Functional Reorganization after Training of Alertness in Two Patients with Right-Hemisphere Lesions

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Funktionelle Reorganisation nach Alertness-Training bei zwei Patienten mit Läsionen der rechten Hemisphere

Zusammenfassung: Bei Patienten mit Alertness-Defiziten nach rechtshemisphärischer vaskulärer Schädigung wurde die individuelle Veränderung des funktionellen Netzwerkes für Alertness nach einem spezifischen Training in einer PET-Aktivierungsstudie untersucht. Die Patienten wurden mit dem Unterprogram Alertness aus dem computergestützten AIXTENT Aufmerksamkeitstraining behandelt. Vor und nach dem Training erfolgte jeweils eine PET- und eine neuropsychologische Untersuchung zur Erfassung von Aufmerksamkeitsstörungen und Hemineglect. In dieser Arbeit präsentieren wir zwei Patienten, von denen einer signifikante Leistungsverbesserungen nach dem Training erzielte. Bei diesem Patienten zeigte sich nach dem Training eine teilweise Restitution des rechtshemisphärischen funktionellen Netzwerks, welches sich bei Gesunden als relevant für die intrinsische Alertness-Kontrolle erwiesen hat. Bei dem zweiten Patienten, der keine Verbesserung zeigte, ergab sich nach dem Training lediglich eine deutliche linkshemisphärische Aktivierung im PET.

Schlüsselwörter: Alertness-Defizit, Alertness-Training, Funktionelle Reorganisation, PET-Aktivierung

Abstract: Training induced changes in the individual functional networks involved in intrinsic alertness in patients with alertness deficits due to right hemispheric vascular brain damage were assessed in a PET activation study. Patients were trained by means of the alertness routine of the AIXTENT computerized attention training. Before and after the training, both a PET and a neuropsychological assessment of attention and hemineglect were carried out. In this paper, we are presenting two patients: one, who improved significantly after training, and another one, who did not. In the patient showing behavioral improvement, the PET activation after training revealed a partial restitution of the right hemisphere functional network known to subserve intrinsic alertness in normal subjects. For the other patient, the PET activation after training showed an increase of activation only in the left hemisphere.

Keywords: Alertness deficit, alertness training, functional reorganization, PET activation

Attention is not a unitary function, rather intensity aspects (alertness, sustained attention and vigilance) and selectivity aspects (selective attention and divided attention) can be discerned (van Zomeren & Brouwer, 1994; Sturm, 1996) with a hierarchical organization (Sturm et al., 1997). Alertness, being the most basic intensity aspect of attention, is considered to be a prerequisite for the more complex aspects of attention selectivity. Intrinsic alertness, i. e. the internal, cognitive control of arousal, can be assessed by simple reaction time measurements without a warning signal. From clinical and experimental studies we know that lesions to the right hemisphere (Howes & Boller, 1975; Posner, Inhoff & Friedrich, 1987) as well as lesions of the brainstem part of the reticular formation (Mesulam, 1985) can lead to severe impairments of alertness.

Recently, several brain imaging studies have revealed the brain structures involved in sustained attention and alertness. Different groups (Cohen et al., 1988; Pardo, Fox & Raichle, 1991; Lewin et al., 1996) identified a right hemisphere fronto-parietal network subserving multimodal sustained attention. Furthermore, Kinomura and co-workers (1996) found an involvement of thalamic and brain-stem structures in the control of alertness. In a recent PET activation study in normal subjects, Sturm and colleagues (1999) demonstrated an extended network including the right anterior cingulate cortex, the right frontal dorsolateral cortex, the right inferior parietal cortex as well as thalamic and brainstem structures (cf. Fig.1). The authors argue that the right hemisphere frontal brain structures exert top-down control via thalamic nuclei on activating, probably, noradrenergic structures in the ponto-mesencephalic part of the brainstem.

As mentioned above, damage to the right hemisphere can lead to alertness deficits. If the impair-

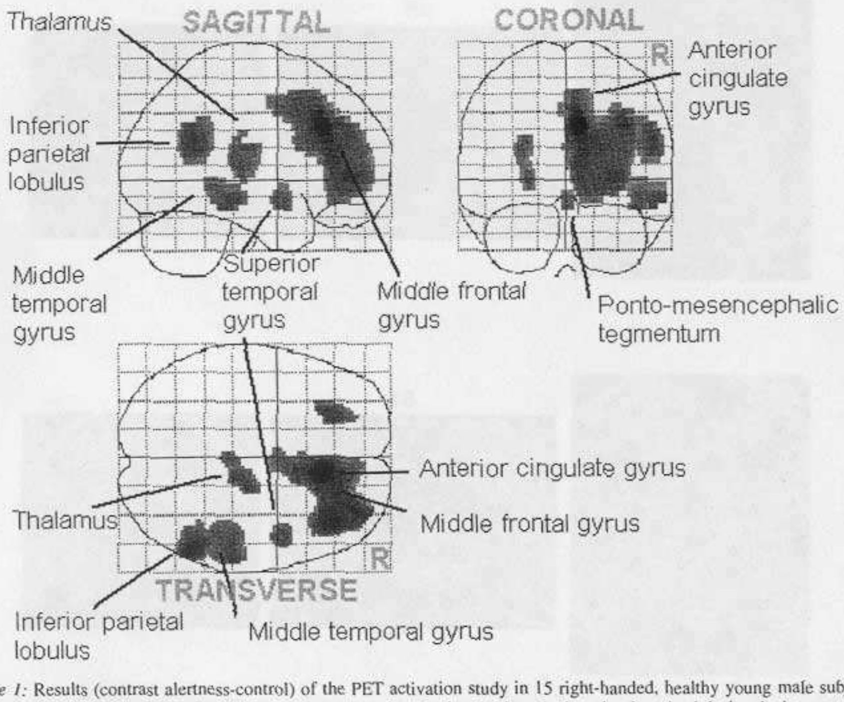

Figure 1: Results (contrast alertness-control) of the PET activation study in 15 right-handed, healthy young male subjects (Sturm et al., 1999). The "glass brain" shows the activated cortical and subcortical predominantly right-hemisphere network involved in intrinsic alertness.

ment persists into the post-acute phase, treatment of alertness deficits is required. Sturm and co-workers (1997) have demonstrated that impaired attention functions can be successfully treated by means of a *specific* computerized training (AIXTENT, Sturm et al., 1993). In particular, intensity aspects of attention (alertness and vigilance) improved up to the normal range in patients suffering from stroke (Sturm et al., 1997) or multiple sclerosis (Plohmann et al., 1998). But what are the neural correlates of recovery from alertness deficits? Most studies on functional reorganization after brain damage have concentrated on recovery of motor functions and language. Little is known about the reorganization of attention functions. In the case of both motor functions and language, perilesional reactivation or reorganization in combination with involvement of the undamaged hemisphere has been demonstrated in a number of studies (Chollet et al., 1991; Weiller et al., 1992; Weiller et al., 1995; Cappa et al., 1997; Karbe et al., 1998). Pizzamiglio and co-workers (1998) showed that recovery from unilateral hemineglect can occur only with involvement of areas similar to those activated in normal subjects. Perani and colleagues (1992) observed that remission of neglect after right hemisphere lesions follows functional metabolic recovery of the intact areas of the right hemisphere and of the left parietal lobe.

The present study deals with the functional reorganization of brain networks involved in intrinsic alertness after training of alertness. For this purpose, right-handed patients with lesions of the right hemisphere, who still presented with deficits of intrinsic alertness in the post-acute phase, were trained by means of a computerized alertness training. Before and after training, both a PET activation and a neuropsychological assessment of attention and hemineglect were carried out. Taking into account the concept of top down control for alertness, it was expected that only those patients would show substantial improvement in intrinsic alertness, i. e. an improvement of response time in a nonwarned reaction time task, who were able to reorganize at least part of the right hemisphere network known to be involved in the control of alertness in normal subjects (cf. Sturm et al., 1999 and fig. 1). In this paper, we are presenting two patients: P.L., who did not show any improvement after training, and H.B., whose performance in alertness improved significantly into the normal range. These patients were chosen from a total sample of five patients because they are typical examples of responders and non-responders with respect to the effects of the alertness treatment. Grossly, the remaining three patients showed comparable results.

Methods and Subjects

Subjects

For inclusion patients had to present with MRI confirmed right hemisphere vascular lesions in the postacute phase, five or more months post onset. They had to present with intrinsic alertness deficits as assessed by means of the subtest "Alertness" of the Test Battery for Attention Performance (TAP; Zimmermann & Fimm, 1995). The percentile ranks for the median RT and/or RT standard deviation in the alertness task without warning signal were no better than 25. Because of the norms available for the TAP, patients had to be no younger than 25 and no older than 70. Exclusion criteria were bilateral lesions, epilepsy and severe internal medical problems which might contribute to progression of the brain disease. Patients were recruited from the in and out patients services of the Neurology Department of the University Hospital in Aachen. Following these inclusion and exclusion criteria, a total of five patients were included in the study, two of which, P.L. and H.B., are presented here.

P.L. is a 68 year old right-handed man who has suffered an infarction of the right basal ganglia. In addition to that lesion, the anatomical MRT scan obtained shortly before the therapy study shows enlargement of the right lateral ventricle and a moderate global atrophy as well as a right local anterior perisylvian atrophy (cf. Fig. 2). He was included in the study 15 months post onset.

H.B. is a 52 year old right-handed woman who had a stroke caused by an occlusion of the right middle cerebral artery. The MRT shows a hypodense area extending from the third frontal gyrus and the frontal operculum to the temporal pole and the third temporal gyrus. The globus pallidus and the head of the caudate nucleus are also damaged (cf. Fig. 2). H.B. was included in the study 18 months post onset.

At the time of inclusion none of the patients presented with hemineglect, visual field defect or severe hemiparesis.

Study Design

A multiple single case study approach and a one-phase treatment design with pre- and post-treatment measurements were chosen. Only if after a baseline phase of at least two weeks patients still presented with alertness deficits they were included in the study. At the end of the baseline phase the patients underwent a comprehensive neuropsychological and the pre-treatment PET examination. After four weeks, comprising 14 computer assisted alertness therapy sessions of 45 minutes each by means of the AIXTENT training programs, which proved to be efficient in efficacy studies on different patient groups (Sturm et al., 1997; Plohmann et al., 1998), both the neuropsychological assessment and the second PET examination were carried out. Both patients gave written consent. The study was approved by the ethical committees of both the University Hospital of Aachen and the University of Düsseldorf and by federal authorities.

Neuropsychological Assessment

With the TAP (Zimmermann & Fimm, 1995) we tested intrinsic alertness, vigilance and visual scanning. A screening for visual field defects was done by means of the subtest "visual field". Hemineglect was assessed with the Behavioral Inattention Test (Wilson, Cockburn & Halligan, 1987) and some clinical tasks (text reading, line bisection, clock drawing, letter and star cancellation,

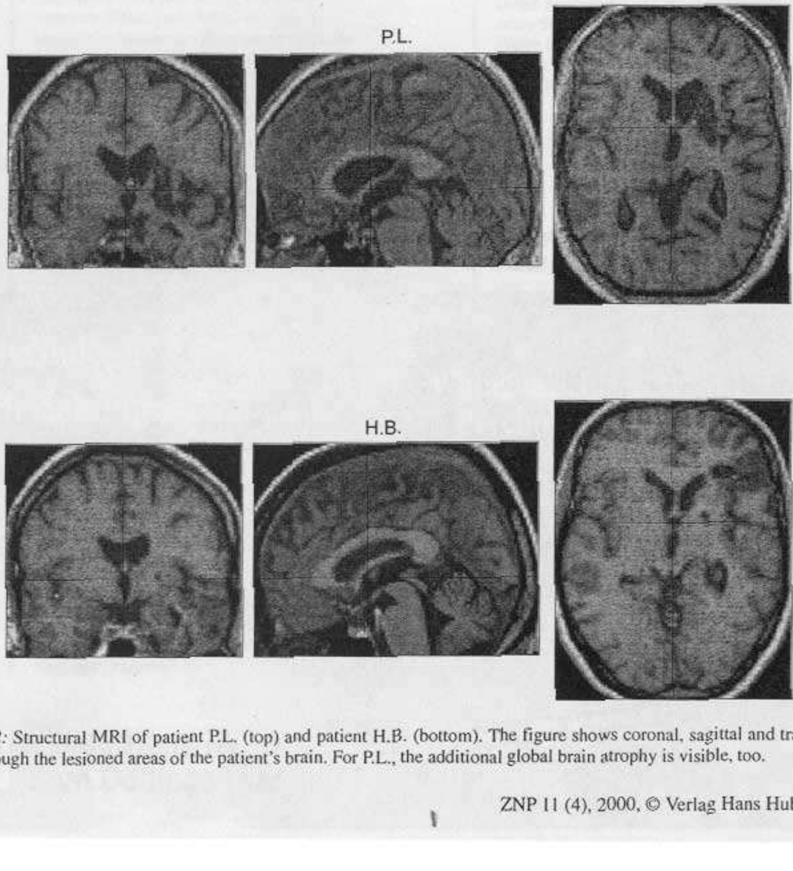

Figure 2: Structural MRI of patient P.L. (top) and patient H.B. (bottom). The figure shows coronal, sagittal and transversal cuts through the lesioned areas of the patient's brain. For P.L., the additional global brain atrophy is visible, too.

copying of simple line drawings). In the following, we will focus only on the intrinsic alertness performance of the patients. The test of intrinsic alertness of the TAP requires a fast right index finger key press to a simple visual, centrally presented stimulus without a preceding warning signal. Fast responses in this task require the patients to elicit an optimal cognitive control of alertness. Handedness was assessed by means of a German translation of the Edinburgh-Handedness-Inventory (Oldfield, 1971).

PET Activation

Scans representing regional cerebral blood flow (rCBF) were obtained for each subject using a Siemens ECAT HR+ (CTI Knoxville) scanner which provides 63 transverse sections through the brain spaced 2.7 mm apart (center to center). Transmission scans performed with a ^{68}Ge rotating line source were used for measured attenuation correction. A laser positioning system helped to obtain images with reference to the highest and lowest slice of the scanner. Emission scans were recorded after the intravenous bolus administration of 550 MBq ^{15}O-butanol (half-life 123 s). Acquisition of data for all 63 slices was started simultaneously with the injection. This data was framed into a single time frame of 40s starting at the tracer's entry into the brain. Using filtered backprojection the reconstructed image resolution was about 8 mm full width at half maximum. The activity images were not further quantified and were regarded as estimates of rCBF. The time interval between scans was about 10 minutes; the total examination time per subject was about 2½ hours including preparation. Each subject underwent twelve PET scans within a single session (maximum radiation dose 3.8 mSv per subject) and a magnetic resonance imaging scan on a different day. During each of the 12 trials the task started approximately 30s before injection.

Data Analysis

PET images were analyzed using Statistical Parametric Maps (SPM96) implemented in MATLAB (Mathworks Inc., Sherborn, MA, USA) and run on a Ultra 60 workstation (SUN Microsystems Inc.). Reconstructed data sets were converted to the ANALYZE format (Robb, 1991) for further processing with SPM96. The functional images were realigned to the first image of each run to avoid movement artefacts and spatially normalized to MNI space before statistical analysis was performed.

In addition, for each subject the (anatomical) MRI scan was co-registered to the functional images and normalized to yield a co-registered MRI template on which the individual results of the statistical analysis were superimposed.

In standard space one voxel represents 4 × 4 × 4 mm in the x, y, and z dimensions, respectively. All images were then smoothed using a Gaussian filter of 12 × 12 × 12 mm to increase the signal-to-noise ratio in the images.

To account for global changes of CBF, the data were adjusted by globally scaling all scans to have the same gCBF of 50 ml/min/dl. Areas of significant changes in brain activity between two experimental task conditions, as specified by appropriately weighted linear contrasts, were determined using the t-statistic on a pixel-by-pixel basis. The set of t-values for a linear contrast was transformed to z-values via probability transformation. Only regions comprising at least 10 voxels and having p-values for individual voxels of at least 0.01 were considered to test in a single subject analysis our hypothesis of an at least partial reorganization of the right hemisphere network in patients who improved after the training. Due to this confirmatory approach no adjustment of individual voxel-wise p-values for multiple testing was required for the target areas of activation.

PET Tasks

There were two different tasks, each of which had to be carried out six times:

1. Alertness: Fast right-hand thumb responses (key presses) to a white light spot (diameter 18 mm) irregularly (intrastimulus interval 3 to 5 sec) appearing centrally at the location of a small square serving as a fixation point on a 17" black monitor screen, which was mounted at a distance of 50 cm from the subject's head. This task is a special adaptation of the alertness subtest of the TAP used for the assessment of alertness deficits.

2. Sensorimotor control for the purely sensory and motor aspects of the alertness condition: right-hand thumb key presses at a self-determined rate (the patients were trained to press the key regularly about every second) while looking at the central white light spot used for the alertness task now flickering at a rate just below the individual flicker fusion frequency. The high flicker frequency was required in order to prevent another alertness task since under this condition subjects are unable to synchronize their key presses with the flicker frequency of the white light. The high frequency of thumb presses was necessary to ensure automatized motor actions without aspects of cognitive control. Thus, it proved impossible to provide a sensorimotor control condition which was more parallel to the alertness condition with respect to the frequency of the stimulus and of the motor response. On the other hand, the alertness task certainly has aspects of a paced sensorimotor integration or "tapping" task, too. Nevertheless, the fact that the patients were asked to respond as fast as possible ascertained a high level of alerting

During all conditions the patients placed their right hand on an arm rest and held their right-hand thumb attached to a 5 × 5 cm response key. Each condition lasted for 60 sec and was given six times in alternating order always starting with the sensorimotor condition.

For both patients, we report on the comparison between the alertness and the sensorimotor control condition.

Alertness Training

The alertness treatment was composed of two routines from the attention training program AIXTENT (Sturm et al., 1993), a software for training four different aspects of attention (alertness, vigilance, selective attention and divided attention). On a computer screen, the patient sees either a car (routine "Race-car") or a motorcycle (routine "Motorcycle") driving on a road. The patient has to handle two response keys: one for gas and the other one for braking. The goal is both to drive the vehicle as quickly as possible and to stop it just in time to avoid crashing into obstacles appearing in front of it. Several parameters like maximum speed, position of the vehicle on the screen, presence and visibility of warning signals can be varied to change the difficulty level of the training. Automatic adaptation of the level according to the patients' performance is also possible as a program option. With each change of difficulty level or whenever a patient requires it, detailed feed-back on the performance is provided in numerical and graphical form.

Results

Patient P.L.

Before therapy, P.L. showed a very poor performance in intrinsic alertness (TAP median RT 364 ms, percentile rank (PR) 4). The neuropsychological assessment after the training comparably slow response times although the performance became more stable, which is reflected in improved percentile ranks for the intraindividual standard deviation of the response time (SD) (cf. Table 1).

In the first PET study immediately before training, we only found a small increase in cerebral blood flow in the left superior frontal gyrus corresponding to Brodmann area (BA) 6 (cf. Table 2) probably representing the motor activity of the right hand while pressing the response key. As

Table 1: Performance in intrinsic alertness of Patient P.L. and Patient H.B. in the subtest "Alertness" of the Testbattery for Attention Performance (TAP) at the beginning (TAP1) and at the end of the baseline phase, immediately before therapy (TAP 2) as well as after the training (TAP 3). The table shows the intraindividual standard deviation of the response time (SD) as well as the response time median, both in ms, and percentile ranks referring to the normative data of the TAP.

		TAP 1	TAP 2	TAP 3
P.L.	SD ms/ PR	326/ PR < 1	109.44/ PR2	60.71/ PR38
	Median ms./ PR	566/ PR < 1	364.00/ PR4	354.00/ PR5
H.B.	SD ms/ PR	105.88/ PR1	84.25/ PR3	34.51/ PR76
	Median ms./ PR	276.00/ PR24	265.00/ PR31	217.50/ PR79

Table 2: Patient P.L. alertness – control (before therapy). Activated brain areas with Talairach coordinates based on SPM96-analysis showing all regions comprising al least 10 voxels and having *p*-values for individual voxels of no more than .01.

Focus/area		side	BA†	Talairach coordinates x	y	z	region size	*p*-value	*z*-value
1.	Gyrus frontalis superior	L	6	−12	−12	68	15	.002	2.93

†BA: Brodmann area

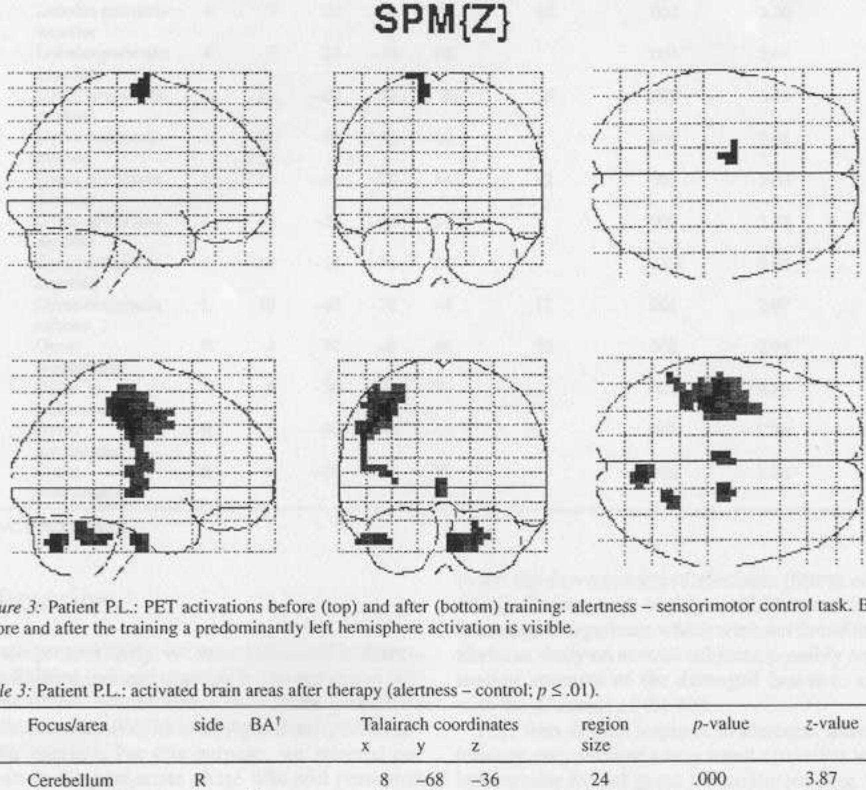

Figure 3: Patient P.L.: PET activations before (top) and after (bottom) training: alertness – sensorimotor control task. Both before and after the training a predominantly left hemisphere activation is visible.

Table 3: Patient P.L.: activated brain areas after therapy (alertness – control; $p \leq .01$).

	Focus/area	side	BA†	Talairach coordinates x	y	z	region size	*p*-value	*z*-value
1.	Cerebellum	R		8	−68	−36	24	.000	3.87
2.	Gyrus postcentralis	L	1	−48	−20	40	175	.000	3.83
	Gyrus postcentralis	L	3	−36	−24	52		.000	3.62
	Gyrus precentralis	L	4	−36	−12	48		.000	3.57
3.	Truncus cerebri	R		20	−16	−36	16	.000	3.32
4.	Cerebellum	L		−44	−44	−36	15	.001	3.21
5.	Nucleus ruber	L		−4	−20	−4	11	.001	3.03
	Thalamus			0	−12	4		.003	2.72
6.	Cerebellum	R		24	−52	−28	12	.002	2.94

† BA: Brodmann area

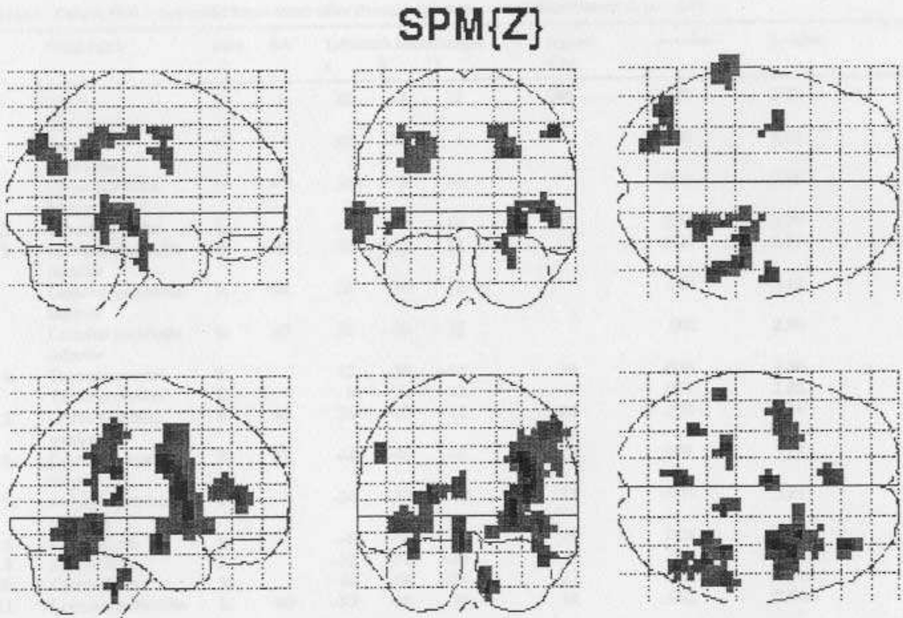

Figure 4: Patient H.B.: PET activations before (top) and after (bottom) training: alertness – sensorimotor control task. A comparison of pre-and post-treatment activations shows a reactivation of right frontal and right-parietal regions known to subserve top-down control of intrinsic alertness in normals.

shown in Figure 3, there was no activation in the right hemisphere at the individual voxel level of $p < .01$.

After training, there was an increase of activation mainly in the left hemisphere (postcentral gyrus (BA 1, BA 3), and precentral gyrus (BA 4) and the thalamus) but also in the right brain stem as well as bilateral activation in the cerebellum (cf. Table 3 and Figure 3).

Patient H.B.

Although the patient had a percentile rank of 31 in the median RT of alertness without warning signal, we included her in the study because the intraindividual variability in response speed was very high (PR 3). After therapy, H.B. improved significantly: she reached an above average median RT (PR 79) and a very stable response level (PR 76 for the intraindividual SD) (see Table 1).

As shown in Figure 4, in the PET examination before training there was bilateral activation. Significant increase in regional blood flow was registered in the following areas: in the left middle temporal gyrus (BA 21), in the left superior and inferior occipital gyrus (BA 19), in the right superior parietal lobulus (BA 7), in the right middle and superior temporal gyrus (BA 21, BA 22), in the right precentral gyrus (BA 4, BA 6).

The post-treatment PET activation also revealed bilateral activations, but with more extended and more frontal activation foci in the right hemisphere: in the right inferior and middle frontal gyrus (BA 47, BA 10 resp.), in the right inferior parietal lobulus (BA 40), in the right precentral gyrus (BA 6), in the left middle frontal gyrus (BA 6), in the left superior temporal gyrus (BA 38), in the left cingulate gyrus (BA 24), in the left inferior and superior parietal lobuli (BA 7, BA 40 resp.), as well as in the cerebellum bilaterally. (cf. Fig. 4 and Table 5). Both patients during the PET activation showed comparable response times as during the "off-line" TAP sessions.

Table 4: Patient H.B. alertness – control (before therapy). Activated brain areas with Talairach coordinates based on SPM96-analysis showing all regions comprising al least 10 voxels and having *p*-values for individual voxels of no more than .01.

	Focus/area	side	BA[†]	Talairach coordinates x	y	z	region size	*p*-value	*z*-value
1.	Hippocampus	R		32	–24	–8	70	.000	3.86
	Gyrus temporalis superior	R	22	44	–24	0		.000	3.73
	Gyrus temporalis medius	R	21	52	–40	–4		.001	2.99
2.	Lobulus parietalis superior	R	7	24	–48	36	45	.001	3.20
	Lobulus parietalis superior	R	7	24	–36	44		.001	3.01
3.	Gyrus temporalis medius	L	21	–68	–32	0	38	.001	3.12
	Gyrus temporalis medius	L	21	–64	–40	–12		.005	2.61
4.	Gyrus occipitalis superior	L	19	–28	–76	44	42	.001	3.03
	Gyrus occipitalis superior	L	19	–28	–68	28		.002	2.87
	Gyrus occipitalis superior	L	19	–36	–72	24		.005	2.61
5.	Gyrus occipitalis inferior	L	19	–40	–72	–4	17	.001	2.97
6.	Gyrus precentralis	R	4	52	–8	48	10	.002	2.94
7.	Gyrus precentralis	R	6	–36	–4	36	21	.002	2.86
	Gyrus precentralis	R	6	–40	–4	44		.003	2.76
	Gyrus precentralis	R	6	–28	–12	36		.004	2.86

† BA: Brodmann area

Discussion

In the present study, we were interested in detecting training induced changes in the activation patterns of intrinsic alertness in patients presenting with alertness deficits after right hemisphere vascular damage. For this purpose, we selected patients in the post-acute phase who still presented with alertness deficits and submitted them to a specific computerized alertness training. Before and after the training, both a neuropsychological assessment and a PET activation study were carried out. We have presented two cases: one patient (H.B.), whose performance in alertness improved with training, and another patient (P.L.), who did not profit from therapy.

None of the patients before the training revealed an activation of the right middle or dorsolateral frontal cortex supposed to play an outstanding role in the top down control of alertness (Sturm et al., 1999). There were highly variable activations across the two patients which were not found in the alertness study on normal subjects, possibly representing attempts of the damaged brains to cope with the demands of the task.

P.L., who did not improve in alertness after the training, only showed a very small activation in the left superior frontal gyrus before the training. The second PET revealed an increase of activation in the left hemisphere and bilateral activation in the cerebellum. On the contrary, patient H.B., who improved significantly after therapy, showed bilateral activations predominantly in the left hemisphere in the first PET. In the second PET, an increased activation of the right hemisphere, especially in frontal and parietal brain areas, was registered.

In the two cases presented, the change of activation patterns after alertness training corresponds to behavioral changes. It may be hypothesized that

Table 5: Patient H.B.: Activated brain areas after therapy (alertness – combined control; $p \leq .01$).

	Focus/area	side	BA[†]	Talairach coordinates x	y	z	region size	*p*-value	*z*-value
1.	Gyrus precentralis	R	6	32	–4	32	245	.000	3.93
	Fasciculus uncunatus	R		28	12	4		.000	3.67
	Gyrus frontalis inferior	R	47	36	8	16		.000	3.56
2.	Truncus cerebri	L		–4	–8	–16	15	.000	3.79
3.	Lobulus parietalis inferior	R	40	36	–36	28	92	.000	3.74
	Lobulus parietalis inferior	R	40	56	–36	52		.001	3.12
	Lobulus parietalis inferior	R	40	32	–48	32		.002	2.90
4.	Truncus cerebri	R		12	–36	–44	14	.000	3.50
	Truncus cerebri	R		8	–28	–32		.002	2.88
5.	Gyrus frontalis medius	R	10	36	40	12	24	.000	3.41
6.	Gyrus temporalis inferior	R	37	44	–48	–4	28	.001	3.27
7.	Lobulus parietalis superior	L	7	–24	–32	16	15	.001	3.21
8.	Cerebellum	L		–8	–64	–8	19	.001	3.11
9.	Cerebellum	L		–32	–52	–20	15	.001	3.11
10.	Cerebellum	R		44	–64	–24	21	.001	3.11
11.	Lobulus parietalis inferior	L	40	–52	–36	36	11	.002	2.94
12.	Gyrus cinguli	L	24	–4	32	20	19	.002	2.93
13.	Gyrus temporalis superior	L	38	–44	0	–8	60	.002	2.90
	Fasciculus uncinatus	L		–28	4	–4		.003	2.79
	Gyrus frontalis medius	L	6	–28	0	12		.004	2.62

[†] BA: Brodmann area

behavioral improvement can only be achieved if at least part of the right hemisphere network, especially the frontal part, known to subserve intrinsic alertness in normal subjects, is reactivated. In patient H.B., in fact there is a perilesional functional reorganization in the vicinity of her frontal lesion. The predominantly left hemispheric increase of activation, as it shows up in patient P.L. after the training, obviously does not lead to successful functional recovery of top down control of alertness. Probably, the left post- and precentral as well as the cerebellar activation are due to an increased effort to press the response key, and an improved sensorimotor coordination (cf. Lutz et al., 2000) although not resulting in faster responses, and thus not indicating an improved level of alertness. A possible reason for the lack of functionally relevant reorganization in P.L. might be that besides his vascular lesions P.L. suffers from generalized and focal right anterior perisylvian brain atrophy possibly diminishing the chance for a successful recovery of function.

These findings are consistent with the data presented by Pizzamiglio and co-workers (1998) on recovery from unilateral hemineglect. In fact, Pizzamiglio and colleagues found that recovery of neglect occurs only with cerebral activation in brain areas in the right hemisphere analogous to those activated in normal subjects. This might indicate that intensity aspects of attention recovery after stroke can take place only with involvement of those structures of the right hemisphere subserving normal functioning. The left, undamaged hemisphere alone cannot compensate successfully for attention deficits caused by right hemisphere damage. Studies with lateralized stimulus presentation in a vigilance task in split-brain patients have demonstrated that the left hemisphere only has a very limited ability to maintain alertness and to control for the intensity level of attention (Dimond, 1979).

These results are in contrast with the early findings on recovery of motor functions and language after vascular brain damage and with more recent results on short term functional improvement after a few minutes of aphasia therapy while the patients still were in the PET scanner (Musso et al., 1999). For these functions, different research groups reported involvement of the undamaged hemisphere in functional reorganization. In other studies, however, reorganization of the left, damaged hemisphere has been recognized as an important mechanism in recovery from language deficits as well (Cappa & Vallar, 1992).

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