Specific Computerized Attention Training in Stroke and Traumatic Brain-Injured Patients

A European Multicenter Efficacy Study

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Abstract: In a multicenter European approach, the efficacy of the AIXTENT computerized training programs for intensity aspects (alertness and vigilance) and selectivity aspects (selective and divided attention) of attention was studied in 33 patients with brain damage of vascular and traumatic etiology. Each patient received training in one of two most impaired of the four attention domains. Control tests were performed by means of a standardized computerized attention test battery (TAP) comprising tests for the four attention functions. Assessment was carried out at the beginning and at the end of a four week baseline period and after the training period of 14 one-hour sessions. At the end of the baseline phase, there was only slight but significant improvement for the most complex attention function, divided attention (number of omissions). After the training, there were significant specific training effects for both intensity aspects (alertness and vigilance) and also for the number of omissions in the divided attention task. The application of inferential single case procedures revealed a high number of significant improvements in individual cases after specific training of alertness and vigilance problems. On the other hand, a non specific training addressing selectivity aspects of attention lead either to improvement or deterioration of alertness and vigilance performance. The results corroborate the findings of former studies with the same training instrument but in patients with different lesion etiologies.

Keywords: attention, therapy, stroke, traumatic brain injury, computerized training

Computergestütztes Training spezifischer Aufmerksamkeitsfunktionen bei Patienten nach Schlaganfall oder Schädelhirntrauma: eine europäische multizentrische Effizienzstudie

Zusammenfassung: In einer multizentrischen europäischen Studie wurde die Effizienz der computergestützten AIXTENT Aufmerksamkeitstrainingsprogramme für Intensitäts- (Alertness und Vigilanz) und Selektivitätsaspekte (selektive und geteilte Aufmerksamkeit) bei 33 Patienten nach Schlaganfall oder Schädelhirntrauma untersucht.

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Jeder Patient erhielt ein Training für eine der beiden bei ihm am deutlichsten beeinträchtigten Aufmerksamkeitsfunktionen. Als Kontrolltests dienten die vier entsprechenden Subtests einer standardisierten computergestützten Aufmerksamkeitstestbatterie (TAP). Jeweils eine Untersuchung wurde zu Beginn und am Ende einer vierwöchigen Baseline-Phase und eine dritte Untersuchung am Ende der anschließenden Therapie-Phase mit 14 jeweils einstündigen Trainingssitzungen durchgeführt. Am Ende der Baseline-Phase zeigte sich lediglich eine leichte signifikante Leistungsverbesserung für die komplexeste Aufmerksamkeitsfunktion (geteilte Aufmerksamkeit, Anzahl der Auslassungen). Nach dem Training gab es signifikante spezifische Trainingseffekte für beide Intensitätsaspekte (Alertness und Vigilanz), aber auch für die Anzahl der Auslassungen bei der Aufgabe zur geteilten Aufmerksamkeit. Mithilfe von Methoden der psychometrischen Einzelfalldiagnostik konnte im Einzelfall für Intensitätsaspekte der Aufmerksamkeit eine besonders deutliche Anzahl von Leistungsverbesserungen nach spezifischem Training nachgewiesen werden. Nach nichtspezifischem Training zeigten sich demgegenüber sowohl Leistungsverbesserungen als auch Leistungsverschlechterungen. Die Ergebnisse bestätigen die Resultate früherer Studien mit dem gleichen Trainingsinstrument bei Patienten mit Hirnschädigungen anderer Ätiologie.

Schlüsselwörter: Aufmerksamkeit, Therapie, Schlaganfall, Schädel-Hirn-Trauma, Computergestütztes Training

Introduction

In a large number of experimental studies it could be demonstrated that at least four attention domains can be discerned. Posner and Boies (1971), Posner and Rafal (1987) as well as van Zomeren, Brouwer, and Deelman (1984) make a distinction between "tonic and 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). Sturm and colleagues (1999) introduced the term "intrinsic alertness" for the cognitive control of self generated alerting in the absence of an external cue. This means that the level of alertness can be modulated in a top-down mode for a subsequent response to an expected stimulus, while the more extrinsically controlled *phasic alerting* strongly relies on external cues (e.g. warning stimuli preceding the response stimulus).

There is also psychometric evidence for the existence of separable attention domains obtained from a standardization study for the computerized Test for Attentional Performance by Zimmermann and Fimm (1997). 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).

Both clinical and experimental neuropsychological studies also provide ample evidence for separable attention aspects. Even if contemporary neuropsychological views of attention favor 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.

Early attempts of attention retraining did not take into account the distinctiveness of attention functions. A number of efficacy studies employing non-specific attention training programs demonstrated a generalized improvement of attention and other cognitive functions in patients with diffuse traumatic lesions (Poser et al., 1992; Sturm et al., 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 an attention training did not generalize to a cognitive task requiring visual processing. Ben Yishay et al. (1987) found no generalization effects at all for the different aspects of their ORM attention training procedure. In fact, there was only improvement for the specific attention domain being 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 generalized training effects in traumatic brain damage to a group of patients with focal unilateral vascular lesions. For this latter group there was considerably less generalization of the training effects. Contrary to the first study there were no effects on vigilance tasks and on verbal and non-verbal 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, specific computerized training programs (AIXTENT: AIX-la Chapelle [Aachen], atTENTion) were developed (Sturm et al., 1993) for the two intensity aspects alertness and vigilance as well as for selective and divided attention representing selectivity aspects of attention. The training programs have a game-like layout and represent the underlying attention paradigms in everyday-like scenarios. To control for therapy effects, the respective subtests of the Test for Attentional Performance (TAP, Zimmermann & Fimm, 1997) were administered. They target the same attention components as the training, but they do it by completely different tasks. Thus, training and test procedures can clearly be separated from each other. In a first study (Sturm et al., 1994, 1997) patients with vascular unilateral lesions, who showed attention deficits in at least two of the four attention domains, i.e. percentile ranks of < 25 in the respective TAP subtests, at first were trained for 14 training sessions in one of the impaired attention domains. After a second test session each patient was trained in one of the other impaired attention functions. At the end of this second therapy phase a third test session was carried out. 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. The results of these earlier studies revealed that especially intensity aspects of attention (alertness and vigilance) have to be trained specifically, i.e. significant improvement can only be achieved by the specific training procedure. For selectivity aspects of attention (selective and divided attention) the error rate, too, could only be influenced positively by the specific training programs. Response time, however, for these attention domains could also be improved by trainings of attention intensity. (Sturm et al., 1997). These results were corroborated by a study in patients suffering from Multiple Sclerosis (Plohmann et al., 1998).

Since the most prominent attention deficits can be expected after traumatic brain injury (TBI), in the present study the efficacy of the training programs was also studied in a mixed group of TBI patients and patients with vascular brain damage. The focus of the study again was put on the question, whether specific attention deficits call for specific training procedures. In contrast to our first study, we now introduced a baseline phase to control for spontaneous recovery and adjacently the patients received a training for only one of their impaired attention functions. Patients were selected and trained in a multicenter study within the scopes of the European BIOMED-I-E.S.C.A.P.E. project (European Standardized Computerized Assessment Procedure for the Evaluation and Rehabilitation of Brain Damaged Patients). The following institutions participated in the project:

BELGIUM: Centre Neurologique William Lennox, Ottignies. FRANCE: Service de Rééducation et de Convalescence Neurologiques, Lille; Service de Rééducation Fonctionnelle, Centre de Réadaptation de Mulhouse, Mulhouse; Hôpital de la Salpêtrière, Paris; Service de Neuropsychologie, Clinique Neurologique Centre Hospitalier Universitaire, Strasbourg; Centre de Rééducation et d'Etude des Activités Mnésiques, Tassin-La-Demi-Lune. GERMANY: Neurological Clinic – Division of Neuropsychology, University Hospital RWTH Aachen, Aachen; Department of Psychology, Albert-Ludwig-University Freiburg, Freiburg. ITALY: Ospedale S. Giorgio, Ferrara; Ospedale Misericordia, Grosseto; Istituto di ricovero e cura a carattere scientifico Ospedale S. Lucia, Roma.

Methods

Training Programs

For this study PC versions of the training programs were developed (AIXTENT-training programs*). In order to minimize 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. In the following, the four attention training programs are described more closely:

Alertness Training

Animated driving tasks with a car or motorcycle displayed in a graphic design on the computer screen are used. The patient has to watch a car or a motorcycle driving on a winding track. The patient is not supposed to actually steer the car or the motorcycle. He/she only

* The PC-adaptation of the AIXTENT-training programs was financially supported by the German Kuratorium ZNS for TBI patients with lesions of the CNS

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 suddenly appearing obstacles. In order to accomplish this, the subject either has to press a "gas" key to speed up the vehicle or to press a "brake" key to diminish the vehicle's speed or to stop it. Forthcoming obstacles are indicated by graphic signs which serve as warning signals. In this way the training operationalizes 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 -flashing, fixed and finally absent- and the position of the vehicle on the screen. Collisions with obstacles are indicated by optical and acoustic feedback.

Vigilance Training

For the vigilance training a radar screen task was constructed. 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 of 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 color and the frequency of relevant events.

A second vigilance training program simulates an assembly line. The patient has to watch objects moving on the assembly line and he/she has to sort out damaged objects by pressing a response key.

Selective Attention Training

For the training of selective attention two programs were developed. In the first program, 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 program is some kind of "photo 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/she has to "take a picture" of these objects (animals, everyday life objects, persons). Irrelevant objects must not be responded to. For both programs 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

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 surpassing of an upper and lower speed limit. The third, auditory source is the motor sound which has to be watched for more than two successive interrupts. For the first training sessions, one auditory and one visual source are combined. During later sessions, to increase the difficulty level, either two visual stimuli are combined or all three stimulus sources can appear in combination.

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

At the end of each training session or whenever the patient or the therapist wanted 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 could be presented. These parameters were stored under the individual patient's name and provided initial parameter values for the next training session.

Control Tests

To examine the efficacy of the training programs we used subtests of the Test for Attentional Performance (TAP; Zimmermann & Fimm, 1994; Zimmermann, North, & Fimm, 1993). There was a test of alertness requiring a response to a simple visual stimulus with or without (intrinsic alertness, see introduction) a preceding auditory warning signal. The difference between the two stimulus conditions was taken as an index of phasic alertness. Visual vigilance was tested over a period of 30 minutes at a rate of one critical stimulus per minute. Patients had to watch a horizontal light bar moving up and down slowly within confined spatial limits. Only about once per minute the bar made a larger movement toward the top of the screen. This

Tabelle 1. Sample characteristics of the 4 training groups.

Sample Characteristics	Training Group Alertness ($n = 9$)	Vigilance ($n = 7$)	Selective Attention ($n = 11$)	Divided Attention ($n = 6$)
Female/male/not reported	1/7/1	3/4	3/8	1/4/1
Etiology (vascular/traumatic/ other or unknown)	3/4/2	2/5	2/6/3	1/3/2
localization (left/right/unknown or diffuse/bilateral)	0/5/3/1	2/2/1/2	4/1/5/1	2/2/2/0
Age (years)	34 (20–60)	26 (20–45)	34 (22–60)	43 (18–56)
Education (years)	9 (8–11)	12 (8–15)	10 (7–12)	12.5 (9–15)
Time post onset (months)	9 (3–90)	38 (12–80)	21.5 (6–31)	28.5 (3–128)

larger movement had to be detected and responded to. To assess selective attention we used a go/nogo 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). All dependent test variables are depicted in table 2. It was decided that, while alertness performance was reflected in response time (RT), the number of errors or omissions was the most important dependent variable for vigilance, selective attention, and divided attention. Thus, for the latter tests RT data unfortunately were not recorded for all patients. This was especially the case during the baseline phase. Available RT data, nevertheless, are presented in the results section. Statistical analyses, however, were only carried out, if data of at least 5 patients existed. It would have been desirable to have access to other sensory or cognitive variables but the multicenter character of the study reflecting different assessment standards in different European countries made it impossible to gather comparable data.

Subjects

A total number of 33 patients was included in the study. Sample characteristics are given in Table 1.

The number of patients per training varied considerably (6–11). Only a quarter of the patients were female. There was a clear predominance of traumatic etiology ($n = 18$) compared to 8 vascular cases. Etiology was not known for 7 cases. For 11 patients localization of lesion was not reported or was diffuse. Although the overall number of left or right sided lesions was similar (8 resp. 9), only right sided, diffuse or bilateral lesions were found in the alertness training group. The situation was almost reverse for the selective attention group. Time post onset varied from 3 months to 13 years. Median duration of illness was much lower for the alertness training group (9 months) compared to all other 3 groups (about 2 years or more).

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 ≤10 (corresponding to T-scores < 38) or more than three errors in the selective and divided attention tests or less than 28 hits in the vigilance task. This error rates also correspond to a percentile rank of ≤10 or T-score < 38. To avoid massive spontaneous recovery effects, only patients at least two months post onset were admitted. Medication was held stable for the whole period of baseline and training. All patients were in-patients and the training was integrated into their therapy schedule. It was taken care that neither before nor during the baseline or training period other kind of attention therapy was carried out. Again, due to the multicenter character of this study it was, however, impossible to control for every other kind of neuropsychological, occupational or psychotherapeutic interventions possibly paralleling the attention training.

Study Design

The study had the following design: after a baseline phase (4 weeks) with two examinations by means of the control tests from the Test for Attentional Performance (Zimmermann & Fimm, 1997) patients received one period of attention training for one of four attention domains (alertness, vigilance, selective attention, divided attention). Only patients who showed impairments (as defined in the inclusion criteria) in at least two attention domains were included in the study. Training for one of the impaired functions was started only if the inclusion criteria held at the second pre-test. Five patients had to be excluded from an original num-

Tabelle 2. Median and range (in brackets) of control test performance for baseline phase 1 (t_1) and 2 (t_2) and for the test session after the training (t_3). All response time data are given in T-scores based on a normal normative sample of $n = 200$ healthy subjects. The error and omission scores are given as raw scores since normative data for these only exist as very coarse percentile ranks less suitable for further statistical processing.

		Training											
		Alertness ($n = 9$)			Vigilance ($n = 7$)			Sel. Attent. ($n = 11$)			Div. Attent. ($n = 6$)		
Control tests	**Depend. test variable**	t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3	t_1	t_2	t_3
Alertness	Phasic Alertness Index[#]	35.5	34	53	27.5	44	45	47	49	42	48.5	52	50
		(26–65)	(28–56)	(43–64)	(22–72)	(22–72)	(22–72)	(22–56)	(26–70)	(22–74)	(31–74)	(43–74)	(34–74)
	RTwoW*	26	29	43	29.5	35	36	32	32	39	40	38.5	38.5
		(22–34)	(20–44)	(20–47)	(22–35)	(22–45)	(22–55)	(22–72)	(22–55)	(22–58)	(24–48)	(25–51)	(31–47)
Vigilance	Errors	2	1	2	3	3	3	21.5	14	26	2.5	2	4
		(0–30)	(0–34)	(0–30)	(1–8)	(0–25)	(2–6)	(3–53)	(0–103)	(1–60)	(0–27)	(0–23)	(0–18)
	Omiss.	5	3	4	9	13	6	3	10.5	7.5	0.5	4	0
		(0–17)	(0–26)	(1–28)	(4–19)	(4–27)	(1–18)	(0–30)	(0–30)	(0–42)	(0–26)	(0–28)	(0–28)
Sel. Att.	Errors	0	0	0	0	1	0	9	4	5	3	0.5	2
		(0–2)	(0–2)	(0–12)	(0–5)	(0–3)	(0–4)	(3–24)	(0–20)	(1–12)	(1–6)	(0–8)	(0–7)
	RT	29	20	42	27	30	33	20	29	32	23	32.5	28
		(20–36)	(20–32)	(20–43)	(20–49)	(20–38)	(20–51)	(20–45)	(20–35)	(20–51)	(20–26)	(20–45)	(20–36)
Div. Att.	Omiss.	5.5	6	6	7	4.5	6.5	5	11	5	17	13	5
		(2–16)	(3–16)	(2–16)	(2–13)	(2–16)	(1–17)	(1–24)	(2–25)	(1–26)	(9–26)	(7–27)	(1–26)

[#]Phasic Alertness Index = difference between response times with and without warning; *RTwoW = Response time without warning (intrinsic, self-controlled alertness).

ber of 38 because at the second pre-test they failed to meet the inclusion criteria. For training, one of the subprograms of the AIXTENT attention training program (Sturm et al., 1993, 1994) aiming at one of the impaired attention functions was used. As already pointed out in the introduction, since each patient showed deficits in at least two attention domains, with this type of study design there was one attention deficit which was trained specifically, and at least another one for which the training was not specific. E.g., if a patient showed impairments both in alertness and vigilance, it was decided according to a pseudo-randomization schedule which of the two attention domains was trained. Given that the training was an alertness training, this training is a specific training for the alertness deficit, but a non-specific one for the vigilance impairment. Each patient was trained individually (no group training) one hour a day for fourteen consecutive training sessions (except on weekends) summing up to a test and therapy time of three weeks. The difficulty level of the training adapted automatically to the patient's performance during the training. After the end of the training the Test for Attentional Performance was administered again.

Due to the low number of patients per training group, specific training effects could not be assessed separately neither with respect to etiology nor localization.

Results

Table 2 gives the descriptive statistical information on performance for the control test variables at the three test occasions. All response time data are given in T-scores based on a normal normative sample of $n = 200$ healthy subjects. The error and omission scores are given as raw scores since normative data due to skewed distributions for these only exist as very coarse percentile ranks less suitable for further statistical processing.

Looking at the medians in table 2, performance after specific training for some of the variables has reached near normal level except for the selective attention RT variable (although the latter results due to missing data are based only on the data of 5 individuals). Furthermore, it is interesting to note that the number of errors (false alarms) in the vigilance task is and stays high for patients who due to selective attention problems were

Tabelle 3. p-values for change of performance (pretest 2 – pretest 1) in the four attention tasks after the baseline phase (Wilcoxon tests, with Bonferroni-α-correction for multiple testing).

Training group (training not given during this phase)	*n*	Alertness phas. Alert. Index	RTwoW	Attention tasks Vigilance Errors	Omiss.	Sel. Att. Errors	RT	Div.Att Omiss.
Alertness training	9	.87	.31	.50	.89	1.00	1.00	.72
Vigilance training	7	.11	.20	.22	.89	.79	1.00	.07
Select. attention training	11	.23	.61	.67	.17	.06		.45
Divided attention training	6	.11	1.00	$n^1 = 4$	$n = 4$	.25	$n = 2$	.046

[1]*n* for the statistical analyses (in case of incomplete sample); if $n < 5$ (caused by missing data), no p-values are reported. If neither p-value nor n are reported, there are no data for this parameter.
Phasic Alertness Index = difference between response times with and without warning
RTwoW = Response time without warning (intrinsic, self-controlled alertness).

Tabelle 4. p-values for change of performance (posttest 1 – pretest 2) in the four attention tasks after the training phase (one sided Wilcoxon tests, with Bonferroni-α-correction for multiple testing). Numbers in **bold** indicate specific training effects.

Training group	*n*	Alertness phas. Alert. Index	RTwoW	Attention tasks Vigilance Errors	Omiss.	Sel. Att. Errors	RT	Div.Att Omiss.
Alertness training	9	**.0039**	**.0173**	.50	.24	.75	.47	.29
Vigilance training	7	.79	.46	**.17**	**.018**	.29	.07	.40
Selective attention training	11	.80	.33	.53	.93	**.38**	**.23**	.22
Divided attention training	6	.22	$n = 4^2$	.72	.27	.50	$n = 2$	**.014**

[1]*n* for the statistical analyses (in case of incomplete sample); if $n < 5$ (caused by missing data), no p-values are reported.
[2]for two patients of the divided attention training group, the RT data for the response time without warning were missing, although the phasic alertness index was reported
Phasic Alertness Index = difference between response times with and without warning
RTwoW = Response time without warning (intrinsic, self-controlled alertness).

trained by the AIXTENT subprograms for attention selectivity. This observation might indicate that this parameter in the given vigilance task does not so much reflect vigilance performance but selectivity aspects of attention. In fact, errors occur, if the patient is not able to discern small from big moves of the light bar of the vigilance test from the TAP.

Inferential statistical analyses were carried out first to test for stability of test performance at baseline and second to look for specific training effects (comparison of second baseline and posttraining test performance). Wilcoxon signed rank tests were used; p-values were two-tailed throughout for the baseline comparisons and for testing non-specific training effects. Specific training effects were tested in a one-tailed fashion ($\alpha = 0.05$) since there were strong predictions from the first study with vascular patients (Sturm et al., 1993, 1994). P-values are only reported, if data from at least 5 patients were available. Table 3 containing the p-values for the baseline comparisons shows that only for the two most complex attention tasks (selective and divided attention) significant or near significant improvement in performance was present. This could be due to test repetition effects, which are more likely with complex tasks for which a certain familiarity is necessary.

Table 4 shows the p-values for the comparison between the second baseline and the posttraining test sessions. Except for the selective attention training, which did not lead to significant effects for any attention function, only improvements for the specific test variables matching the training procedure were present. The vigilance training also had a marginally ($p = .07$) beneficial effect for the reaction time parameter of the selective attention control test – a finding, which was also present in the first efficacy study (Sturm et al., 1997). Although not significant, there was a tendency for reaction time improvement in the selective attention task after selective attention training which, however, was much smaller than the practice or test repetition effect during the baseline phase. There was no effect for the error rate of the selective attention task.

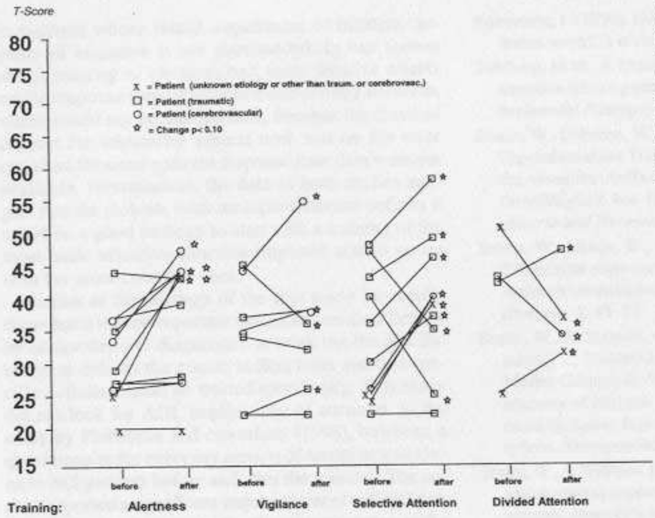

Figure 1. Individual changes in performance (T-scores) in the control test variable "alertness without warning (intrinsic alertness score)" after training of alertness, vigilance, selective or divided attention. Significant changes for single patients ($p < .10$) are indicated by an asterisk.

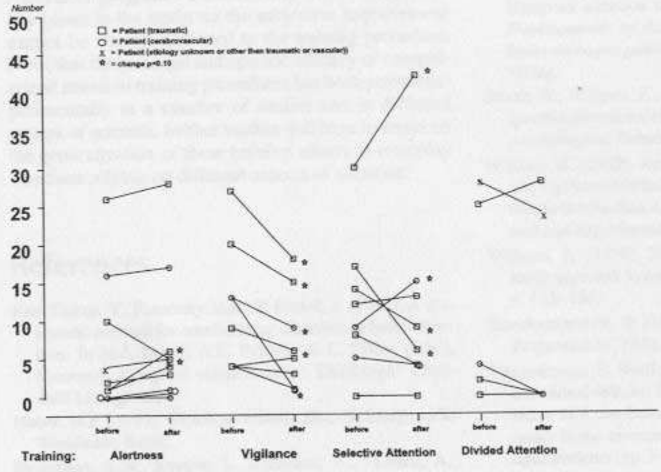

Figure 2. Individual changes in performance (number of omissions) in the control test "visual vigilance" after training of alertness, vigilance, selective or divided attention. Significant changes for single patients ($p < .10$) are indicated by an asterisk.

Again, the pattern of changes in performance was similar to that found in the first study.

Evaluation of Individual Patients

Since for the reaction time data of the Alertness test 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 posttest, this change in performance cannot be attributed to measurement errors alone.

With a given reliability of $r_{tt} = .981$, d_{crit} for the RT without warning (intrinsic alertness score) of the Alertness test was 4.

For the non-standardized omission scores of the vigilance test the numbers of omissions in pre- and posttest were compared by Fisher's exact test. For single case analysis a type-I-error of 10% is generally recommended (Huber, 1973; Willmes, 1990).

Figures 1 and 2 show the performance of single cases after specific or unspecific attention training for the two test variables representing intensity aspects of attention (alertness, vigilance). These variables were chosen because they present with the largest overall training effects in the inferential group statistics.

Figure 1 shows the T-scores for response times in the intrinsic alertness task before and after training of alertness, vigilance, selective attention or divided attention. The figure demonstrates that the specific training for alertness in most cases (8 out of 11) lead to a numerical (3) or significant (5) improvement in the alertness test of the TAP (a significant change is indicated by an asterisk). None of the patients got worse. Due to the fact that the patients included in the study showed impaired performance in at least two of the four attention tests used as control tasks, there also was a number of patients who before the training showed below average performance in the alertness test but received a different training which was non-specific with respect to their alertness impairment. Figure 1 shows that some patients can improve alertness after selective or divided attention training, too. On the other hand, other patients did not improve after the respective non-specific training but their performance even became significantly worse. This effect was most pronounced with a training focusing on selective or divided attention.

Figure 2 presents similar effects for the number of omissions in the vigilance task. After the specific vigilance training there is a consistent decrease of omissions. Only few patients show improvement after non-specific training and again in some patients there seems to be further deterioration of performance following a "wrong" (non-specific) training, here especially after training of selective attention.

Discussion and Conclusions

Although the overall number of left or right sided lesions was similar, only right sided, diffuse or bilateral lesions were found in the alertness training group. The situation was almost reverse for the selective attention group. The data thus are in line with the notion of a different involvement of the right and left hemisphere in the cognitive control of alertness resp. selective attention (see also: Sturm et al., 1997). It might have been desirable to have additional data e.g. for sensory or other cognitive deficits in our patients. The multicenter approach of this study, however, revealed the different standards of neuropsychological assessment in different European countries where comparable data were not available. The problem of occasionally missing data was a shortcoming of this approach, too.

Despite these methodological shortcomings, the results of this multicenter study corroborate many findings of the former studies by Sturm and coworkers (1997) and by Plohmann and coworkers (1998) showing again specific training effects especially for intensity aspects of attention performance (alertness and vigilance) but also for divided attention. Neither response time nor error rate of the selective attention control test could be improved significantly by the selective attention training. In our previous study in patients suffering from attention deficits after stroke the selective attention training lead to a significant improvement of response time in the control test. A numerical improvement of RT can be seen in the present study, too, but this did not reach significance because due to missing data RT data were only available for 5 of the 11 patients of the selective attention training group.

In this study, comparable training effects are achieved both for patients with vascular etiology of brain damage and for traumatically brain damaged patients. This can best be seen in fig. 1 and 2, where CVA and TBI patients are depicted as single cases. During the baseline phase, only slight improvements for selectivity aspects of attention – probably caused by practice effects during test repetition – occurred, but no changes for the intensity aspects alertness and vigilance. Thus, especially the specific effects for intensity aspects of attention during the training phase cannot be interpreted as effects of test repetition or spontaneous recovery. Analysis of individual patients' changes in control test performance after the training showed that a specific training of alertness or vigilance significantly improved the respective attention function in nearly every single patient. Alertness and vigilance, in some patients, could be improved by non-specific training, too, especially after training of selective and divided attention. This might be due to the fact that these two training procedures besides focusing on selectivity also aim at an improvement of response times and thus have an alerting effect on their own. On the other hand, the single case analysis also reveals that in some patients suffering from alertness or vigilance impairments, a non-specific training focusing on selectivity aspects of attention may even cause further deterioration of performance. This might be explained by the notion that intensity aspects of attention like alertness and the ability to maintain a certain level of activation over time are prerequisites for more complex attention functions. If patients suffer from basic attention deficits, a training of selectivity aspects of attention, which is performed in a rather complex task setting, may lead to an "overload" and further breakdown of the attentional system due to a lack of processing capacity in these patients. Interestingly, this seems to happen even in patients whose initial impairment of intensity aspects of attention is not pronounced. In our former study, training of alertness had some positive effects on the response time of selective and divided attention, which could not be studied here, because the focus of interest for selectivity aspects now was on the error rates and for some patients response time data were not available. Nevertheless, the data of both studies suggest that for patients with multiple attention deficits it might be a good strategy to start with a training of the most basic attention function impaired and to go on with the more complex ones.

Similar to the findings of the first study the results show that it is very important to start an attention therapy by comprehensive diagnostics to work out the specific attention deficits the patient suffers from and that specific deficits should be treated specifically. This study did not look for ADL implications of attention. In the study by Plohmann and coworkers (1998), however, a questionnaire for everyday aspects of attention was given to MS patients before and after the training. The authors reported a significant improvement of self estimated attention performance after the administration of the AIXTENT programs. Unfortunately there was no baseline phase in the study, so the subjective improvement cannot be clearly attributed to the training procedure. Now, that the principal and specific efficacy of computerized attention training procedures has been proved experimentally in a number of studies and in different groups of patients, further studies will have to focus on the generalization of these training effects to everyday functions relying on different aspects of attention.

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