing to "9" were drawn as nine o'clock. The first sweep hand and the one between "12" and "1" as eleven o'clock, the one pointing to "1" as four o'clock

side of the bed, she raised her voice and pronounced her words carefully as if they were standing far away.

Line bisection

We asked the patient to bisect lines of different length and repeated each length four times. In half of the cases the patient bisected the line towards her intact hemifield, in 33% toward the neglected hemifield, and in 17% the line bisection was within the normal range. The deviation toward the intact field was more pronounced (mean 1.25 cm) than the deviation toward the neglected hemifield (mean 0.3 cm).

Clock drawing

We asked the patient to write down the dials of a clock in their proper positions along a prescribed circle (diameter 13.6 cm). Then we asked her to draw the positions of the sweephands of the clock for different times. The arrangement of the hours and the notation of the different times documented a profound neglect of the left part of the circle (see Fig. 2).

Imagining the positions of letters in words

We used the imagination of words to analyze neglect in mental imagery. We used words rather than visual scenes to control for the extension of the visual scene and because the writing probes had shown that the patient normally made no spelling errors. The task was to indicate the letters at different positions in words that varied in length ("Which is the fourth letter in 'sleep'?"). Extending the length of the words to more than four letters and the position up to the third letter showed that the patient had enormous difficulties with such kinds of tasks: She was right only in 50% of the cases. The performance declined even more if the chosen positions were greater than three. Generally, the patient answered to such questions by naming the last letter.

Assessment of directional hyperkinesia

The investigation of the mental imagery of words documented a typical behavioral pattern: Movements toward the intact hemifield seemed to stop only if a prominent anchor was reached (the last letter of the imagined word). This can be interpreted as a motor hyperkinesia [11] toward the intact field. To analyze the role of movements for the neglect we assigned the patient two different tasks: The first task was to copy the length of an arrow on a separate sheet of paper. The position of the arrows with regard to the patient was always directly in front of her. The starting points of the arrows were marked on the separate sheets and the patient had to start drawing at these points toward the tip and to stop when she reached a distance similar to the length of the arrow.

The second task was to reproduce the distance between two points, marked on a 61-cm wide strip of paper (7 cm high). Reproductions had to be done either toward the right or towards the left. The two points were marked either in the middle of the strip or at the left or right end of the strip. (In this case the reproductions had to be done only toward the opposite end of the strips.)

We expected that a directional hyperkinesia should be accompanied by a pronounced overestimation toward the intact hemifield and an underestimation toward the neglected hemifield. The results supported our expectations. Firstly, it was possible that the patient shifted her attention (by cuing) into the neglected field and therefore could perform the reproductions. Secondly, the reproduction did not differ in the position of the parts in the hemifields, but in the direction in which the reproductions had to be done. Reproductions toward the neglected hemifield were systematically underrated, whereas reproductions toward the intact hemifield were overestimated. Moreover, in several of the cases where the

direction in question was toward the neglected hemifield, the patient solved the tasks by acting toward the intact hemifield. On the other hand, in none of the trials toward the intact field did the patient err in the correct direction.

The behavior of the patient in these tasks resembled the performance of patients with allochiria. Halligan et al. [12] reported a patient who copied parts of a figure located in the neglected field to her reproduction of the figure, but into the opposite half, i.e., the intact hemifield. Moreover, the localization of the hemorrhage of Halligan's patient and that of ours was quite similar (frontoparietal, right hemisphere) and so were the results of the neuropsychological investigations. Halligan et al. argued that motor hyperkinesia could not explain their results because of the global drawing performance and because they observed allochiria only under conditions of dual stimulation by the original picture. On the other hand, motor hyperkinesia was not tested directly.

The reported findings contradict the interpretation of Halligan et al. The existence of allochiria was coupled to the specific direction in which the patient had to move her arm (we observed allochiria in 55% of all trials toward the neglected hemifield against 0% of the trials toward the opposite direction). Perceptual features can be ruled out as an explanation, because we did not use double stimulation and all stimuli were equivalent, except for their location in the patient's egocentric space.

EDA and EMG measurement

Procedure

We used electrodermal activity and muscle tonus as indicators for unconscious activation of the left arm and left hand. Electrodermal activity was registered by a skin resistance measuring device (Bruno ZAK VDI), and registration of muscle tonus was conducted by an EMG-feedback device of the same manufacturer.

The EDA was registered at the right thenar and the hypothenar eminences of the left and right hand. Artifact-free amplitudes of skin conductance responses (SCR) of at least 0.02 μs (microsiemens) with a latency of 1–3 s were scored as stimulus-evoked changes. In order to find a baseline for both hands, the measurement started with a general relaxation period. Thereafter, we proceeded with different mental imagery conditions ranging from "having a warm bath" to "grasping a bottle" or "potato peeling". We requested the patient also to grasp a bottle we were holding next to her left hand.

The EMG was registered at the forearm (above the musculus flexor carpi radialis). The analogous output of the measuring device was normalized to a range between -1 and +1 voltage effective and registered each 13 ms by an Apple IIe (Apple Computer, Cupertino). We used a single case experimental design for measuring the EMG. We started with a baseline ("A") and introduced different interventions ("B", "C", ...) always followed by a baseline period. Each intervention was repeated several times.

The following interventions were carried out repeatedly: unspecific mental imagery of a movement sequence embracing the left hand, imagery of movements that had been executed at an earlier time in her life (clapping her hands after an exciting theater performance, cleaning the windows of her home) and requests to grasp a hand or a bottle we were holding next to her left hand. We

also put a bottle near her left hand and then asked the patient to unscrew the stopper with her right hand.

Results

For the EDA measurement we found a considerable difference of SCL for the right and the left hand (6.7 μs for the right vs. 2.0 μs for the left hand). We then noticed different responses for the mental imagery of either having a warm bath or of potato peeling (see Table 2). Tactile stimulation of the left arm yielded no significant response, and the same holds for the request to grasp a bottle. On the other hand, painful stimulation (pinching of the left arm) was followed by a significant electrodermal response.

The measurement of EMG included the baseline periods and several experimental situations. We tested the different experimental situations against all baselines we had measured (we measured 17 baselines followed by the experimental situations, cf. Fig. 3 and Table 3). As we had registered deflections of effective voltage, our EMG data varied around a mean 0 voltage. For calculating significant alterations of the experimental conditions we conducted two different tests. Firstly, we used the F-statistic to compare directly the variances of the EMG values during baseline and experimental conditions. Most of these separate tests (17 baseline against 16 experimental conditions) were significant, partly due to the high degrees of freedom. Only the condition of unspecific mental imagery of movements documented a considerable portion of insignificant results (41% for riding a bicycle and 24% for clapping one's hands; see Table 3). For a second and more conservative test we averaged the variance of the EMG values over the 17 baseline conditions and computed the mean variance of the resting potential and its standard deviation. A mean of variance during the intervention periods outside the range of the mean variance of the resting potential plus one standard deviation was taken as a significant modification.

All statistical evaluations were done by using the software package STATGRAPHICS (Statistical Graphics Cooperation). Testing for significant experimental conditions led partly to significant increases in muscle innervation depending on the kind of interventions (see Table 3).

Requesting the patient to form unspecific mental images of movements showed the lowest increase in EMG, followed by the request to grasp with the left hand for a bottle or for a hand without touching them. These two

Table 2 EDA responses for the patient

Condition	Right hand Baseline of 6.7 μs	Left hand Baseline of 2.0 μs
Relaxation		
Mental imagery of having a warm bath	0.02 \leq 0.04 μs ^a	0.02 \leq 0.04 μs
Mental imagery of grasping a bottle	0.02 μs	No response
Tactile stimulation ^b	0.02–0.04 μs	No response
Pinching ^b	> 0.04 μs	0.02 \leq 0.04 μs
Mental imagery of potato peeling	Not done	0.02 \leq 0.04 μs
Request to grasp a bottle	Not done	No response

^a Amplitude of skin conductance response (SCR)

^b SCR was measured at the same body side to which we applied tactile stimulation. Application was done to upper arm

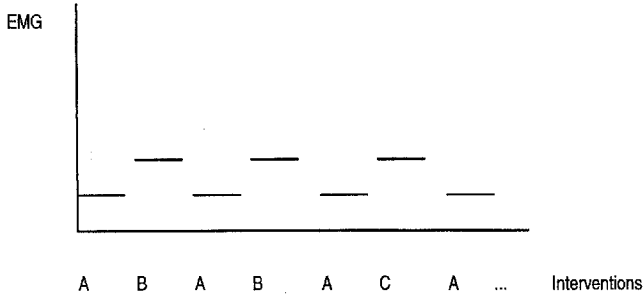


Fig. 3 Single case experimental design for electromyographic measurement

Table 3 Interventions and deflections of the EMG tested against standard deviation of mean variance of 17 baselines

Interventions	Variance	
	Right hand	left hand
<i>Unspecific mental imagery</i>		
Riding a bicycle	1 s < v 2 s	v < 1 s
Clapping one's hands	1 s < v 2 s	v < 1 s
<i>Specific mental imagery</i>		
Clapping one's hands at a theater visit	1 s < v 2 s	1 s < v 2 s
Cleaning the windows	1 s < v 2 s	1 s < v 2 s
<i>Grasping trials</i>		
Shaking one's left hand		v < 1 s
Request to take a bottle		v < 1 s
Putting the bottle into the plegic hand		3 s < v < 4 s
<i>Bimanual tasks</i>		
Grasping the bottle with both hands		v < 4 s
Unscrewing the bottle		v < 4 s
Closing the bottle		v < 4 s

conditions yielded no significant results, which for unspecific mental imagery of movements is in accordance with our tests by the F-statistic. The remembering of past experiences of movements with the left hand and the tasks involving a bimanual control of the bottle after it has been put into the left hand led to a considerable increase in muscle tonus. In these cases the observed increase in muscle innervation always followed directly after our verbal command (see Fig. 4).

On the other hand, we did not observe any movements of the hemiplegic hand, except in the case of bimanual coordination when the hand was moved passively because of the actions of the right hand. The patient felt no sensation of control for movements and no alterations in the left arm and hand for all the reported situations.

Discussion

The main finding of our investigation was that an anosognostic patient with left hemiplegia and a motoric hyperki-

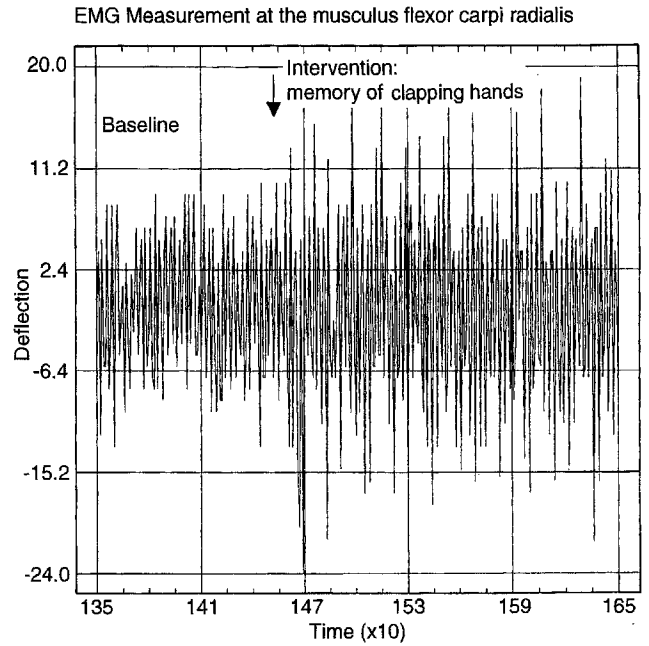


Fig. 4 Increase of the muscle tonus after request to form a mental image about a past event of clapping hands at an exciting performance. The graph documents the higher deflections during the intervention period (see Table 3). Measurements were samples each 13 ms and normalized to -1 to +1 voltage effective

nesia was able to control her forearm muscle activity, but only to an extent that did not result in overt behavior. Together with her alloaesthesia this endorses the possibility of unconscious processing in neglect for motor responses. Efferent discharge was also found for the sympathetic nervous system.

The alterations in activation depended on the task structures. We would like to argue that this hierarchy is a result of the intentional character of the task structures. Actions that are based on willed intention and conscious purposes yielded no responses in EDA measurement and the smallest amount of increase in muscle tonus. Remembering past actions was accompanied by a slightly higher innervation and the situations that referred to more or less automatized bimanual control revealed the most impressive results. The paralysis of the left arm and the left hand of our patient therefore appeared to be a high-level cognitive phenomenon related to a subjective reconstruction of the personal space after a severe damage of right-hemispheric brain regions. On the other hand, subconscious and uncontrolled automatized or instinct movements as in the case of the "alien hand sign" [13], though not observed by us, were reported by the patient and her family. Broadly speaking, our results are in accordance with early century theories of neglect as a disturbance of the body image or of more recent theories about the representation of the proximal grasping space [14-16]. The subjective reconstruction of this space did not fit the possibilities of afferent and efferent processing that were preserved.

Recent investigations with single cell recording have shown that primate brains are organized in different levels

of receptive fields starting from inputs by a limited number of retinal neurons in V1 (area 17 of Brodmann) up to relying on the input of the whole visual field in TE (areas 20 and 21 of Brodmann) [17]. There is some evidence that cortico-cortical connections exist between such early perceptive input systems and the motor areas of the frontal lobe, and that these connections prime for specific actions but are not capable of releasing actions on their own [18]. Libet [19] and Smid et al. [20, 21] and Frith and Done [22] have demonstrated by event-related potentials and EMG measurement that already-activated motor responses can be suppressed by supervisory attentional control, and that this response inhibition partly involves the peripheral preactivation of the effector muscles. From the results of Smid et al. there is a strong evidence for a parallel activation of input processing and response-selection mechanism, the latter already starting unconsciously before input identification has been terminated.

Goldberg [23] has argued for the existence of two routes of action, one of them starting at the posterior parietal lobe projecting to the arcuate premotor areas and then extending to the primary motor areas of the frontal lobe, especially the representations for arm and face movements. The second route begins in the superior parietal lobe, projecting to the supplementary motor area, and from there either directly to the spinal centers or to the basal ganglia. Functionally, the first route seems to be stimuli driven, whereas the second route is closely correlated with the execution of voluntary movements. Paus et al. [24] have found that lesions to the medial frontal lobe and the included anterior cingulate cortex do not influence the reactivity of eye movements toward extraneous stimuli per se, but lead to an impairment of the inhibition of reflex-like saccades.

In our case the connections of the first route may have bypassed the brain damage. The CT scans show that the occipital lobe, the posterior parietal, and the temporal lobe were not involved in the mass bleeding. Following Goldberg's review the mass bleeding of our patient may have resulted in a lesion of parietal areas responsible for visual spatial attention and a disconnection between these right hemispheric centers and the premotor areas of the frontal lobe especially the anterior cingulate cortex (cf. Fig. 1). At the same time the parallel and automatic routes for response selection originating in the inferior and posterior parietal lobe were spared.

Although we have no definite results, we are inclined to argue that the patient's impression of her left hand as a foreign hand might have been a result emerging from the same mechanisms. Unconscious processing of the arm's and the hand's activation without adequate localization in proximal space could have led to a cognitive reconstruction of her own hand belonging to another person.

Analyses of the performance of neglect patients have documented that preattentive modules lose their influence on conscious representation, but still do process environmental stimuli [25, 26]. Our findings can be interpreted as an analogous disturbance pattern for unconscious response selection: The EDA and EMG measurement have

demonstrated this preserved ability, although conscious and intended execution of left hand and arm movement were impossible.

References

- Schacter DL, McAndrews MP, Moscovitch M (1988) Access to consciousness: dissociations between implicit and explicit knowledge in neuropsychological syndromes. In: Weiskrantz L (ed) *Thought without language*. Clarendon Press, Oxford, pp 242–278
- Bauer RM (1986) The cognitive psychophysiology of prosopagnosia. *Bibl Psychiatr* 164: 253–267
- Damasio R, Damasio H, Tranel D (1986) Prosopagnosia: anatomic and physiologic aspects. *Bibl Psychiatr* 164: 268–272
- Vallar G, Bottini G, Sterzi R, Passerini D, Rusconi ML (1991) Hemianesthesia, sensory neglect, and defective access to conscious experience. *Neurology* 41: 650–652
- Vallar G, Sandroni P, Rusconi ML, Barbieri S (1991) Hemianopia, hemianesthesia, and spatial neglect: a study with evoked potentials. *Neurology* 41: 1918–1922
- Berti A, Rizzolatti G (1992) Visual processing without awareness: evidence from unilateral neglect. *J Cogn Neurosci* 4: 345–351
- Eglin M, Robertson LC, Knight RT (1989) Visual search performance in the neglect syndrome. *J Cogn Neurosci* 1: 372–385.
- Allport A (1988) What concept of consciousness? In: Marcel AJ, Bisiach E (eds) *Consciousness in contemporary science*. Clarendon Press, Oxford, pp 159–182
- Shallice T (1988) *From neuropsychology to mental structure*. Cambridge University Press, Cambridge
- Weinstein EA, Friedland RP (1977) Behavioral disorders associated with hemi-inattention. In: Weinstein EA, Friedland RP (eds) *Hemi-inattention and hemisphere specialization*. Raven Press, New York, pp 51–62
- Heilman KM, Bowers D, Coslett HB, Whelan H, Watson RT (1985) Directional hypokinesia: prolonged reaction times for leftward movements in patients with right hemisphere lesions and neglect. *Neurology* 35: 855–859
- Halligan PW, Marshall JC, Wade DT (1992) Left on the right: allochiria in a case of left visuo-spatial neglect. *J Neurol Neurosurg Psychiatry* 55: 717–719
- Goldberg G, Bloom K (1990) The alien hand sign. *Am J Phys Med Rehabil* 69: 228–238
- Schilder P (1950) *The image and appearance of the human body*. International University Press, New York
- Bisiach E, Dyschiria BA (1987) An attempt at its systematic explanation. In: Jeannerod M (ed) *Neurophysiological and neuropsychological aspects of spatial neglect*. Elsevier, Amsterdam, pp 183–201
- Grüsser OJ (1983) Multimodal structure of extrapersonal space. In: Hein A, Jeannerod M (eds) *Spatially oriented behavior*. Springer, Berlin Heidelberg New York, pp 327–352
- Moran J, Desimone R (1985) Selective attention gates visual processing in the extrastriate cortex. *Science* 229: 782–784
- Smid H-G, Lamain W, Hogeboom M-M, Mulder G et al (1991) Psychophysiological evidence for continuous information transmission between visual search and response processes. *J Exp Psychol Hum Percept Perform* 17: 696–714
- Libet B (1985) Unconscious cerebral initiative and the role of conscious will in voluntary action. *Behav Brain Sci* 8: 529–566
- Smid HGOM, Lamain W, Hogeboom MM, Mulder G, Mulder LJM (1991) Psychophysiological evidence for continuous information transmission between visual search and response processes. *J Exp Psychol Hum Percept Perform* 17: 696–714
- Smid HGOM, Mulder G, Mulder LJM (1990) Selective response activation can begin before stimulus recognition is complete: a psychophysiological and error analysis of continuous flow. *Acta Psychol* 74: 169–201

22. Frith CD, Done DJ (1986) Routes to action in reaction time tasks. *Psychol Res* 48: 169–177
23. Goldberg G (1985) Supplementary motor area structure and function: review and hypotheses. *Behav Brain Sci* 8: 567–616
24. Paus T et al (1991) Medial vs lateral frontal lobe lesions and differential impairment of central-gaze fixation maintenance in man. *Brain* 114: 2051–2067
25. Gainotti G, D'Erme P, Bartolomeo P (1991) Early orientation of attention toward the half space ipsilateral to the lesion in patients with unilateral brain damage. *J Neurol Neurosurg Psychiatry* 54: 1082–1089
26. McGlinchey-Berroth R, Milberg WP, Verfaellie M, Alexander M, Kilduff PT (1993) Semantic processing in the neglected visual field: evidence from a lexical decision task. *Cogn Neuropsychol* 10: 79–108