Training-induced brain plasticity in aphasia

Mariacristina Musso, 1 Cornelius Weiller, 1 Stefan Kiebel, 1 Stephan P. Müller, 2 Peter Büalü 3 and Michel Rijntjes 1

1 Department of Neurology, Friedrich-Schiller-Universität Jena, 2 Department of Nuclear Medicine, Universität Essen and 3 Neurorehabilitationsklinik, Waldbreitbach, Germany

Summary
It has long been a matter of debate whether recovery from aphasia after left perisylvian lesions is mediated by the preserved left hemispheric language zones or by the homologous right hemisphere regions. Using PET, we investigated the short-term changes in the cortical network involved in language comprehension during recovery from aphasia. In 12 consecutive measurements of regional cerebral blood flow (rCBF), four patients with Wernicke’s aphasia, caused by a posterior left middle cerebral artery infarction, were tested with a language comprehension task. Comprehension was estimated directly after each scan with a modified version of the Token Test. In the interval between the scans, the patients participated in brief, intense language comprehension training. A significant improvement in performance was observed in all patients. We correlated changes in blood flow measured during the language comprehension task with the scores achieved in the Token Test. The regions which best correlated with the training-induced improvement in verbal comprehension were the posterior part of the right superior temporal gyrus and the left precuneus. This study supports the role of the right hemisphere in recovery from aphasia and demonstrates that the improvement in auditory comprehension induced by specific training is associated with functional brain reorganization.

Keywords: PET; recovery; stroke; aphasia

Abbreviations: rCBF = regional cerebral blood flow; sTT = short version of the Token Test; TT = Token Test

Introduction
Patients with aphasia following localized, acute damage to the language zones of the brain, such as those with vascular or traumatic lesions, undergo some degree of spontaneous recovery over time in almost all instances (Lomas and Kertesz, 1978; Lendrem and Lincoln, 1985; Basso, 1992; Wertz, 1996). The effectiveness of language rehabilitation has long been a matter of debate. Most authors assume a beneficial specific effect of language therapy, particularly when it is intense and starts early (Basso et al., 1979; Sarno, 1979, 1981; Kertesz, 1984; Robey, 1994). The neuronal processes underlying recovery, however, remain largely unknown. Several theories, partly supported by experimental and clinical data, have been put forward to explain this phenomenon. Some PET studies emphasize the role of the preserved language zones in the left hemisphere in the recovery process (Cappa et al., 1997; Price et al., 1992; Heiss et al., 1997). Alternatively, as originally proposed by Wernicke (1874) and Gowers (1875) and successively demonstrated from several different sources of evidence, the restitution of language functions after a stroke may be mediated through compensation by analogous brain regions in the contralateral, undamaged hemisphere (i.e. the right hemisphere in right-handers) (Kinsbourne, 1971; Winner and Gardner, 1977; Papanicolau, 1988; Basso, 1989; Cappa and Vallar, 1992; Gainotti, 1993). In a recent FDG ([18 F]fluorodeoxyglucose)-PET study, Cappa and colleagues found that activation in the right temporoparietal region in the acute phase was highly predictive of the recovery of auditory comprehension in aphasia patients (Cappa et al., 1997). Our previous PET study in recovered Wernicke’s aphasia patients with lesions in the left posterior language zones showed increased activation in the preserved left frontal language zones (Broca’s area and dorsolateral prefrontal cortex) and in homologous right hemisphere regions (superior temporal gyrus, dorsolateral prefrontal cortex and inferior frontal lobe) during a verb generation task (Weiller et al., 1995). These data suggest that the reorganization of the language-related cortical network, consisting in the activation of the undamaged areas on both hemispheres, but particularly on the right, may be crucial for the recovery of impaired language function after a stroke. The present study aimed to clarify which of these areas mediate the recovery of functions.
For this purpose, training-induced improvement of language comprehension in patients with Wernicke’s aphasia was correlated with changes in brain activation during a language comprehension task. The idea was to assess the short-term changes in the pattern of activation during the training session rather than to compare status after with status before rehabilitation. We hypothesized that improvement of altered comprehension in stroke patients would relate to a redistribution of activity to the unaffected areas of the neuronal network as the central mechanism of recovery from stroke (Mesulam, 1994; Weiller et al., 1998).

**Methods**

**Subjects**

In a pilot study, 20 patients with Wernicke’s aphasia (10 male and 10 female; age 42–70 years, mean age 55 years) were exposed to the specific language comprehension training (see below) to test its effectiveness. Four other patients (three male, one female; age 55, 58, 58 and 60 years) participated in the PET study. All patients were right-handed (Olfield, 1971) and had suffered from a stroke in the temporoparietal regions of the left hemisphere, including the presumed Wernicke’s area. The exact location of the infarct in the four patients who participated in the PET study, as derived from high-resolution MRI scanning, is shown in Fig. 1. The language disorder was classified as Wernicke’s aphasia according to the Aachen Aphasia Test battery (Huber et al., 1984). Details for the four patients who were examined with PET are given in Table 1. The patients had no hand apraxia, as this would have interfered with the experimental task. None had a previous history of neurological or psychiatric diseases. At the time of PET scanning, all four patients showed complete recovery from other neurological deficits, such as right hemiparesis (K.J., R.I., Z.E.) and right hemianopia (A.A.). Before the PET investigation, their initial language deficit was treated through therapy sessions at home or in rehabilitation clinics. Informed consent was obtained from all subjects. The study was approved by the local ethics committee.

**Experimental design**

The aim of this study was to define not the physiological cortical network for language comprehension but the compensatory changes involved in recovery after focal lesions. A correlation-type setup was used, in which increases in rCBF equivalents [a surrogate marker of neuronal activity (Jueptner and Weiller, 1995)] are related to an external variable, i.e. language comprehension. This design seems to be the optimal approach to the identification of the modification of the spatial activation pattern involved in the improvement of language comprehension during training. In 12 repetitive measurements of rCBF only one condition was studied: language comprehension. While waiting for the degradation of radioactivity (~5 half-lives, i.e. 12 min) between scans, the patients underwent a language comprehension test, a short version of the Token Test (sTT), immediately followed by specific and effective language comprehension training (Fig. 2). The estimate of language comprehension was used to specify a linear model with which the measured PET signal was characterized.

In our study we decided to investigate specifically language comprehension as this function is almost invariably altered in aphasia and has a good recovery potential (Basso, 1992). For the activation task and for testing the concrete comprehension improvement during training we used the concept of the Token Test (TT) for its sensitivity to verbal comprehension in aphasic patients (De Renzi and Vignolo, 1962). In this test, comprehension is assessed by the numbers of correct answers to series of commands of increasing complexity in semantics and syntax. The TT has been very well validated; several neuropsychological and [18 F]FDG-PET longitudinal studies have used it to monitor recovery in poststroke aphasia (De Renzi and Vignolo, 1962; Heiss et al., 1993, 1997; Jarzewska, 1996). At the behavioural level, the TT examines auditory comprehension without overt output. At the cognitive level the TT is a comprehension test that, although excluding some pragmatic aspects of language comprehension, requires not only linguistic capacities but also good short-term verbal and non-verbal memory and preserved attention. However, the process involved in understanding a sentence reflects an interaction between linguistic and non-linguistic levels of representation (e.g. working memory) (Rosaleen et al., 1987; Carpenter et al., 1992; MacDonald et al., 1995; Caplan et al., 1996). It was not our intention to individuate the importance and the consistency of each of these specific aspects of language comprehension, but to induce and test its recovery globally.

To meet the experimental requirements in our study, several modifications of the TT were needed.

**Task**

The language comprehension task during PET scanning in patients with Wernicke’s aphasia must be easy enough to be executed with good performance in different patients and should require limited motor output and no overt verbal output. The TT could not be used directly as its execution during PET scanning would cause too many movement artefacts and the performance would not be constant. Therefore we used a modification of it, a subtest of the Aachen Aphasia Bedside Test (Biniek et al., 1992) used for acute patients at the bedside. Despite the simple sentence construction, sensitivity for auditory comprehension is not reduced (Biniek et al., 1992). In the activation task, the subjects were required to understand the difference between two auditory commands: ‘take’ or ‘point to’ an everyday object (such as a fork or a spoon). Prior to scanning, the object was shown to the subjects and placed near their left hand, and the test was explained. The subjects were not
Training-induced brain plasticity in aphasia

Fig. 1 Maps of infarcted areas showing individual lesions in four patients as derived from high-resolution MRI scanning (neurological convention: left = left). Each infarct was plotted on a standard MRI: white corresponds to the infarcted area in patient K.J., black with white points in patient R.I., white with black dots in patient Z.E. and the grid in patient A.A.

required to speak or to look at the object. During the scans, the subjects were asked to follow one of two oral instructions: ‘point to’ or ‘take’ the object. The oral commands were presented every 10 s from prerecorded tapes.

Test of improvement of comprehension
Because of the simplicity of the comprehension task used to index the rCBF during scanning, a more sensitive test was needed to assess the level of comprehension. Since the original TT would last too long and because time is rather limited between the PET scans, we designed a short version of the TT (sTT). It consisted of a series of 10 instructions, conveyed through sentences that gradually increased in length and syntactic complexity (see Appendix 1).

Training
A short-term, intense and effective training program for language comprehension was needed which was suitable for simultaneous PET scanning. The training we designed consisted of 11 sessions of ~8 min each and was performed in the interval between the 12 scans, starting after the first. The aim of the training was to stimulate the conscious use of the processes that make linguistic and conceptual knowledge available. This approach was grounded on the hypothesis that the basic impairment in patients with Wernicke’s aphasia is the inability to access linguistic information rather than the loss of linguistic knowledge (Warrington et al., 1975; Byng and Blank, 1995; Warrington and Cipolotti, 1996). We used different types of cueing procedures with various linguistic and non-linguistic materials. To ensure that the patient concentrated on the meaning of the sentences and not on sentence structure, we used syntactically simple auditory sentences that required only a ‘yes’ or ‘no’ response. The training included five different tasks: (i) a tactile–verbal matching task, in which an everyday object was given to the subject along with different oral verbal commands (five commands per object); (ii) a visual–verbal matching task, in which the patient saw pictures with different objects and had to indicate one of them after an oral command; (iii) a semantic decision-making task for oral sentences, in which the patient had to evaluate the semantic correctness of the sentences; (iv) a phonological decision-making task for oral sentences, in which the patient had to judge the phonological accuracy of the sentences; and (v) a picture–sentence matching task. In this last session different pictures were shown to the patient with three
Table 1: Clinical data and results of the Aachen Aphasia Bedside Test in four patients with Wernicke’s aphasia

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Formal education</th>
<th>Interval*</th>
<th>Logopaedic</th>
<th>COM</th>
<th>ART</th>
<th>AUT</th>
<th>SEM</th>
<th>PHO</th>
<th>SYN</th>
<th>TT</th>
<th>REP</th>
<th>WRIT</th>
<th>NAME</th>
<th>COMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>K.J.</td>
<td>M</td>
<td>58</td>
<td>10 years private business</td>
<td>18 months</td>
<td>4 m 5 x weekly</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>R.I.</td>
<td>F</td>
<td>58</td>
<td>9 years housewife</td>
<td>9 months</td>
<td>3 m 5 x weekly</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Z.E.</td>
<td>M</td>
<td>60</td>
<td>9 years private business</td>
<td>9 months</td>
<td>3 m 5 x weekly</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>A.A.</td>
<td>M</td>
<td>55</td>
<td>17 years electrical engineer</td>
<td>6 months</td>
<td>1 m 2 x weekly</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

The Aachen Aphasia Test consists of six six-point spontaneous speech rating scales (COM = communicative behaviour; ART = articulation and prosody; AUT = automated language; SEM = semantic structure; PHO = phonologic structure; SYN = syntactic structure) and five subtests (TT = Token Test; REP = Repetition; WRIT = Written Language; LAB = Label; COMP = Comprehension). The scores for the Aachen Aphasia Test are expressed in percentile ranks. For further description see the paper by Huber et al. (Huber et al., 1984). *Time between stroke onset and PET scanning.

Descriptive sentences. The patient had to indicate which one of the oral sentences was correct. The five tasks were repeated, each task being similarly constructed but becoming more complex with each session. The order of presentation of the five tasks changed from one session to the next. In the eleventh session the tasks proved to be the most difficult for all patients. The patients were encouraged to evaluate the correctness of the answers. Specific cues or hints were used to give them the possibility of using different strategies. This helped them to detect their errors, creating the condition for self-correction.

The effects of this language comprehension training programme were tested in the 20 pilot patients with Wernicke’s aphasia. For this, we used the TT before and after the training sessions. In all patients we observed a significant increase in the number of correct answers in the test after training (one-sided t test of difference, P < 0.0001). Therefore, we concluded that this PET-compatible training was effective in patients with Wernicke’s aphasia.

To assess the specificity of the training, the same four patients who underwent the PET scanning were tested off-line (i.e. outside the camera) using the same setup. However, instead of the language comprehension training described previously, we exposed the patients to non-specific stimuli such as writing, watching television and speaking. This stimulation was also organized in 11 sessions of 8 min each. As in the PET study, improvement of language comprehension was measured with the sTT, after the execution of the language task. This non-specific stimulation did not improve the performance (Fig. 3).

Data acquisition and data analysis

rCBF was estimated with an ECAT 953/15 PET scanner (CTI Inc., Knoxville, Tenn., USA) after slow bolus injection of a maximum of 700 MBq H215O per application in 2D mode. After attenuation correction (using a transmission scan), the data were reconstructed into 15 transaxial planes by filtered back-position with a Hanning filter with a cutoff frequency of 0.5 cycles/pixel (1.96 mm pixel size), resulting in a full width half maximum resolution of 8 mm in the reconstructed image (Weiller et al., 1995). The integrated counts accumulated were used as an index of rCBF (Fox and Mintun, 1989). Due to the small axial field of view of the camera (5.4 cm), the gantry was inclined ~3° with respect to the intercommisural line (AC–PC line), aiming to position the lower border of the first transaxial slice at the lower border of the middle temporal gyrus. Positioning is crucial with such a limited field of view. It was performed by an experienced PET scientist using the information from the individual T1-weighted MRI. However, the PET scans only partly overlapped, such that the common stereotaxic space covered by all subjects ranged from ~5 to 28 mm in the z axis. This field of view covers all ‘primary’ language-related areas (e.g. Wernicke’s, Broca’s, dorsolateral prefrontal cortex (DLPFC) and inferior parietal lobe). However, activation in
Training-induced brain plasticity in aphasia

Fig. 2 Design of paradigm. During each of the twelve PET scans the subjects underwent the same activation task, which required them to understand and follow one of two different auditory commands: ‘take’ or ‘point to’ an everyday object. In the interval between the scans (~12 min), while waiting for the degradation of radioactivity, the subjects were exposed first to the sTT, which was followed by one of the 11 training sessions.

Fig. 3 Effect of the specific and intensive language comprehension training (closed circles) and of non-specific stimulation (open circles) applied between the 12 PET investigations, tested off-line in four patients with Wernicke’s aphasia. The training consisted of 11 sessions. The improvement in language comprehension was measured carrying out the sTT after each training session. Performance measured with the TT significantly improved only during the specific language comprehension training ($P < 0.0001$).

areas outside this restricted field of view (e.g. supplementary motor area) could not be assessed. We used statistical parametric mapping (SPM96; Frackowiak et al., 1997) for the analysis of the data. All the scans were realigned to each other. The images were then transformed into a standard stereotaxic anatomical space, corresponding to Talairach and Tournoux’s atlas (Talairach and Tournoux, 1988; Friston et al., 1991; Friston, 1995). We used the following procedure to normalize the patients’ scans: a weighted mean of the unsmoothed PET images after segmentation of extracerebral structures (scalp, skull, etc.) was coregistered with the corresponding anatomical, $T_1$-weighted, segmented MRI of the same individual using SPM. The individual MRI was used to derive the transformation parameters for the stereotaxic fit, which were applied to the individual single coregistered PET images. The normalized images were smoothed with a Gaussian filter of $10 \times 10 \times 6$ mm at full width half maximum for individuals and of $20 \times 20 \times 12$ mm for group comparisons. Statistically significant pixels were found using the general linear model and the theory of random Gaussian fields at $P < 0.01$ (Frackowiak and Friston, 1994; Frackowiak et al., 1997). To localize the brain areas related to the improvement of language comprehension, a correlation analysis was performed between the measured PET signal and the values of the short version of the TT as the covariate of interest.
Results

All four patients participating in the PET study were already able to perform the task correctly before the training. The improvement in language comprehension in each patient during PET investigation was documented from performance during the sTT, carried out after each scan (Table 2). The simple sentences of part I of the sTT, such as ‘Touch the red circle’, were not understood initially by only one patient (R.I.), who had particular difficulty in understanding the word ‘circle’. At the onset all four patients were impaired to different degrees; after a few scans their performance gradually improved, most notably in sentence construction of parts II and V of the sTT. They demonstrated problems particularly with long sentences, as in part IV of the sTT. The same patients when exposed to non-specific training showed no improvement in language comprehension.

The group results of the PET data showed activation in two areas of the brain correlating with the improved values of the sTT performed after each scan: the posterior part of the superior temporal gyrus in the right hemisphere (+48, –46, +12 mm; Z score = 3.97), homotopic to the supposed Wernicke’s area in the left hemisphere (Fig. 4). The second focus of activation was found along several planes of the posterior part of precuneus in the left hemisphere (–14, –62, +20 mm; Z score = 4.53).

The single results are summarized in Table 2.

Discussion

Brief but intense comprehension training had the effect of improving language performance in patients with Wernicke’s aphasia due to a stroke destroying the left perisylvian areas. The main novelty of our study was that we measured the direct correlation between performance in the sTT, which reflected the improvement of language abilities of each patient, and the change in rCBF during a language comprehension task. Our study shows for the first time that short-term clinical recovery of language performance correlated with fast modification of the activation pattern in a bilateral cortical network comprising brain regions directly or indirectly related to language.

The most consistent finding across all subjects was increased activation of the right superior temporal gyrus and the left precuneus. Additional areas in individual patients comprised the peri-infarctual area on the left side, the middle temporal and supramarginal gyrus in the right hemisphere, the prefrontal cortices in both hemispheres, and the left cingulate gyrus. Most of these areas are related to language processing under normal conditions (Damasio, 1989; Demonet, 1992; Mazoyer et al., 1993; Mesulam, 1994) and after recovery from aphasia (Weiller et al., 1995; Musso et al., 1997). It is generally acknowledged that the main difference between healthy right-handed subjects and stroke patients in the pattern of activation of the bilateral language processing network is the indisputable left-hemisphere dominance in the former. Several functional imaging studies on the recovery of language in the chronic stage have shown (Weiller et al., 1992, 1993, 1995, 1998; Cappa et al., 1997; Heiss et al., 1997), and our results clearly emphasize, the right hemispheric components of this language network. The posterior part of the right superior temporal lobe seems to be a crucial area for the recovery of language comprehension, compensating for the functional loss of its homologue in the left hemisphere, Wernicke’s area, as was hypothesized from a number of previous reports (Wernicke, 1874; Moore and Weidner, 1974; Sheldon, 1985; Demeurisse et al., 1985; Papanicolaou, 1988; Weiller et al., 1995). The peri-infarctual region and frontal areas in the left hemisphere (Demeurisse and Capon 1987; Naeser et al., 1987; Heiss et al., 1993) seem not to represent the main effect in our study, as they were found only in a few subjects. It may be assumed that these areas contribute to the recovery process on an individual basis.

The improvement of language comprehension requires specific linguistic factors, but also non-linguistic factors (e.g. attention, memory, motivation), as does the TT, with which
Fig. 4 Cerebral regions correlating with the increase of rCBF during the execution of the language comprehension task and the performance in the sTT, the latter carried out after each scan. The patterns of activation were rendered onto a standard 3D anatomical template (top) and are overlaid on the mean group MRI in transverse slices and parallel to the AC–PC (anterior–posterior commissure) line (bottom). The co-ordinates of the activated areas and their significance levels are as follows: right superior temporal gyrus, +48, –46, +12 mm; Z score = 3.97; posterior part of precuneus in the left hemisphere, –14, –62, +20 mm; Z score = 4.53.
we estimated comprehension. Therefore it comes as no surprise that the areas correlated with recovery are not exclusively associated with the linguistic aspects of language. The superior temporal gyrus, the supramarginal gyrus and the inferior frontal gyrus in both hemispheres are found to be activated during short-term verbal memory tasks, albeit to a greater extent in the left hemisphere (Paulus et al., 1993). Activation in the precuneus, together with the superior and middle frontal gyrus, dorsolateral prefrontal cortex and anterior cingulate, is often found during long-term memory tasks, e.g. the retrieval of word lists (Frith et al., 1991, MacLeod et al., 1998). Thus, the recovery could be due to an improvement in working memory competence. Proficiency in language comprehension may depend on working memory capacity (MacDonald et al., 1992; Just and Carpenter, 1992). The language comprehension problems of some patients with aphasia have been attributed to a deficit of working memory (Wilson et al., 1989, 1995; Hermann, 1992). However, our patients’ improvement was least in Part IV of the sTT, the performance of which requires the greatest number of extralinguistic factors like attention and short-term memory (see Appendix 1) (De Renzi and Vignolo, 1962; Meier et al., 1990). There may be more factors involved in the improvement of word comprehension that are related to conscious and unconscious processes (Waters and Caplan, 1996), but it is unknown whether they involve different neuronal pools or are separable by functional brain imaging.

It is uncertain whether these results represent general long-term recovery of aphasia. Clearly, the short-term training that we used is different from several weeks of aphasia rehabilitation. However, such short-term training sessions represent an integral part or the main constituent of logopaedic rehabilitation programmes for aphasic patients. In addition, all the areas that correlated with improvement in our study are in accordance with previous PET or fMRI studies on recovery of language in the chronic stage (Weiller et al., 1995; Cappa et al., 1997; Heiss et al., 1997; Weiller, 1998).

One possible confounding factor is whether these effects are due to the training rather than to a non-specific time effect. The term ‘time effect’ refers to all linearly increasing effects over time (scans), which may be the result of habituation or repetition. Since we specified a general linear model and training improved the sTT values over scans, there is a theoretical overlap between the covariates associated with time and training effects. This question can be answered definitely only by studying the same subjects with the same paradigm with and without the training, which is not possible using PET. However, as stated above, the effect of the training is specific, as a non-specific stimulation and repetition of the task over the same time span did not result in improvement in the values of the sTT. We therefore speculate that, in our patients, the areas found to be activated are due to a training effect. In addition, habituation and repetition form an integral part of aphasia therapy, potentially constituting a ‘specific time effect’. Initially we stressed the hypothesis that the inability to access linguistic information rather than the loss of its knowledge per se forms the basis of aphasia. Although stimulation, an important part of our training, is seen as the major factor involved in reversing lost access to preserved knowledge in aphasia, it may be assumed that repetition is necessary to effect the availability of the renewed functional connections.

Our study has shown that reorganization of the brain may be beneficial for stroke patients. It substantiates the evidence that rehabilitation techniques may influence brain organization, which has so far been shown in only one other study in hemiparessis after stroke (Liepert et al., 1998). In our opinion, there is no single crucial component of recovery. Rather, recovery of language function seems to imply the ‘reconnection’ or perhaps better the recon-ordination of a network of areas, each of which may be specialized in one or more aspect of language processing but requires coherent support from the others to reach a high level of proficiency (Mesulam, 1994).

Acknowledgements
We wish to thank the members of the logopaedic team and particularly Miss Ockroi at the Neurorehabilitationsklinik in Waldbreitbach, the nuclear medicine technical assistants in Essen and all the healthy volunteers and the patients. This work was supported by an EU grant (BIOMED I CT 1262/94), by the Kuratorium ZNS, Bonn-Bad Godesberg (both to C. W.) and by DAAD (to C. W. and M. M.; 314 Vigoni).

References


Appendix 1: The short version of the Token Test

The short version of the Token Test (sTT) that we used in this PET study presents the same construction and uses the same material as the TT. It consists of tokens like those used in card games, which are denoted by an abstract noun, such as ‘circle’ and ‘rectangle.’ They have five colours: red, blue, green, yellow and white. The test includes five parts, which are progressively more difficult. In the first four parts, commands are expressed in an elementary grammatical and syntactic form: subject, verb and object. The fifth part introduces more complex grammatical and syntactic structures, the exact understanding of which is necessary for correct performance. Each subtest of the sTT contains only two and not 10 items, as in TT commands. (Part I) Large rectangles and large circles only are arranged in two rows. There is no particular rule for the distribution of colours. Speaking with a clear and measured voice, without any special prosodic emphasis, the examiner invites the patient to take two different tokens, one after the other, saying simply: ‘Pick up the yellow rectangle,’ ‘Pick up the white circle,’ and so on. The patient must put back each token in its place on each occasion. (Part II) Small circles and small rectangles are added to the tokens already on the table, in a specific arrangement. Three specific words are now necessary in order to identify a particular token, such as: ‘Pick up the small white rectangles’, ‘Pick up the large blue circle,’ and so on. (Part III) Large tokens only are placed before the subject, as in Part I; however, the patient is invited to take two of them, for example: ‘Take the red circle and the green rectangle.’ (Part IV) All tokens are replaced on the table, as in Part II, and the patient is asked to take two of them every time: ‘Take the white large circle and the small green rectangle.’ (Part V) Large rectangles are placed in the first row in front of the patient and large circles are put in the second row. There is no particular rule for the distribution of colours, except that the yellow rectangle must be near the green one. Instructions are as follows: ‘Put the red circle on the green rectangle’ or ‘Put the white rectangle behind the yellow circle’.