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Do Specific Attention Deficits Need Specific Training?

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The efficacy of game-like computerised adaptive training programmes for intensity aspects of attention (alertness and vigilance) and selectivity aspects of attention (selective and divided attention) was studied in patients with left or right focal brain damage of vascular aetiology. Each patient received consecutive training in the two most impaired of the four attention domains. Control tests were performed by means of a standardised computerised attention test battery comprising tests for the four attention functions. Assessment was carried out at the beginning and after each of two training periods of 14 one-hour sessions each. There were significant specific training effects for both intensity aspects (alertness and vigilance), and also for response time in the selective attention and error rate in the divided attention task. For selectivity aspects of attention, reaction time also improved after training of basic attention domains. The application of inferential single case procedures revealed not only a high degree of specific training effects in individual cases but also a substantial number of deteriorations in performance after non-specific training of basic attention problems by tasks requiring selectivity of attention. The results are discussed in the light of a hierarchical organisation of attention functions.

INTRODUCTION

In more recent psychological and neuropsychological theorising, attention is not considered to be a unitary function. In a large number of experimental studies it could be demonstrated that at least four attention domains can be discerned. In line with Posner and Boies (1971), Posner

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and Rafal (1987), and van Zomeren, Brouwer, and Deelman (1984) we wish to make a distinction between "phasic alertness", "vigilance", "selective attention" and "divided attention". While the first two represent intensity aspects of attention, the latter two are related to processes of information selection under conditions of limited attention capacity (van Zomeren & Brouwer, 1994).

Phasic alertness is defined as the capability to enhance response readiness following a warning stimulus. Typical tasks for the assessment of phasic alertness are simple reaction paradigms with and without presentation of a warning stimulus preceding the target stimulus. The reduction in response time after warning serves as an indicator of phasic alertness. *Tonic alertness* on the other hand, is a relatively stable level of activation, which changes only slowly and involuntarily. Tonic changes of alertness are mostly attributed to physiological, diurnal changes in the organism.

Vigilance tasks, following the definition of Mackworth (1948), require the subject to stay alert for prolonged periods of time (possibly hours) in order to detect relevant but very infrequent stimuli, which appear at irregular intervals during the task. Watching a radar screen, sorting out defective items on an assembly line, monitoring displays in a power plant for critical events or driving a car on a highway at night-time are typical everyday tasks requiring vigilance. In contrast, long lasting tasks with frequent relevant stimuli should be defined to require *sustained attention.*

One aspect of *selective attention* is the ability to focus on certain features of a task and at the same time to suppress voluntarily responses to irrelevant features. Typical examples for this kind of selective attention are choice reaction paradigms. This aspect of selective attention only involves mental selection processes with rather low mental load and represents selectivity similar to Broadbent's early notion of information processing (Broadbent, 1958). We will not consider other concepts of selective attention, like Sokolov's orienting response (1963), orientation in extrapersonal space (Berlucchi & Rizzolatti, 1987), or overt and covert shifts of attention described by Posner (1980).

Divided attention is required in so-called dual task paradigms, in which a subject has to monitor simultaneously two different sources for relevant stimuli appearing in either one or simultaneously in both of them. Such tasks are designed to tap the capacity limits of attention (Kahneman, 1973; Posner & Boies, 1971; Treisman, 1969). The more automatised or overlearned certain aspects of this dual task are, the less attention capacity is needed (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Wickens (1984) postulates a multiple resources model of attentional capacity. With regard to this model two tasks, which tap the same attention resources, e.g. with respect to processing codes (spatial–verbal), modalities, stages, or response modalities, show the greatest amount of interference.

There is also psychometric evidence for the existence of separable attention domains obtained from a standardisation study for a computerised attention test battery of Zimmermann and Fimm (1992). A hierarchical cluster analysis and nonmetric multidimensional scaling applied to the intercorrelation matrix of the reaction time performances of 200 healthy subjects for the subtests "alertness", "divided attention", "go-no-go" (selective attention) and "vigilance" (visual and auditory) revealed that different parameters of the same attention task as well as different attention tasks tapping similar aspects of attention (e.g. the divided attention and selective attention task reflecting the aspect of selectivity) were linked together more closely than tests from different attention domains (Sturm & Willmes, 1993).

Looking at these definitions of specific domains, it is evident that there is always a close relation to some experimental paradigm with which they have been examined; but there is also clear evidence for their involvement in everyday life performance.

Both clinical and experimental neuropsychological studies also provide ample evidence for separable attention aspects. Even if contemporary neuropsychological views of attention favour its implementation in widespread cortical and subcortical networks (Posner & Petersen, 1990; van Zomeren & Brouwer, 1994) numerous studies have shown that specific attention functions can be impaired selectively by focal brain damage. Both impairments of phasic alertness and vigilance or sustained attention have been reported after lesions of the brainstem part of the reticular formation (Mesulam, 1985) and after lesions of the right hemisphere (Hosokawa, Isagoda, & Shibuya, 1977; Howes & Boller, 1975; Nakamura & Taniguchi, 1977; Sturm & Büssing, 1986). Furthermore, studies with lateralised stimulus presentation in healthy subjects (Dimond & Beaumont, 1973; Heilman & Van den Abell, 1979; Sturm, Reul, & Willmes, 1989) and in split-brain patients (Dimond, 1979) corroborate the assumption that the right hemisphere plays a crucial role in maintaining and controlling intensity aspects of attention. Additional evidence for right hemisphere dominance in sustained attention comes from measurement of cerebral blood flow in a positron emission tomography (PET) activation study (Pardo, Fox, & Raichle, 1991). Certain aspects of attention selectivity are impaired in patients with left hemisphere cortical lesions (Dee & Van Allen, 1973; Sturm & Büssing, 1986) leading to slowing of response time and to increased error rates in choice reaction paradigms. Bisiach, Mini, Sterzi, and Vallar (1982) as well as Jansen, Sturm, and Willmes (1992) also showed left hemisphere dominance for choice reactions in studies with lateralised stimulus presentation in healthy subjects.

There is a PET scan study by Corbetta et al. (1991) pointing to a potentially important role of the dorsolateral prefrontal cortex of the right hemisphere in a divided attention task. Unfortunately, the task used by the authors did not strictly follow the commonly accepted divided attention paradigm (see above) but closely resembled a sustained attention task. In a "selective attention" condition of their experiment, the subjects had to respond only to changes of *one* feature (colour, speed or shape) in a visual task, whereas in the "divided attention" condition the subjects were asked to respond to changes of *any* of these features. Since the latter task condition neither asks for any kind of selectivity nor shows any features of a dual or multiple task paradigm the interpretation of the results in terms of a divided attention task become equivocal. There is, however, additional evidence from animal studies focusing on the important contribution of the dorsolateral frontal cortex in memory and attention control processes (Funahashi, Bruce, & Goldman-Rakic, 1989; Goldman-Rakic, 1987). These findings are in line with a frontal supervisory attentional system proposed by Shallice (1988) which is very similar to Baddeley's notion of a central executive in working memory (1986). The strong connection between these two processes is pointed out by Baddeley's recent notion (1993) that "one is attending with one's working memory".

Earlier attempts of attention retraining did not take into account the distinctiveness of attention functions. A number of efficacy studies employing non-specific attention training programmes demonstrated a generalised improvement of attention and other cognitive functions in patients with diffuse traumatic lesions (Poser, Kohler, Sedlmeier, & Strätz, 1992; Sturm, Dahmen, Hartje, & Willmes, 1983; for a critical evaluation of study designs and results see also Robertson, 1990). There are, however, some studies which cast doubt on the generality of these training effects. Sohlberg and Mateer (1987) showed that attention training did not generalise to a cognitive task requiring visual processing. Ben Yishay, Piasetzky, and Rattok (1987) found no generalisation effects at all for the different aspects of their orientation remedial module (ORM) attention training procedure. In fact, there was only improvement for the specific attention domain trained. Ponsford and Kinsella (1988) pointed out that when spontaneous recovery and practice effects are controlled for, little additional benefit due to training remained at all. Sturm and Willmes (1991) readministered their complex reaction training yielding generalised training effects in traumatic brain damage to a group of patients with focal unilateral vascular lesions. For this latter group there was considerably less generalisation of the training effects. Contrary to the first study there were no effects on vigilance tasks and on verbal and nonverbal intelligence tests whether they were speeded or without time pressure. It is, however, difficult to interpret the results of these studies because either not all relevant aspects of attention were considered for training or testing, or because the control tests were similar or even identical to the training tasks. Especially in the latter case it would be hard to argue that the training effects are more than mere drill or practice effects due to numerous task repetitions.

So the question arises, whether specific attention deficits call for specific training procedures. In order to test this hypothesis, we developed specific computerised training programmes for the two intensity aspects alertness and vigilance as well as for selective and divided attention representing selectivity aspects of attention (Sturm, Hartje, Orgass, & Willmes, 1994). The training programmes have a game-like layout and represent the underlying attention paradigms in everyday-life scenarios. Another advantage of these training programmes is that they can be used in an adaptive mode adjusting the task difficulty level to the individual patient's performance. Control tests were taken from the above mentioned computerised attention test battery by Zimmermann and Fimm (1992). The subtests chosen from this battery follow the same attention paradigms as our training procedures. In contrast to the training programmes, these control tasks do not represent everyday-life attention demands but mirror the experimental operationalisations of the four trained attention aspects. In this way it is possible to assess specific training effects beyond trivial effects of task repetition.

METHODS

Training Programmes

For this study Commodore 128 versions of the training programmes were used (more recent versions are available for PC). In order to minimise motor demands on the training procedure, the patient had to respond to the training tasks using only one or two large response keys. These keys were also used exclusively for the responses to the control tests. Patients with hemiparesis also had no difficulty in operating both keys with one hand. The four attention training programmes were as follows.

Alertness Training Task. Animated driving tasks with a car or motorcycle displayed on the computer screen are used. The patient has to watch the car or motorcycle driving on a winding track. The patient is not supposed to steer the car or the motorcycle: He or she only has to control the speed of the vehicle in such a way that a high average speed is maintained, at the same time avoiding collisions with obstacles which suddenly appear. In order to accomplish this, the subject either has to press a "gas" key to speed up the vehicle, or a "brake" key to slow the vehicle or stop it. Forthcoming obstacles are indicated by graphic signs which serve as warning signals. In this way the training operationalises the task paradigm of phasic alertness (reaction time task with warning signal). The difficulty level of the task can be changed by varying the maximum speed of the vehicle, the brake length, the visibility of the warning signals, and the position of the vehicle on the screen. Collisions with obstacles are indicated by optical and acoustic feedback.

Vigilance Training Task. A radar screen task was constructed for the vigilance training task. The subject has to watch several flying objects (planes, helicopters, balloons) on a radar screen. The objects move very slowly across the screen and the subject either has to respond to sudden changes in the speed of the objects or to additional objects appearing on the screen for a short time. Variation of task difficulty is introduced by changing the distinctiveness of the objects according to type and colour, and the frequency of relevant events.

A second vigilance training programme simulates an assembly line. The patient has to watch objects moving on the assembly line and he or she has to reject damaged objects by pressing a response key.

Selective Attention Training Task. Two programmes were developed for the training of selective attention. In the first programme a "trap shooting" task is simulated with objects flying across the screen in front of a scenic background. The patient is required to push a response key only if a particular object or particular pairs of objects defined at the beginning of the task appear on the screen. The second programme is a kind of "photographic safari", in which the subject has to watch for relevant single or double objects popping up in front of a scenic background. By pressing the response key he or she has to "take a picture" of these objects (animals, everyday-life objects, people). Irrelevant objects must not be responded to. For both programmes, an increase in difficulty level can be effected by changing the overall number of objects and/or the number of relevant objects, as well as by varying the time interval for object presentation. For some variants of the trap shooting task the patient also has to watch for typical sounds associated with the objects. There is always an immediate optical or acoustic feedback for correct or false responses. The training procedure follows the paradigm of choice reaction tasks.

Divided Attention Training Task. In contrast to the other three training programmes, this one is less like a game. The patient has to monitor two independent stimulus sequences. By pressing corresponding response keys, he or she has to detect two sequential identical stimuli or stimuli defined to be equivalent according to certain criteria (e.g. shape, colour, category) appearing in either one or both of the two channels. The information presented via the two channels is either visual–auditory or visual–visual. Following the resources model of Wickens (1984) the simultaneous processing of two stimulus sequences in the same modality is particularly capacity demanding. Other variations of difficulty include change of duration of stimulus presentation (0.5–7.5 sec), or interstimulus interval (0.5–4 sec), or degree of temporal overlap between critical stimulus sequences of both channels. Despite its testlike appearance, this training task is completely different from the control task. For the PC version of the divided attention training, a "flight simulator" task was developed, in which the subject has to monitor up to three different stimulus sources in combination. One source is the horizon, which moves up and down within certain limits. If the horizon surpasses one of these limits (the upper edge of the cockpit or the upper edge of the instrument panel) the subject has to respond. A second stimulus source is the speedometer which has to be monitored for passing an upper and lower speed limit. The third, auditory source, is the motor sound which has to be listened for for two successive interruptions.

All training programmes automatically adapt their difficulty level according to the performance of the patient. The adaptation criterion is a minimum of 90% correct responses over 50 responses for increasing the difficulty, and a minimum of 33% errors for decreasing it.

At the end of each training session or whenever the patient or the therapist want it, a numerical and graphical feedback of the mean reaction time, the kind and number of errors and the difficulty level of the different task parameters achieved can be presented. These parameters are stored under the individual patient's name and provide initial parameter values for the next training session.

Control Tests. To examine the efficacy of the training programmes we used subtests of a computerised attention test battery (Zimmermann & Fimm, 1992; Zimmermann, North & Fimm, 1993). There was a test of tonic and phasic alertness requiring a response to a simple visual stimulus with or without a preceding auditory warning signal. Visual vigilance was tested over a period of 30 min at a rate of one critical stimulus per minute. To assess selective attention we used a go-no-go task in which the subject had to respond to only two critical visual patterns out of a total number of five. The divided attention test required monitoring a two-way array of visual stimuli for a specific square pattern as well as detecting the presence of two consecutive identically pitched tones in an otherwise alternating sequence of low or high-pitched tone signals. For these subtests normative data from $n = 200$ healthy controls were available (Sturm & Willmes, 1993).

SUBJECTS

Within 18 months, a total of 38 patients with unilateral vascular lesions were included in the study. Eleven were consecutive patients from the rehabilitation ward of the neurological clinic in Aachen, and 27 from the neurological rehabilitation clinic in Bernkastel-Kues. Twenty-two patients had focal lesions in the left hemisphere (LBD group) and 16 in the right hemisphere (RBD group). Nineteen patients of the LBD group were aphasic. As can be seen in Table 1, the two groups were comparable with respect to sex, age, and time post onset.

Only patients without symptomatic epilepsy or any progressive neurological and internal disease were included. A second inclusion criterion was poor performance in at least two of the attention domains as assessed by the subtests of the attention test battery, i.e. for the reaction time measurements percentile ranks of ≤ 25, or more than three errors in the selective and divided attention tests, or less than 28 hits in the vigilance

TABLE 1
Sample Characteristics

	Total	*LBD*	*RBD*
N	38	22	16
Sex (f/m)	17/21	8/14	9/7
Age (yr)			
range	24–64	28–63	24–64
median	48.0	46.0	50.5
Time post onset (months)			
range	2–35	2–35	2–19
median	5.5	3.5	9.0
Hemianopia	1	1	0
Visual Neglect*	8	0	8
Lesion site			
middle	9	6	3
frontal and middle	5	3	2
frontal, middle, and basal ganglia	4	3	1
middle and basal ganglia	5	2	3
basal ganglia	10	6	4
posterior	1	1	0
middle and posterior	1	1	0
no CT available	3	0	3

*Performance below percentile rank 10 in the subtest "Neglect" of the attention test battery by Zimmermann & Fimm (1992).

task. To avoid massive spontaneous recovery effects, only patients at least two months post onset were admitted.

STUDY DESIGN

A study design with a minimum of two therapy periods is necessary for the assessment of specific intervention effects (Coltheart, 1983). Therefore every patient—after a pretest with the subtests of the attention test battery—received a first training for three weeks in one of the two most severely impaired attention domains. From those two, the function trained first was selected at random. There was a total of 14 one-hour training sessions for each patient and for each attention function trained. After this first training period all attention functions were assessed again followed by the second training period of identical duration and intensity for the other severely impaired attention domain. Immediately after the second training period the attention tests were administered a third time.

Since each patient showed deficits in at least two attention domains, with this type of study design in each of the two therapy periods there was one attention deficit which was trained specifically, and at least another one for which the training was not specific. For example, if a patient showed impairments both in alertness and vigilance, it was decided, at random, which of the two attention domains was trained first. Given that the first training was in alertness, this was specific for the alertness deficit, but not specific for the vigilance impairment. In the second treatment period vigilance training was administered, which is specific for the vigilance deficit, but is not specific for alertness problems. In this way during each of the two training phases there were groups of patients who received a specific training for one of their impaired attention functions, while the same patients, at the same time, due to their additional attention deficits represented another group of patients with attention impairments, for which the given training was not specific. The frequency of particular training given in the first or in the second training period or in both periods combined is reported in Table 2. One RBD patient was discharged from hospital after the first training period for reasons not related to the training.

Table 3 shows the pattern of impaired and non-impaired attention functions at pretest, separately for right and left brain-damaged patients. A function was considered impaired if either the reaction time or the hit rate (respectively the error rate) fell below the cut-off levels described above. Furthermore, Table 3 presents statistics for each of the eight variables considered. The table shows that about 75% of all patients were impaired in more than two attention domains. Thirteen out of the 16 RBD patients (81%) show impairment patterns including alertness, whereas for

TABLE 2
Frequency of the Different Types of Attention Training Administered to the Two Patient Groups

Training	*LBD*	*RBD*	*Total*
Training phase 1			
Alertness	3	5	8
Vigilance	4	5	9
Selective attention	8	1	9
Divided attention	7	5	12
Total	22	16	38
Training phase 2			
Alertness	4	4*	8
Vigilance	4	4	8
Selective attention	4	1	5
Divided attention	10	6	16
Total	22	15*	37
Total			
Alertness	7	9	16
Vigilance	8	9	17
Selective attention	12	2	14
Divided attention	17	11	28
Total	44	31	75

*One patient without second training phase.

the LBD patients, impairment patterns are more evenly distributed. Furthermore, RBD patients performed significantly worse in alertness and marginally worse in vigilance than LBD patients.

The primary focus of the study is on specific versus non-specific training effects. Therefore, inclusion of a baseline period to control for spontaneous recovery or test repetition effects was not considered necessary. First, demonstration of a specific training effect encompasses a general corroboration of the efficacy of that training procedure. Second, absence of training effects for non-specifically trained attention domains renders spontaneous recovery or test repetition effects unlikely. Furthermore, in our previous study, which included baseline periods, there was never an improvement of test performance across study periods without training. These considerations do not preclude differences between the control tests with respect to their sensitivity to detect changes in performance. If, on the other hand, one does find similar degrees of specific effects for the different attention domains, this result speaks against the sensitivity argument.

An optimal research strategy would have been a two-period cross-over design for each combination of two impaired attention domains. With

TABLE 3
Frequency of the Different Patterns of Impairment in the LBD and RBD Patients (+ = not impaired), *Descriptive Statistics for the Different Test Parameters and P-values for the* Comparison LBD–RBD

Pattern of impairment						
Alertness	*Vigilance*	*Selective Attention*	*Divided Attention*	*LBD (n = 22)*	*RBD (n = 16)*	*Comparison LBD–RBD (P-value)*
−	−	+	−	3	6	
−	+	−	+	1	0	
−	+	+	−	1	1	
−	+	−	−	2	2	
−	−	−	−	5	4	
+	−	+	−	3	2	
+	−	−	+	5	0	
+	+	−	−	2	1	
Mean RT without *warning* (*T*-Score)				45.0 (8.2)*	39.1 (7.8)	.03
Mean RT with warning (*T*-Score)				45.9 (8.2)	40.1 (9.2)	.09
	Mean RT (*T-Score*)			47.6 (9.6)	54.1 (13.5)	.15
	Hits			28.9 (8.0)	23.5 (6.9)	.07
		Mean RT (*T*-Score)		44.2 (11.9)	44.1 (14.9)	.97
		Errors		1.4 (1.8)	0.8 (1.1)	.37
			Mean RT (*T*-Score)	41.3 (11.0)	38.5 (10.6)	.42
			Errors	3.5 (3.6)	3.5 (3.2)	.92

*Standard deviations in parentheses.

such an experimental plan it is possible both to examine the specificity of the training programmes for the two impaired functions and to check for a positive or negative after-effect of the first training on the second one: Since in our sample only *11 out of 12 possible pairs of training* were *present* and no combination was represented more than six times, an evaluation according to such a cross-over design was not possible. Therefore, assessment of specific training effects had to be confined to the analysis of the first training period. The interpretation of the results from the second training period is less clearcut because of the possible general or differential after-effects from the first to the second training.

From the number of patients with unilateral lesions for each training (Table 2) it is obvious that separate analyses for LBD and RBD patients cannot be carried out.

It is interesting to note that the frequency of alertness and vigilance training was significantly higher for RBD than for LBD patients (Fisher's exact test $P = .045$, one-tailed) whereas for the LBD patients the frequency of selective attention training was significantly higher ($P = .009$, one-tailed). This finding, too, is in congruence with the hypothesis of a stronger involvement of the right hemisphere for intensity aspects of attention and, furthermore, it also corroborates the notion of a special left hemisphere role in selectivity aspects of attention. Nevertheless, due to the very small number of patients studied for particular training in the two groups, all subsequent statistical analyses had to be carried out irrespective of the side of lesion.

Significant changes in performance after the training could also be assessed individually according to psychometric single case analysis procedures (Huber, 1973; Willmes, 1985), since all control tests were standardised with known reliability coefficients.

RESULTS

Descriptive statistics for the various attention control test parameters, before and after training phase 1, are given in Table 4 separately for the four training groups.

Wilcoxon signed-ranks tests were used to compare pre- and post-test performance for the first training period. Table 5 shows the P-values adjusted for multiple testing using the Bonferroni method with a total type-I error-level of 5% per attention domain.

Specific training effects were present for the tonic alertness function (response time without warning signal) and for the hit-rate of the vigilance task, since significant improvement for these parameters could only be achieved by the specific training procedures. There were also effects of specific training for the error rate of the divided attention task and the reaction time of the test for selective attention. But for the divided attention task, response time also improved with alertness training and training for selective attention. On the other hand, response time for selective attention was also improved by the training programmes for alertness, and marginally by vigilance training. For the vigilance training

TABLE 4

Median and Range (in Brackets) of Control Test Performance for Training Phase 1 at the First (t_1) and at the Second (t_2) Test Period (all Response Time Data are Given in *T*-scores Based on a Normative Sample of $n = 200$ Healthy Subjects)

	Training							
	Alertness (n = 8)		*Vigilance* (n = 9)		*Selective Attention* (n = 9)		*Divided Attention* (n = 12)	
Control tests	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2
Alertness								
RTwoW*	34	41	42	47	48	46	43	44.5
	(24–40)	(31–54)	(27–60)	(24–59)	(31–56)	(34–68)	(39–56)	(35–59)
RTwW	37.5	44	47	49	50	49	46.5	49
	(33–48)	(36–47)	(24–53)	(24–62)	(33–63)	(35–56)	(31–54)	(24–64)
Vigilance								
Hits	30.5	35	19	27	32	30	24	28.5
	(25–52)	(29–49)	(11–27)	(20–35)	(20–43)	(26–40)	(18–32)	(20–33)
RT	44.5	53	47	53	49	56	56.5	55.5
	(24–76)	(24–70)	(37–56)	(39–76)	(37–63)	(43–76)	(35–76)	(36–73)
Selective attention								
RT	39	55.5	52	56	39	52	47.5	54.5
	(24–63)	(27–68)	(24–64)	(30–64)	(24–69)	(35–70)	(27–62)	(24–62)
Errors	0	0.5	0	1	2	1	1	0
	(0–2)	(0–3)	(0–3)	(0–2)	(0–7)	(0–3)	(0–3)	(0–7)
Divided attention								
RT	35	41	37	46	47	51	36.5	43
	(24–51)	(32–58)	(27–73)	(30–76)	(34–63)	(40–76)	(24–58)	(24–61)
Errors	2.5	3	2	3	2	2	3.5	2
	(0–6)	(0–6)	(0–10)	(0–6)	(0–10)	(0–10)	(0–13)	(0–8)

*RTwoW = Response time without warning; RTwW = Response time with warning.

group, average pretraining performance in the selective attention task was already well within the normal range. This finding that response times but not error rates for the divided and selective attention task could also be improved by seemingly nonspecific training procedures can be explained by taking into account the fact that the main objective of these training programmes is to improve response time but not selectivity.

Although—as pointed out earlier—after-effects from the first to the second training period may be a possible confounding factor, results for the second training phase were similar to those for the first phase. For reasons of space, they are not reported in detail here. Rather, for a demonstration of the specificity of training effects we chose to analyse the

TABLE 5
P-values for Change of Performance (t_2–t_1) in the Four Attention Tasks after Different Training (One-sided Wilcoxon Tests with Bonferroni-α-correction for Multiple Testing). Numbers in bold indicate Specific Training Effects

		Attention tasks							
		Alertness		*Vigilance*		*Sel. Att.*		*Div. Att.*	
Training	*n*	*RTwoW*	*RTwW*	*Hits*	*RT*	*RT*	*Errors*	*RT*	*Errors*
Alertness training	8	**0.018**	**0.063**	0.272	0.855	0.017	0.180	0.018	0.735
Vigilance training	9	0.779	0.128	**0.011**	**0.234**	0.050	0.893	0.407	0.363
Selective attention training	9	0.767	0.944	0.767	0.286	**0.008**	**0.484**	0.017	0.345
Divided attention training	12	0.450	0.638	0.060	0.906	0.480	0.800	**0.333**	**0.028**

data from the first training period in a different way: For each control test, we compared the change in performance of the specifically trained attention functions with a change in performance for all other attention functions trained *non*-specifically. These change scores are reported in the upper part of Table 6. The lower part of Table 6 shows the one-tailed *P*-values of these intergroup comparisons by means of the *U*-test. The results indicate that for alertness and vigilance for the first training phase there is significantly more improvement after specific training. For selective attention this effect is marginal, for divided attention there is no such specificity.

Evaluation of Individual Patients

Since for all reaction time parameters of the control tests standard norms (*T*-scores) as well as reliability estimates are available, critical differences according to the methods of psychometric single case analysis (Huber, 1973; Willmes, 1985; 1990) were computed. If the critical difference is surpassed by the observed difference between pre- and post-test, this change in performance cannot be attributed to measurement errors alone. For the non-standardised error scores the numbers of errors in pre- and post-test were compared by Fisher's exact test. For single case analysis a type-I-error of 10% is generally recommended (Huber, 1973; Willmes, 1990).

Table 7 shows the results separately for specifically and non-specifically trained patients. The table also contains results of the comparison of the relative frequency of significant individual improvements for patients with specific compared to non-specific training, again using Fisher's exact test.

TABLE 6

Comparison of Change of Performance in the Four Attention Tasks after the First (t_2–t_1) Training Phase following Specific or Non-specific Training in that Training Phase. The Lower Part of the Table Shows *P*-values for the Comparison of Both Types of Treatment

Type of training	*Alertness*		*Vigilance*		*Selective Attention*		*Divided Attention*	
	*RTwoW**	*RTwW*	*Hits*	*RT*	*RT*	*Errors*	*RT*	*Errors*
Specific training								
M (s)	9.4 (7.4)	4.5 (5.7)	7.7 (4.5)	4.6 (9.0)	14.2 (11.2)	– 0.8 (2.7)	3.9 (14.0)	– 2 (3.2)
Median	7	4	8	2	11	– 1	3	– 1
Range	0–20	– 4–12	– 2–14	– 3–22	1–37	– 6–3	– 22–28	– 11–1
Non-specific training (t_2–t_1)								
M (s)	1.0 (6.8)	2.2 (9.1)	2.0 (4.5)	2.0 (8.9)	5.4 (13.8)	0.1 (1.7)	6.7 (8.8)	– 0.5 (2.4)
Median	– 1	0	2	0.5	6	0	7	– 1
Range	– 9–20	– 16–23	– 6–12	– 12–26	– 34–35	– 3–6	– 10–32	– 6–4
Specific vs unspecific training (t_2– t_1)								
P	.005	.350	.002	.566	.063	.417	.413	.227

*RTwoW = Response time without warning; RTwW = Response time with warning.

TABLE 7
Comparison of the Number of Significant Improvements or Deteriorations in Single Patients (Individual Difference Score > d_{crit}) and Cases without Change in Performance after Specific or Non-specific Training in Training phase 1

		Training						
		Specific			*Non-specific*			*Comparison + vs. (Ø,–)*[3] *by Fisher's test, P-value (one-sided)*
Control test	d_{crit}[1]	+[2]	Ø	–	+	Ø	–	
Alertness								
RTwoW	3	6	2	—	11	13	6	0.062
RTwW	3	4	3	1	12	10	8	0.453
Vigilance								
Hits		5	4	—	1	27	—	0.002
RT	5	2	7	—	4	18	6	0.458
Selective attention								
RT	6	7	2	—	17	9	3	0.264
Errors		1	8	—	1	28	—	0.423
Divided attention								
RT	10	3	8	1	3	22	—	0.400
Errors		1	11	—	1	24	—	0.550

[1] d_{crit} for $\alpha = 10\%$ (two-sided). [2] + significant improvement in the single case ($\alpha = 10\%$); Ø no significant change; – significant deterioration. [3] Ø and – combined.

There were significantly more patients with significant improvement in performance for the vigilance hit-rate, and marginally more for the response time in tonic alertness. Furthermore, the table shows that for the groups with non-specific training there was a high number of patients who either did not show any significant change in performance, or even deteriorated significantly after non-specific training. For selective and divided attention, the relative frequency of patients who improved after specific training is consistently larger numerically than for patients who received non-specific training.

Figures 1 and 2 give a clear visual impression of the superiority of the specific attention training for the two test variables representing intensity aspects of attention. Figure 1 shows the *T*-scores for response times in the tonic alertness task before and after training in alertness, vigilance, selective attention, and divided attention in the first training phase. The figure demonstrates that the specific training did not lead to deterioration of performance but mostly to significant improvement (a significant change is indicated by an asterisk).

Figure 2 presents similar effects for the vigilance task. These figures, however, provide no information about how patients, who improved in one or both control test variables related to specific training, succeeded for

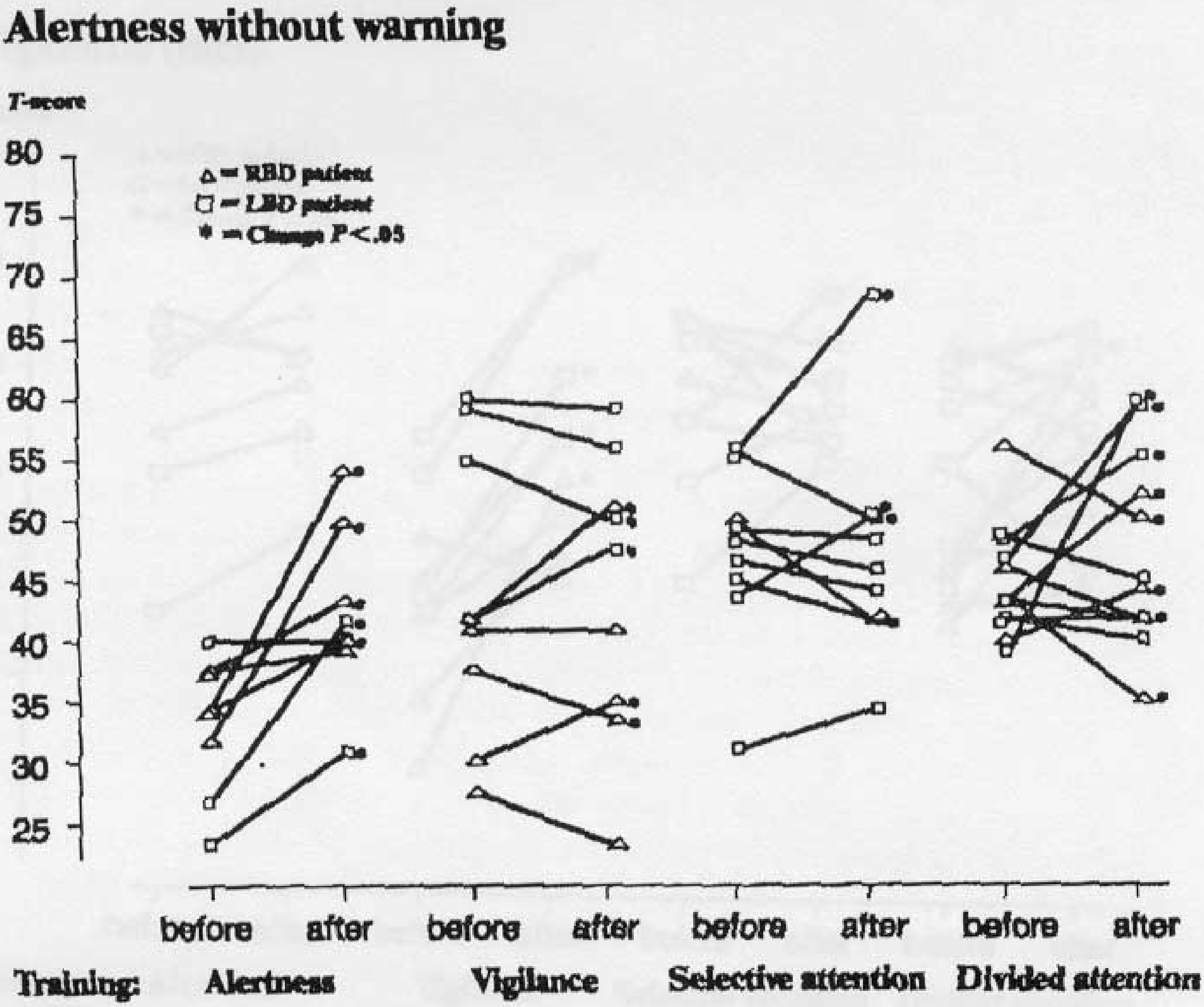

FIG. 1. Individual changes in performance (*T-scores*) in the control test variable "alertness without warning" (*tonic alertness*) after training for alertness, vigilance, selective or divided *attention*. Significant changes for single patients ($P < .10$) are indicated by an asterisk.

the other, non-specifically trained attention domains. Therefore, in each of the 24 patients who showed at least one specific improvement we examined whether he or she deteriorated in at least one of the six control test variables for which the training was non-specific. Surprisingly, there was significant deterioration in 21 (87.5%) of the cases.

DISCUSSION

The main results of this study corroborate the hypothesis that, in patients with localised vascular lesions, specific attention disorders need specific training. This is particularly true for more basic attention functions such as alertness and vigilance, reflecting intensity aspects of attention. For these functions significant improvement was achieved only after specific training. Since test and training procedures had a different setup—although following the same paradigm—these improvements cannot be

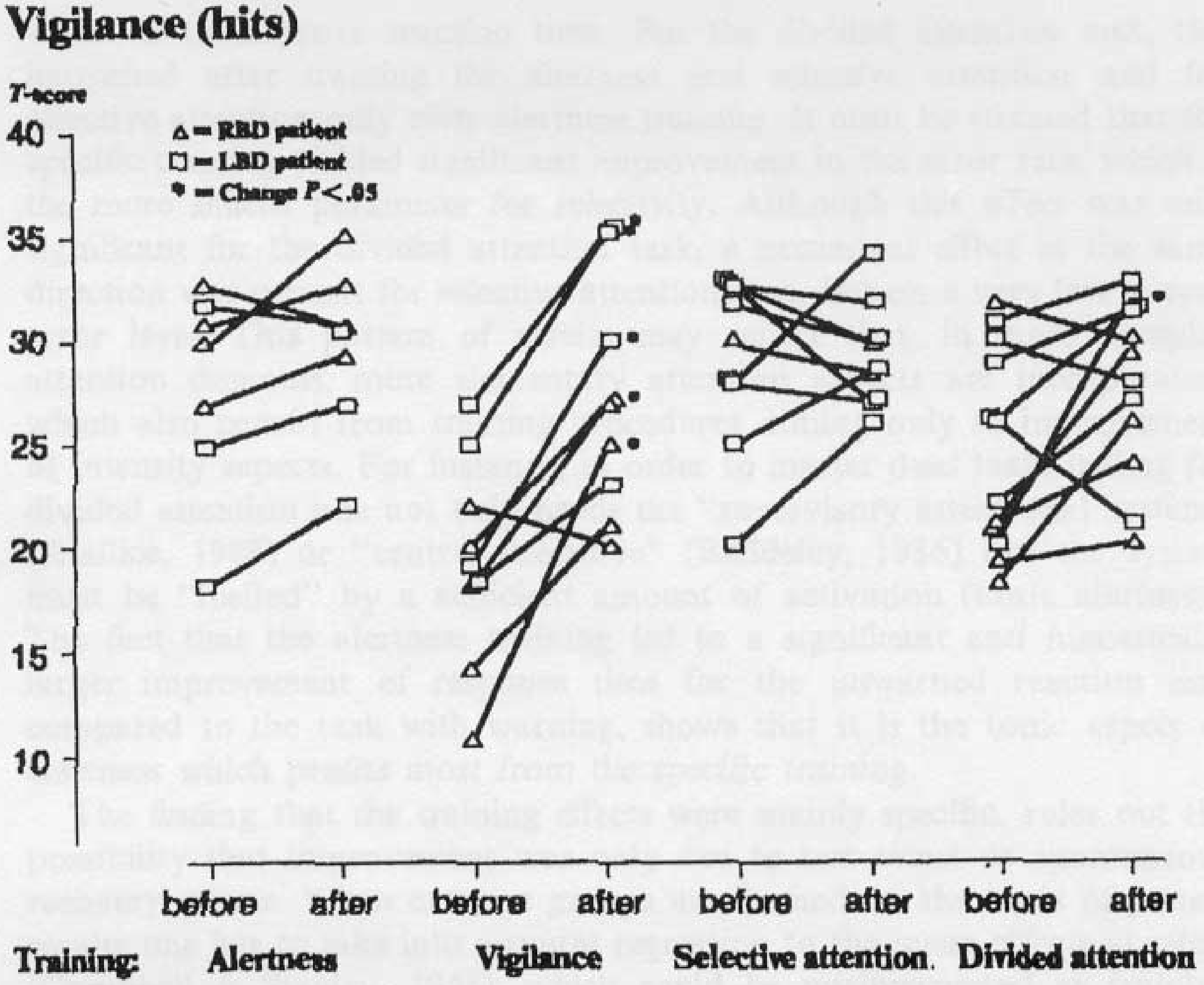

FIG. 2. Individual changes in performance (hit rate) in the control test "vigilance" after training for alertness, vigilance, selective, and divided attention. Significant changes for single patients ($P < .10$) are indicated by an asterisk.

attributed simply to pure practice effects. To give an example: If improvements after training were due to simple practice effects one would have expected that the training of alertness, which followed the paradigm of phasic alertness tasks (improving response time after a warning stimulus), would yield most beneficial effects on the phasic alertness variable of the attention test battery. This, however, was not the case. To the contrary, the only significant improvement was found for the tonic alertness variable, i.e. reaction time without warning. This shows that after training the attention activation level was increased intrinsically, not having to rely on external stimulating factors.

There were also specific training effects for the tests reflecting the selectivity aspect of attention (selective and divided attention). For the divided attention task, the error rate decreased only after specific training. Response times were also reduced for the selective attention task. In addition, for the latter two attention domains we also found significant shortening of response times after training programmes, one objective of which is to improve reaction time. For the divided attention task, this happened after training for alertness and selective attention and for selective attention only after alertness training. It must be stressed that the specific training yielded significant improvement in the error rate, which is the more salient parameter for selectivity. Although this effect was only significant for the divided attention task, a numerical effect in the same direction was present for selective attention, too, but on a very low overall error level. This pattern of results may reflect that, in more complex attention domains, more elementary attention aspects are incorporated, which also benefit from training procedures aiming only at improvement of intensity aspects. For instance, in order to master dual tasks calling for divided attention one not only needs the "supervisory attentional system" (Shallice, 1988) or "central executive" (Baddeley, 1986) but the system must be "fuelled" by a sufficient amount of activation (tonic alertness). The fact that the alertness training led to a significant and numerically larger improvement of response time for the unwarned reaction task compared to the task with warning, shows that it is the tonic aspect of alertness which profits most from the specific training.

The finding that the training effects were mainly specific, rules out the possibility that improvement was only due to test–retest or spontaneous recovery effects. When extreme groups are formed on the basis of pretest results one has to take into account regression to the mean effects at retest (Campbell & Stanley, 1966), which could be misinterpreted as training effects. Since we included only patients who were impaired in at least two attention domains (percentile ranks below 25 at pretest) regression to the mean effects would have implied improvement of all impaired attention functions after the first training period irrespective of the training administered. To the contrary, we only observed significant improvement that could be attributed to the specific aspects of the training employed.

Analysis of individual patient's control test performance with inferential statistical procedures showed that specific effects not only hold for the patient groups as a whole but also for a large number of individual patients. A novel and unexpected finding was that for a sizeable number of patients control test performance even deteriorated significantly, if an inadequate, non-specific training was chosen. Mostly this happened for patients with impaired intensity aspects of attention when treated with too complex training procedures focusing on selectivity aspects.

All observations of this study taken together support the hypothesis of a hierarchical organisation of attention functions: The lowest level is represented by the intensity factors alertness and sustained attention or vigilance which are prerequisites for higher selectivity functions of attention. Among these, stimulus selection as a special feature of selective attention forms the next level which again is a prerequisite of the ability to divide attention between several aspects of the task, tapping, for example, different modalities as expressed in the model by Wickens (1984). Such a hypothesis implies that impairments on a given level can only be approached by training on the same or a subordinate level. On the other hand, when using training for a superordinate level this might lead to overload of the system, yielding further deterioration for subordinate levels of attention.

Of course, the general question arises, what causes the specific training effects? None of our training is designed to induce specific strategies in the patients, nor did the therapist offer any verbal hints to cope with the task. The only possible exception to this rule was that the patients receiving selective attention training in the first half of training were instructed to improve their error rate and in the second half were additionally asked to improve their response time. This means that the training effects occurred simply after having carried out the tasks, i.e. by repeatedly stimulating the impaired attention function. A similar beneficial effect of stimulation on a task for which no specific strategies had been offered was also found recently by Robertson and coworkers (1995). After training for sustained attention they found significant improvement not only for a sustained attention task but also for spatial neglect symptoms in right brain-damaged patients. This was attributed to a spreading of activation from anterior to posterior attention systems within the same hemisphere. During training, only strategies to improve the sustained attention deficit were presented, but the neglect problem per se was not addressed at all by the training. Functional improvement caused by stimulation is often explained as a process of restitution (e.g. Rothi & Horner, 1983). Further research, for example, by means of functional magnetic resonance imaging before and after stimulation training, however, will be necessary to test this hypothesis and to put it on a more neuroanatomical and neurophysiological basis.

Finally, we would like to stress again that the aim of our study was to delineate the effects of specific attention training on specific attention deficits. We feel that this question had to be addressed prior to looking for training effects on everyday-life attention performance. Although undoubtedly, brain-damaged patients do show very specific attention deficits in clinical and experimental neuropsychological assessment, everyday situations are mostly characterised by a mixture of different attention requirements. This makes it nearly impossible to look for specific deficits in activities of daily living. This, however, does not imply that it is not necessary to disentangle these everyday attention requirements to look for specific impairments in the individual patient to address them with specific therapeutic methods. We feel that only after having looked at these more theoretically based questions should one start to study the effects of these training programmes on everyday life attention performance.

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