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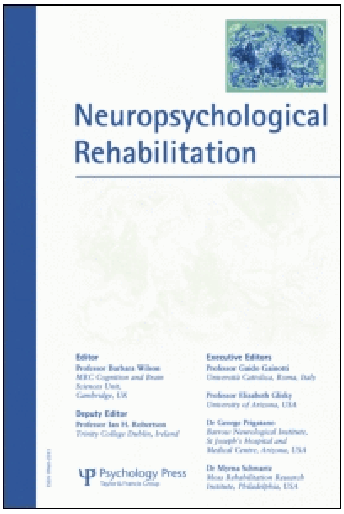


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# Rehabilitation of divided attention after severe traumatic brain injury: A randomised trial

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Patients with severe traumatic brain injury (TBI) frequently suffer from a difficulty in dealing with two tasks simultaneously. However, there has been little research on the rehabilitation of divided attention. The objective of the present study was to assess the effectiveness of a rehabilitation programme for divided attention after severe TBI. Twelve patients at a subacute/chronic stage after a severe TBI were included. A randomised AB vs. BA cross-over design was used. Training lasted six weeks, with four one-hour sessions per week. It was compared to a non-specific (control) cognitive training. During experimental treatment, patients were trained to perform two concurrent tasks simultaneously. Each one of the two tasks was first trained as a single task, then both tasks were given simultaneously. A progressive hierarchical order of difficulty was used, by progressively increasing task difficulty following each patient's individual improvement. Patients were randomised in two groups: one starting with dual-task training, the other with control training. Outcome measures included target dual-task measures, executive and working memory tasks, non-target tasks, and the Rating Scale of Attentional Behaviour addressing attentional problems in everyday life. Assessment was

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not blind to treatment condition. A significant training-related effect was found on dual-task measures and on the divided attention item of the Rating Scale of Attentional Behaviour. There was only little effect on executive measures, and no significant effect on non-target measures. These results suggest that training had specific effects on divided attention and helped patients to deal more rapidly and more accurately with dual-task situations.

***Keywords***: Divided attention; Traumatic brain injury; Cognitive rehabilitation.



## INTRODUCTION

Deficits of attention are one of the most frequent and disabling consequences of severe traumatic brain injury (TBI) (Leclercq & Azouvi, 2002; Ponsford & Kinsella, 1992; Van Zomeren & Brouwer, 1994). Among the wide spectrum of attentional problems, patients with TBI have repeatedly been found to show difficulties in divided attention (Azouvi et al., 2004; Azouvi, Jokic, Van der Linden, Marlier, & Bussel, 1996; Leclercq et al., 2000; McDowell, Whyte, & D'Esposito, 1997; Vallat-Azouvi, Weber, Legrand, & Azouvi, 2007; Veltman, Brouwer, van Zomeren, & van Wolffelaar, 1996). Patients, their relatives and rehabilitation professionals frequently report difficulties in doing two things at the same time, and this difficulty has been found to be significantly correlated with non-return to work two years post-injury (Ponsford & Kinsella, 1991; Van Zomeren & Van den Burg, 1985).

Divided attention refers to the ability to carry out two competing tasks simultaneously (Van Zomeren & Brouwer, 1994). From a theoretical point of view, divided attention is a complex function, closely related to executive functioning and working memory. Indeed, it is usually considered as one of the key functions of the Central Executive system of working memory (Baddeley, 2002). Dual-task processing requires strategic allocation of attention, task switching and synchronisation (Rabbitt, 1997). Research on divided attention in patients with TBI showed that patients perform normally on divided attention tasks that can be carried out relatively automatically, while they are impaired relative to healthy controls in more complex tasks performed under high time-pressure, including substantial working memory load, or requiring executive control (Leclercq & Azouvi, 2002; Park, Moscovitch, & Robertson, 1999).

To our knowledge however, there has to date been little research on the rehabilitation of divided attention after TBI. A number of studies on rehabilitation of attention after TBI have been reported, with heterogeneous results (Ben-Yishay, Piasetsky, & Rattok, 1987; Gray & Robertson, 1989; Ponsford & Kinsella, 1988; Sohlberg & Mateer, 1987; Sturm et al., 2002; Sturm, Willmes, Orgass, & Hartje, 1997). In a meta-analysis, Park and Ingles

(2001) concluded that studies that used an adequate control condition produced only small and statistically non-significant improvements in performance of cognitive functions and specific measures of attention. They found however that specific-skills training significantly improved performance of trained tasks requiring attention. In a very recent review, Ponsford (2008) also concluded that "despite the large number of attention rehabilitation studies conducted to date, there is still limited evidence of their success". However, there is some evidence suggesting that more specific approaches, using a training programme focused on one specific impaired attentional process may be more effective. Sturm and colleagues conducted two randomised studies in patients with brain injuries of various origins (stroke or TBI), and showed that specific attention deficits need specific training (Sturm et al., 1997; 2002). They found highly specific training effects, especially for intensity aspects of attention performance (vigilance and alertness) but also for divided attention. They concluded that it is very important to start an attention therapy by comprehensive diagnostics to work out the specific attention deficits the patient suffers from. However, they did not look for improvements of daily-life activities related to attentional functions. Very recently, a preliminary randomised controlled trial of dual-tasking training has been reported. (Evans, Greenfield, Wilson, & Bateman, 2009). Ten patients with dual-tasking difficulties after stroke or TBI practised exercises involving walking combined with cognitive tasks. An improvement was found on a task similar to the trained tasks, but without generalisation to other dual-task situations. Recent studies also suggest that closely related functions, such as the central executive of working memory, could also be improved by a specific cognitive training (Cicerone & Giacino, 1992; Duval, Coyette, & Seron, 2008; Serino et al., 2007; Vallat-Azouvi, Pradat-Diehl, & Azouvi, 2009; Vallat et al., 2005; Westerberg et al., 2007).

The objective of the present study was to assess the effectiveness of a rehabilitation programme for divided attention in patients with severe TBI at the subacute/chronic stage. This programme was based on a progressive training of dual-task processing, starting with simple and relatively automatic tasks, then including more complex and resource-demanding conditions. It is always difficult, in rehabilitation studies, to control for non-specific effects, such as spontaneous recovery, practice with tests, placebo effect, or global cognitive stimulation. To control, as far as possible, for these confounding effects, a randomised cross-over design was used, in which specific dual-task training was compared to a non-specific cognitive training not including dual-task or working memory training. The cross-over design was used in order to minimise the effect of inter-individual variability in a relatively small patient sample. To assess the specificity of effect, three sets of measures were used: specific divided attention tasks, that were expected to improve with specific training; non-specific but related executive and working memory measures, to assess some degree of transfer to tasks sharing some characteristics with trained tasks, but that nevertheless could be assumed to rely on quite different mechanisms; and non-target tasks that had little common characteristics with the target tasks. Finally, it was expected that improvement, if present, was not limited to psychometric measures, but also concerned everyday life functioning. To address this issue, a standardised attentional questionnaire was used.

# METHODS

## Participants

Patients included in this study were consecutively referred to one of two specialised neuro-rehabilitation units at a subacute/chronic stage (five months or more) after a severe TBI, as defined by a lowest post-resuscitation score of 8 or less on the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974). They were out of post-traumatic amnesia (PTA), as defined by a score of 76 or more on two consecutive days on the Galveston Orientation and Amnesia Test (Levin, O' Donnell, & Grossman, 1979). The main criteria to be included in the present study were the presence of a deficit of divided attention, that was operationally defined as a score below the fifth percentile of the standardisation sample on the Divided Attention subtest of the Test for Attentional Performance (TAP; Zimmermann & Fimm, 1995, 2002), and by a complaint regarding a difficulty in doing two things at the same time on the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991). Exclusion criteria were previous psychiatric or neurological diseases, substance abuse, severe behavioural modifications, motor or visual impairments or severe cognitive deficits that precluded completion of the rehabilitation programme. Twelve patients (nine men) were included in this study, in two participating centres. They were randomised to two groups, AB and BA (cf. study design, following section). The main demographic and clinical characteristics of the two groups of patients are displayed on Table 1 (PTA duration was not available in two cases). The two groups did not differ significantly in terms of age, education duration, lowest post-resuscitation GCS score, coma duration, PTA duration, and time since injury (all $p$s $> .1$). Although patients in the BA group tended to be in a slightly more chronic stage, this difference did not reach statistical significance, $F(1, 8) = 2.0$, $p = .2$.

## Study design

A randomised AB vs. BA design was used. This included two successive phases of six-weeks duration each (total: 24 hours training per phase). During each phase, patients were given four individual one-hour training

TABLE 1
Main demographic and clinical characteristics of the patients included in the study (PTA duration was not available in two patients). Table shows the mean (*SD*; range).

| | *AB (n = 5)* | *BA (n = 7)* |
|---|---|---|
| Age | 23.8 (7.6; 18–37) | 26.7 (4.8; 20–35) |
| Education (years) | 13.0 (1.4; 12–15) | 14.1 (4.6; 8–21) |
| GCS | 4.8 (1.5; 3–7) | 4.8 (1.3; 3–7) |
| Coma duration (days) | 8.4 (4.3; 3–15) | 11.4 (10.8; 2–30) |
| PTA (days) ($n = 10$) | 21.8 (7.0; 15–30) | 15.4 (7.1; 7–24) |
| Time since injury (months) | 6.3 (1.2; 5–8) | 16.1 (14.7; 5–38) |

GCS = Glasgow Coma Scale (this refers to the lowest post-resuscitation score); PTA = post-traumatic amnesia

sessions per week. "A" referred to control training, "B" to experimental rehabilitation. Randomisation was conducted individually by the study coordinator (PA), blind to each patient's clinical status. Control training used various cognitive tasks that did not tap on divided attention or working memory. During the experimental rehabilitation phase, patients were given specific dual-task training. Patients were randomly assigned to one of the two groups, one starting with the control training for six weeks, then receiving the experimental rehabilitation for six weeks (AB), the other one with the reverse order (BA). Patients were informed of the experimental aim of the study and gave their written consent to participate. Patients were informed that the aim of the study was to assess a "new" experimental treatment for divided attention, in comparison with an "old" treatment. It was not explicitly stated that the control training was not supposed to improve their performance. The study protocol complied with Helsinki declaration and was approved by the local ethical committee.

## Experimental rehabilitation of divided attention

The objective was to train patients to perform two concurrent tasks simultaneously. Each one of the two tasks was first trained as a single task, to ensure that the patient was able to complete the task efficiently. Then, both tasks were given simultaneously. A progressive hierarchical order of difficulty was used, by increasing task difficulty following each patient's individual improvement. As soon as a patient achieved a nearly perfect (about 90% accuracy) performance at a given level, a higher difficulty level was given by modifying either time pressure, and/or executive demands and/or working memory load of the tasks. Different tasks and combinations of tasks were used from one session to the other, in order to minimise familiarity with tasks and re-test effects. Both paper-and-pencil and computerised tasks were used. Examples of computerised tasks were: choice reaction time, go–no or *n*-back tasks (with letters, numbers or words). Examples of paper-and-pencil tasks were: forward or backward counting, verbal fluency, word spelling, summarising a short text, and word sorting in alphabetical order. Moreover, therapists tried to use tasks that were, as much as possible, close to each patient's daily life needs (for example: cooking tasks; simulation of daily-life situations, such as money management or shopping; summarising and commenting on recent events heard on the TV or read in magazines about sport, arts, music, politics, according to the patient's own interests). The therapists also addressed awareness of deficits. Information and explanations were regularly given to the patients on their difficulties, and feedback was provided on their performance during training sessions.

In contrast, control training used tasks (either computerised or paper and pencil) that did not tap on divided attention or working memory (e.g., for computerised tasks: vigilance or simple visual search tasks; for paper-and-pencil tasks: verbal or visual long-term memory tasks, simple problem-solving or logical reasoning, summarising short texts, crossed words, and lexical search for synonyms or antonyms).



## Outcome measures

Outcome measures were obtained first upon inclusion, before training, then at the end of each training phase (control training or experimental rehabilitation). A follow-up assessment was given one month after the end of the trial. This means that each patient had four assessment sessions: at inclusion, after the control treatment, after the experimental treatment, and at follow-up. For practical reasons, three patients could not complete the follow-up assessment (BA group). Although, at the beginning of the study, we had the intention of conducting blinded assessment by a clinician not aware of the group of each individual patient, this was unfortunately not possible for practical reasons. Assessment and rehabilitation were conducted by the same clinicians (JC, SS, GL).

Four sets of measures were obtained (all different from exercises used during rehabilitation): specific divided attention tasks; executive and working memory tasks; non-target measures, that were assumed not to tap on divided attention and/or working memory and that were not supposed to improve with therapy; and an assessment of attention in everyday life.

### *Specific divided attention measures*

*The Divided attention subtest of the TAP* (Zimmermann & Fimm, 1995). In this test, two simultaneous choice reaction times tasks (one visual and one auditory) were given. The visual task consisted of crosses that appeared in a random configuration in a 4 × 4 matrix. Patients had to detect whether the crosses form the corner of a square. The auditory task included a regular sequence of high and low beeps. Patients had to detect an irregularity in the sequence. The dual task was preceded by a practice session, in order to ensure that patients were able to perform single tasks without difficulty. Measures were number of omissions and reaction times

*Go–no go and digit span* (Leclercq & Peters, 2007). This is a combination of two different tasks. Each one was first performed as a single task then the tasks were given simultaneously. In the go–no go task, four coloured figures (two targets and two foils) appeared randomly on the centre of a computer videoscreen. Patients were instructed to press on a response button as fast as possible when a target appeared, and to retain pressing for foils. Sixty-four stimuli were presented for 2 seconds each, with an inter-stimulus interval randomly ranging from 1 to 7 seconds. Simultaneously, they were presented with series of digits that they had to repeat in the same order. The number of digits to repeat was individually adjusted to each patient's forward digit span (that was defined here as the number of digits successfully repeated on three successive trials). Measures were reaction times and omissions in the go–no go task, and percentage of hits in the digit span task.

## *Executive and working memory tasks*

*Flexibility sub-test of the TAP* (Zimmermann & Fimm, 1995). This test requires mental alternation between two sets of targets, letters and numbers. A letter and a number were presented simultaneously and randomly on the left or the right side of a fixation point (on the centre of the computer videoscreen). From one presentation to the other, the target changed from letter to number and vice-versa. The subjects had to press as quickly as possible the key on the side of the target (left or right). Measures were mean reaction times.

*Trail-Making test* (Reitan, 1958). This test also addresses mental flexibility. The measure used here was the difference between time of completion of form B and form A.

*Stroop test* (Stroop, 1935). This test was used to assess inhibition and focused attention. The measure was the interference score (difference between interference and reading condition).

*Working memory: Brown-Peterson paradigm* (Brown, 1958; Peterson & Peterson, 1959). The Brown-Peterson paradigm requires simultaneous storage and processing of information. Patients were asked to recall consonant trigrams after three delays (5, 10 or 20 seconds) with or without an interfering task (motor task, articulatory suppression and digit addition). The outcome measure was the percentage of hits under the more demanding condition (mental calculation as interfering task).

### *Divided attention in everyday life*

The Rating Scale of Attentional Behaviour was originally designed to assess attentional problems in everyday life, and has been found to be sensitive to TBI (Ponsford & Kinsella, 1991). It includes 14 questions rated on a 5-point scale (range: 0–4), one of the questions being related to divided attention and dual-task situations in everyday life. The mean score of the divided-attention question of the scale was used as the outcome measure (range: 0–4). The scale was used as an observation scale, as suggested in the seminal paper (Ponsford & Kinsella, 1991). It was also intended to use the scale as a complaint list, filled in by the patient, but due to anosognosia, scores were not reliable and these latter data will not be presented here.



### *Non-target measures*

*Speed of processing*. Basic speed of processing was assessed with a simple reaction time test (“phasic alertness” subtest of the TAP; Zimmermann & Fimm, 1995). Patients had to press on a response button when a target (white square) appeared on the centre of the computer videoscreen.

*Go–no go and digit span as single tasks* (Leclercq & Peters, 2007). Before completion of the go–no go and digit span dual-task described above, each one of these two tasks was completed alone, as a single task. Performance on the single tasks was not expected to improve after training.

## Statistical analyses

In order to assess the effect of intervention, two methods were used. The first analysis used a repeated-measures ANOVA, with group (AB vs. BA) as a between-subject variable, and time (baseline, 6-week, 12-week, follow-up) as a within-subject variable. This analysis yielded three effects. The main effect of group was expected to be non-significant, as the two groups were assumed to be similar in terms of cognitive impairments; the main effect of time was expected to be significant, at least for target measures, due to an improvement with time; the most important effect here was the group $\times$ time interaction. If improvement was related to the specific intervention on divided attention, a significant interaction was expected, due to an improvement at the 6-week assessment for group BA, and at 12-week assessment only for group AB. When a significant interaction was found, post-hoc analyses were conducted to compare the two groups at the 6-week time point, since at this time, patients in the BA group were expected to outperform patients in the AB group. In order to minimise type I error on multiple comparisons, the $p$ value was arbitrarily set at .01.

In addition, effect-sizes (Cohen's $d$) of changes for each outcome measure after experimental treatment and after control training were computed by the following formula: mean score at the end of the 6-week phase (either experimental or control) minus mean score at the beginning of the corresponding phase, divided by the pooled *SD*.

## RESULTS



For all outcome measures, the main effect of group was non-significant on repeated-measures ANOVAs (all $p$s $> .1$), suggesting that the two groups did not differ in terms of baseline cognitive impairments.

### Specific divided attention measures

*Divided attention subtest of the TAP* (Zimmermann & Fimm, 1995). Performance of the two groups of patients is illustrated in Figure 1A (median reaction times) and 1B (omissions). The main effect of time and the group $\times$ time interaction were significant, both for median reaction times, $F(3, 21) = 21.5$, $p < .0001$; $F(3, 21) = 20.7$, $p < .0001$, respectively, and omissions, $F(3, 18) = 22.3$, $p < .0001$; $F(3, 18) = 13.2$, $p < .0001$, respectively. Post-hoc analyses showed that the two groups differed significantly at the 6-week assessment time point, due to a better performance of group BA after specific training, for reaction times, $F(1, 10) = 13.8$, $p < .01$, and omissions, $F(1, 10) = 12.4$, $p < .01$). As illustrated in Figure 1, performance remained stable during control training and improved only after specific training, both in terms of speed of response and of accuracy. Improvement remained stable at follow-up.

Effect-sizes measures showed that experimental training had a large effect both on reaction times and on omissions (Cohen's $d > 1.5$), while control training was associated with minor changes ($d < 0.2$) (Table 2).

*Go–no go and digit span dual-task* (Leclercq & Peters, 2007). Performance under the dual-task condition is illustrated on Figure 2A (reaction times), 2B (omissions) and 2C (percentage of hits in the digit span task). The main effect of time and the group $\times$ time interaction were both significant for the go–no go dual-task reaction times, $F(3, 18) = 12.3$, $p < .0001$; $F(3, 18) = 17.5$, $p < .0001$, respectively, and the digit span dual-task,

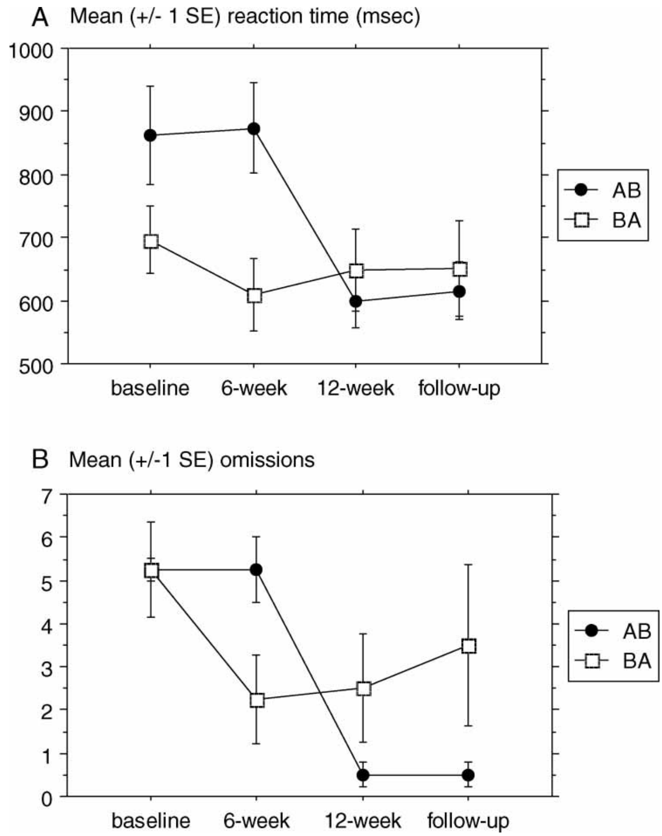


**Figure 1.** Divided attention subtest of the TAP. The figures illustrate evolution of performance upon inclusion, at the end of the fist 6-week period, at the end of the second 6-week period and at follow-up (follow-up data could not be obtained for three patients). Group AB: Control training first, experimental rehabilitation second; group BA: Experimental rehabilitation first, control training second.

Figure 1A: Median reaction times; Figure 1B: Mean number of omissions.

$F(3, 18) = 84.6, p < .0001$; $F(3, 18) = 28.4, p < .0001$, respectively. Regarding omissions in the attentional task, the effect was less dramatic, probably due to a ceiling effect (see Figure 2): the main effect of time was significant, $F(2, 20) = 6.7, p < .01$, but the interaction did not reach significance, $F(2, 20) = 2.4, p = .12$. Post-hoc analyses showed that group BA obtained a significantly better performance than AB at the 6-week assessment time point for the digit span dual-task, $F(1, 10) = 27.6, p < .001$, although this effect did not reach significance for omissions, $F(1, 10) = 7.1, p = .02$. Regarding reaction time, visual inspection of Figure 2A might suggest that at 6 weeks, there was a trend for a decrease of performance of AB (control)

TABLE 2
Effect-sizes (Cohen's *d*) of the experimental treatment and of control training for the different outcome measures. To facilitate reading, scores are presented so that positive effect-sizes correspond to an improvement, and negative scores to a decrease of performance

| | | *Treatment* | *Control* |
|---|---|---|---|
| **Specific divided attention measures** | | | |
| | Divided attention (TAP), RT | 1.65 | –0.14 |
| | Divided attention (TAP), omissions | 2.64 | 0.03 |
| | Go–no go dual-task, RT | 0.89 | –0.22 |
| | Go–no go dual-task, omissions | 1.19 | 0.00 |
| | Digit span dual task, % hits | 2.48 | –0.04 |
| **Executive and working memory tasks** | | | |
| | Flexibility (errors) | 1.42 | 0.08 |
| | TMT (B–A) | 0.53 | 0.13 |
| | Stroop, interference score | 0.60 | –0.03 |
| | Brown-Peterson, addition | 0.95 | 0.12 |
| **Divided attention in everyday life** | | | |
| | RSAB, divided attention | 1.52 | 0.04 |
| **Non-target measures** | | | |
| | Simple RT | 0.60 | –0.04 |
| | Go–no go single task, RT | 0.47 | 0.64 |
| | Go–no go single task, omissions | 0.20 | 0.20 |
| | Digit span single task, % hits | 0.80 | –0.02 |

TAP = Test for Attentional Performance; RT = Reaction time; RSAB = Rating Scale of Attentional Behaviour.



group, in parallel with a modest improvement of group BA (experimental). However, this should be regarded with caution, since the 6-week between-group difference did not reach statistical significance, $F(1, 10) = 2.0$, $p > .1$.

Effect-sizes of experimental training were in the large range ( $> 0.8$) for all three outcome measures (reaction times and omissions in the go–no go task and percent of hits in the digit span task), while again control training had only minor effects (Table 2).

## Executive and working memory tasks

Results are shown on Table 3. The main effect of time and the group × time interaction were significant for the interference score of the Stroop test, $F(3, 15) = 11.6$, $p < .001$; $F(3, 15) = 10.1$, $p < .001$, respectively, and for the number of errors in the flexibility subtest of the TAP, $F(3, 21) = 9.4$, $p < .001$; $F(3, 21) = 5.5$, $p < .01$. For technical reasons, only errors were recorded in this latter test; reaction times could not be analysed. However, post-hoc comparison revealed no significant between-group

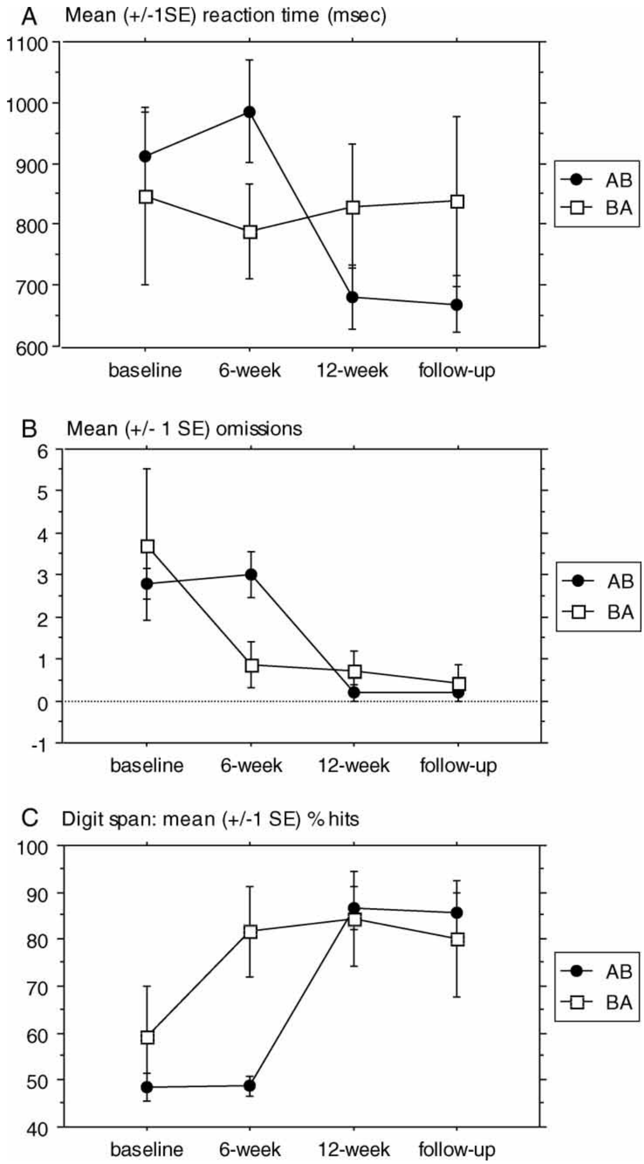


**Figure 2.** Go–no go and digit span dual-task. The figures illustrate evolution of performance upon inclusion, at the end of the fist 6-week period, at the end of the second 6-week period and at follow-up (follow-up data could not be obtained for three patients). Group AB: Control training first, experimental rehabilitation second; group BA: Experimental rehabilitation first, control training second.

Figure 2A: Mean reaction times; Figure 2B: Mean number of omissions in the go–no go test; Figure 2C: Percentage of hits in the digit span task.

TABLE 3
Executive and working memory tasks. The table shows mean (*SD*) performance of the two groups of patients. Follow-up data could not be obtained for three patients

| | *Group* | *Baseline* | *6-week* | *12-week* | *Follow-up* |
|---|---|---|---|---|---|
| Flexibility | | | | | |
| | AB | 5.6 (1.5) | 4.8 (1.3) | 1.4 (0.5) | 1.6 (0.5) |
| | BA | 5.1 (2.2) | 2.0 (3.7) | 2.1 (2.8) | 4.5 (5.4) |
| TMT (B–A) | | | | | |
| | AB | 47.6 (9.3) | 37.2 (21.3) | 22.6 (9.1) | 22.5 (4.8) |
| | BA | 76.8 (73.1) | 46.6 (37.4) | 47.4 (36.1) | 47.0 (47.7) |
| Brown-Peterson | | | | | |
| | AB | 0.7 (0.1) | 0.8 (0.2) | 0.9 (0.1) | 0.7 (0.4) |
| | BA | 0.7 (0.1) | 0.8 (0.2) | 0.8 (0.2) | 0.4 (0.5) |



difference for these two measures at the 6-week time point (both *p*s $> .1$). The main effect of time was not significant for the trail-making test (B minus A), nor for the Brown-Peterson task (addition condition), and there was no significant between-group difference at the 6-week assessment.

Effect-sizes of experimental training on executive and working memory measures were all in the moderate to large range ($>0.5$), while effect-sizes were minor ($>0.2$) after control training (Table 2).

## Divided attention in everyday life

The mean score of the divided-attention item of the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991) was used as outcome measure. Results are illustrated in Figure 3. A significant main effect of time and a significant group × time interaction were found, $F(3, 21) = 56.7$, $p < .0001$; $F(3, 21) = 10.8$, $p < .001$, respectively. As illustrated in Figure 3, everyday ratings were stable during control training and dramatically decreased after experimental training. The 6-week between group difference was significant, $F(1, 10) = 14.5$, $p < .01$, due to lower score in the BA group.

The effect-size of experimental training on the divided attention item of the scale was large, while it was close to 0 for control training (Table 2).

To assess the specificity of effect on divided attention, we also compared the mean scores on the 13 other questions of the scale, related to other aspects of attention. This analysis showed no significant difference after control training or after specific rehabilitation.

## Non-target measures

Results for the non-target measures are presented In Table 4. A significant effect of time was found for simple reaction time, $F(3, 21) = 8.6$, $p < .001$,

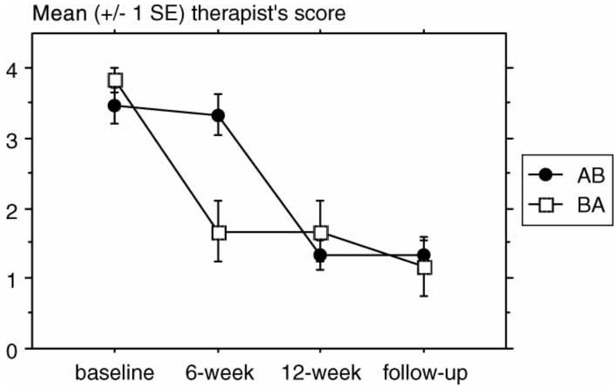


**Figure 3.** Mean score (therapist's rating) of the divided-attention item of the Rating Scale of Attentional Behaviour (maximal score: 4). The figure illustrates evolution of performance upon inclusion, at the end of the fist 6-week period, at the end of the second 6-week period and at follow-up (follow-up data could not be obtained for three patients). Group AB: Control training first, experimental rehabilitation second; group BA: Experimental rehabilitation first, control training second.



but the group × time interaction was just above the significance level, $F(3, 21) = 4.4$, $p = .015$, and the two groups did not differ at the 6-week assessment, $F(1, 10) = 1.6$, $p > .1$. The go–no go and the digit span performed as single tasks showed a significant main effect of time for the digit span, $F(3, 21) = 5.4$, $p < .01$, and a non-significant trend for go–no go reaction times, $F(3, 18) = 4.3$, $p = .02$, but without any significant group × time interaction, nor any significant between-group difference at the 6-week assessment (all $p$s $> .1$).

Measures of effect-sizes showed that experimental training had a less dramatic effect on non-target measures (range: 0.2–0.8) than on target

TABLE 4
Non-target measures. The table shows mean (*SD*) performance of the two groups of patients. Follow-up data could not be obtained for three patients

| | *Group* | *Baseline* | *6-week* | *12-week* | *Follow-up* |
|---|---|---|---|---|---|
| Simple reaction time | | | | | |
| | AB | 280.2 (40.4) | 285.2 (20.8) | 238.8 (21.0) | 239.4 (24.2) |
| | BA | 257.3 (39.9) | 247.46 (3.0) | 247.4 (64.9) | 237.5 (55.4) |
| Go–no go (single task) | | | | | |
| | AB | 641.7 (52.8) | 605.7 (47.3) | 587.6 (42.8) | 597.2 (56.1) |
| | BA | 706.8 (136.1) | 648.7 (58.9) | 609.4 (77.4) | 571.4 (63.4) |
| Digit span (single task) | | | | | |
| | AB | 76.6 (20.0) | 76.2 (16.8) | 92.4 (6.7) | 89.3 (7.2) |
| | BA | 79.1 (19.9) | 88.4 (16.1) | 88.2 (20.2) | 91.5 (19.1) |

measures (range: 0.53–2.64). Moreover, some of the effect-sizes for non-target measures were identical or even lower than that of control training (Table 2).

## DISCUSSION

The objective of the present study was to assess the efficacy of a rehabilitation programme for divided attention in patients at the subacute/chronic stage after a severe TBI. A specific experimental dual-task training programme was given to 12 patients and compared to a control training not including dual-task processing. Both trainings were conducted for the same amount of time (6 weeks, 4 sessions/week). A randomised cross-over design was used. Some of the patients received control training first (AB), then the experimental treatment, other patients (BA) were given the reverse order of training. The two groups did not differ in terms of demographics, injury severity, time since injury, nor baseline cognitive deficits. To assess the specificity of effects, target outcome measures focusing on dual-task processing were used and compared to executive tasks not requiring divided attention, but that could nevertheless be assumed to improve also, due to the executive nature of dual-tasks, and to non-target measures, that were not assumed to improve after training. Generalisation to everyday life was addressed with the divided attention item of the Rating Scale of Attentional Behaviour (Ponsford & Kinsella, 1991).

Results showed a dramatic training-related improvement of the two target tasks of divided attention. Performance improved both in terms of speed of response and accuracy. As expected, the group who received treatment first (BA) performed significantly better than the other group at the 6-week assessment time point for three out of the five measures that were used across the two dual-tasks, suggesting that specific training was more effective than control training. A non-significant trend was found for the two remaining measures. In addition, effect-sizes were computed, and revealed that experimental training had a large ($d > 0.8$) effect on all five divided attention measures, while control training was associated with minor or negligible changes (see Table 2). Similar findings were found with the divided attention question of the behavioural scale (while other attention-related failures in everyday life were not significantly modified by the treatment).

Divided attention training had only moderate impact on other executive and working memory tasks not including dual-task processing. A significantly greater improvement during treatment as compared to control was found only for the flexibility subtest of the TAP, suggesting that there might be some treatment-related effect in this task. However, the two groups did not significantly differ at the 6-week assessment. No significant treatment-related effects were found for other measures (Stroop, Trail-Making, Brown-Peterson). This did not seem to be related to a ceiling effect: indeed, performance in some of these tasks (particularly the Stroop test) tended to improve with time in the two groups, but improvement was similar after control and after experimental rehabilitation. The lack of a significant effect of dual-task training on the Brown-Peterson test, which is a measure of the functioning of the central executive of working memory, is interesting. Indeed, divided attention is a function that is usually assumed to be closely related to the central executive. A reverse dissociation was found in a recent rehabilitation single-case study of working memory in two patients with severe TBI, who showed a dramatic improvement of performance on the Brown-Peterson test, with little effect on dual-task processing (Vallat-Azouvi et al., 2009). The dissociation between improvement of working memory and divided attention again gives further support to the specificity of training. In addition, from a theoretical point of view, these results are in line with recent findings suggesting that divided attention deficits and working memory limitations could be, at least in part, independent in patients with severe TBI (Asloun et al., 2008).

Non-target, non-executive tasks, such as simple reaction time, go–no go task, or forward digit span, were not associated with any significant treatment-related improvement. Again, this did not seem to be due to a ceiling effect, since performance improved with time, but not more after the experimental rehabilitation. It is important to note that the same go–no go and digit span tasks that were used as single-tasks as non-target measures were used in combination in the dual-task procedure. A specific training-related improvement was found for these tasks performed under the dual-task condition, but not under the single-task condition, thus giving further support to the specificity of the training procedure. Indeed, this suggests that training did not change the ability to deal with each task separately, but only improved the ability to complete the two tasks simultaneously.

In summary, these results suggest that the specific rehabilitation programme for divided attention had specific effects on divided attention and was useful and helped patients to deal more rapidly and more accurately with dual-task situations. This improvement was found both on psychometric measures and on an everyday-life scale, while non-target measures were not significantly modified. Some treatment-related improvement was also found on one executive task (addressing mental flexibility) but not on other widely used executive and working-memory measures.

There are, however, some limitations to this study. First, the patient sample is relatively small. It is quite difficult to recruit patients to a long-duration and effortful rehabilitation programme. However, we feel that patients included in this study were quite representative of severe TBI patients referred to an outpatient rehabilitation facility at the subacute stage. In this regard, it is our opinion that these results could easily be generalised to other similar settings.

The second limitation is that assessment was not blinded. At the beginning of the study, we had the intention of conducting blinded assessment, by a clinician not aware of the group of each individual patient. Unfortunately, for practical reasons, this was not possible. As a result, an examiner's bias cannot be completely excluded. The third limitation is that we did not use an everyday divided attentional measure, apart from the item from the Rating Scale of Attentional Behaviour. In future studies, it should be useful to design standardised tests of divided attention in a naturalistic setting, to assess the generalisation of training.

In conclusion, these results are encouraging. They are in accordance with the results obtained by Sturm and colleagues. (Sturm et al., 1997, 2002) suggesting that specific attention deficits need specific training. Further studies should try to replicate these findings in different patients/settings, and look at the cerebral correlates of training-induced changes with brain functional imaging techniques.



## REFERENCES

Asloun, S., Soury, S., Couillet, J., Giroire, J. M., Joseph, P. A., Mazaux, J. M., & Azouvi, P. (2008). Interactions between divided attention and working-memory load in patients with severe traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *30*(4), 481–490.

Azouvi, P., Couillet, J., Leclercq, M., Martin, M., Asloun, S., & Rousseaux, M. (2004). Divided attention and mental effort after severe traumatic brain injury. *Neuropsychologia*, *42,* 1260–1268.

Azouvi, P., Jokic, C., Van der Linden, M., Marlier, N., & Bussel, B. (1996). Working memory and supervisory control after severe closed head injury. A study of dual task performance and random generation. *Journal of Clinical and Experimental Neuropsychology*, *18,* 317–337.

Baddeley, A. (2002). Fractionating the Central Executive. In D. T. Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 246–260). New York: Oxford University Press.

Ben-Yishay, Y., Piasetsky, E., & Rattok, J. (1987). A systematic method for ameliorating disorders in basic attention. In M. J. Meier, L. Benton, & A. L. Diller (Eds.), *Neuropsychological Rehabilitation* (pp. 165–181). London: Churchill-Livingstone.

Brown, J. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, *10,* 12–21.

Cicerone, K., & Giacino, J. T. (1992). Remediation of executive functions deficits after traumatic brain injury. *Neurorehabilitation*, *2,* 12–22.

Duval, J., Coyette, F., & Seron, X. (2008). Rehabilitation of the central executive component of working memory: A re-organisation approach applied to a single case. *Neuropsychological Rehabilitation*, *1*(4), 430–460.

Evans, J. J., Greenfield, E., Wilson, B. A., & Bateman, A. (2009). Walking and talking therapy: Improving cognitive-motor dual-tasking in neurological illness. *Journal of the International Neuropsychological Society*, *15*(1), 112–120.

Gray, J. M., & Robertson, I. (1989). Remediation of attentional difficulties following brain injury: Three experimental single case studies. *Brain Injury*, *3*(2), 163–170.

Leclercq, M., & Azouvi, P. (2002). Attention after traumatic brain injury. In M. Leclercq & P. Zimmermann (Eds.), *Applied Neuropsychology of Attention* (pp. 251–273). Hove, UK: Psychology Press.

Leclercq, M., Couillet, J., Azouvi, P., Marlier, N., Martin, Y., Strypstein, E., & Rousseaux, M. (2000). Dual task performance after severe diffuse traumatic brain injury or vascular prefrontal damage. *Journal of Clinical and Experimental Neuropsychology*, *22,* 339–350.

Leclercq, M., & Peters, J. P. (2007). *Batterie d'Attention William Lennox* (Version 4.0). Louvain-la-Neuve: FAC diffusion.

Levin, H. S., O' Donnell, V. M., & Grossman, R. G. (1979). The Galveston Orientation and Amnesia Test. A practical scale to assess cognition after head injury. *Journal of Nervous and Mental Disease*, *167,* 675–684.

McDowell, S., Whyte, J., & D'Esposito, M. (1997). Working memory impairments in traumatic brain injury: Evidence from a dual-task paradigm. *Neuropsychologia*, *35,* 1341–1353.

Park, N. W., & Ingles, J. L. (2001). Effectiveness of attention rehabilitation after an acquired brain injury: A meta-analysis. *Neuropsychology*, *15*(2), 199–210.

Park, N. W., Moscovitch, M., & Robertson, I. H. (1999). Divided attention impairments after traumatic brain injury. *Neuropsychologia*, *37,* 1119–1133.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology*, *58,* 193–198.

Ponsford, J. (2008). Rehabilitation of attention following traumatic brain injury. In D. T. Stuss, G. Winocur, & I. H. Robertson (Eds.), *Cognitive Neurorehabilitation: Evidence and Application* (2nd ed., pp. 507–521). Cambridge: Cambridge University Press.

Ponsford, J. L., & Kinsella, G. (1988). Evaluation of a remedial programme for attentional deficits following closed-head injury. *Journal of Clinical and Experimental Neuropsychology*, *10,* 693–708.

Ponsford, J., & Kinsella, G. (1991). The use of a rating scale of attentional behaviour. *Neuropsychological Rehabilitation*, *1,* 241–257.

Ponsford, J., & Kinsella, G. (1992). Attentional deficits following severe closed head injury. *Journal of Clinical and Experimental Neuropsychology*, *14,* 822–838.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of Frontal and Executive Function* (pp. 1–38). Hove, UK: Psychology Press.

Reitan, R. M. (1958). Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills*, *8,* 271–276.

Serino, A., Ciaramelli, E., Santantonio, A. D., Malagu, S., Servadei, F., & Ladavas, E. (2007). A pilot study for rehabilitation of central executive deficits after traumatic brain injury. *Brain Injury*, *21*(1), 11–19.

Sohlberg, M. M., & Mateer, C. A. (1987). Effectiveness of an attention training program. *Journal of Clinical and Experimental Neuropsychology*, *9,* 117–130.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18,* 643–662.

Sturm, W., Fimm, B., Cantagallo, A., Cremel, N., North, P., Passadori, A., et al. (2002). Computerized training of specific attention deficits in stroke and traumatic brain-injured patients: A multicentric efficacy study. In M. Leclercq & P. Zimmermann (Eds.), *Applied Neuropsychology of Attention* (pp. 365–380). Hove, UK: Psychology Press.

Sturm, W., Willmes, K., Orgass, B., & Hartje, W. (1997). Do specific attention deficits need specific training? *Neuropsychological Rehabilitation*, *7,* 81–103.

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness: A practical scale. *Lancet*, *2,* 81–84.

Vallat-Azouvi, C., Pradat-Diehl, P., & Azouvi, P. (2009). Rehabilitation of the central executive of working memory after severe traumatic brain injury: Two single-case studies. *Brain Injury*, *23*(6), 585–594.

Vallat-Azouvi, C., Weber, T., Legrand, L., & Azouvi, P. (2007). Working memory after severe traumatic brain injury. *Journal of the International Neuropsychological Society*, *13,* 770–780.

Vallat, C., Azouvi, P., Hardisson, H., Meffert, R., Tessier, C., & Pradat-Diehl, P. (2005). Rehabilitation of verbal working memory after left hemisphere stroke. *Brain Injury*, *19*(13), 1157–1164.

Van Zomeren, A. H., & Brouwer, W. H. (1994). *Clinical Neuropsychology of Attention*. New York: Oxford University Press.

Van Zomeren, A. H., & Van den Burg, W. (1985). Residual complaints of patients two years after severe head injury. *Journal of Neurology, Neurosurgery, and Psychiatry*, *48,* 21–28.

Veltman, J. C., Brouwer, W. H., van Zomeren, A. H., & van Wolffelaar, P. C. (1996). Central executive aspects of attention in subacute severe and very severe closed head injury patients: Planning, inhibition, flexibility and divided attention. *Neuropsychology*, *10,* 357–367.

Westerberg, H., Jacobaeus, H., Hirvikoski, T., Clevberger, P., Ostensson, M. L., Bartfai, A., & Klingberg, T. (2007). Computerized working memory training after stroke – a pilot study. *Brain Injury*, *21*(1), 21–29.

Zimmermann, P., & Fimm, B. (1995). *Test for Attentional Performance (TAP).* [English version]. Herzogenrath: Psytest.

Zimmermann, P., & Fimm, B. (2002). A test battery for attentional performance. In M. Leclercq & P. Zimmermann (Eds.), *Applied Neuropsychology of Attention* (pp. 110–151). Hove, UK: Psychology Press.

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