NEUROPSYCHOLOGICAL REHABILITATION, 1999, *9* (2), 135–154

Evaluation of the Attention Process Training Programme

Norman W. Park

Kunin-Lunenfeld Clinical Research Unit and Department of Psychology, Baycrest Centre for Geriatric Care, North York, Ontario, Canada

Guy-B. Proulx, and Wanda M. Towers

Department of Psychology, Baycrest Centre for Geriatric Care, North York, Ontario, Canada

This study evaluated the effectiveness of attention process training (APT), a training programme that provides practice in a variety of tasks requiring several different types of attention. The APT programme was administered to 23 traumatically brain-injured (TBI) participants. Training lasted about 40 hours, and typically consisted of 2-hour sessions spread out over 7 months. Results show that performance of the TBI participants improved after training on the primary outcome measures, but did not improve significantly more than the performance of a control group, given the outcome measures twice, but no training. We conclude that direct training does not improve the integrity of damaged attention functions, but does result in learning of specific skills.

Impaired attention is a common consequence of traumatic brain injury (TBI). A review by Gronwall (1987) found that people with moderate to severe TBI commonly reported having problems of attention that persisted two years post-trauma. The reported attention deficits have been validated using objective tests (e.g. Gronwall, 1987; Van Zomeren, 1981; Van Zomeren, Brouwer, & Deelman, 1984).

Requests for reprints should be sent to Norman W. Park, Kunin-Lunenfeld Clinical Research Unit and Department of Psychology, Baycrest Centre of Geriatric Care, 3560 Bathurst St., Suite 4W-02, North York, Ontario, Canada, M6A 2E1.

This research was funded by a grant from the Ontario Mental Health Foundation. We thank Don Stuss for generously providing us with the data used to construct a control group, Morris Moscovitch and Ian Robertson for providing helpful suggestions during the project, Brian Conrod and Steve Mann for assembling and coding the data, and Ruby Nishioka for assisting in the preparation of the manuscript.

Several studies have investigated whether cognitive rehabilitation of attention is effective (e.g. Ben-Yishay, Piasetsky, & Rattok, 1987; Malec, Jones, Rao, & Stubbs, 1984; Niemann, Ruff, & Baser, 1990; Ponsford & Kinsella, 1988; Robertson, Gray, & McKenzie, 1988; Ruff et al., 1994; Sohlberg & Mateer, 1987; Sturm, Willmes, Orgass, & Hartje, 1997; Wood & Fussey, 1987). For the present purposes Sohlberg and Mateer (1987) carried out the most directly relevant study because their study and the current one used the Attention Process Training (APT) programme developed to treat brain-injured patients with attention deficits. Sohlberg and Mateer (1987) hypothesised that attention actually consists of several distinct cognitive capacities, each of which requires specific training. Accordingly, the training programme provides practice in five types of attention: focused, sustained, selective, alternating, and divided.

Sohlberg and Mateer (1987) administered the APT programme to four patients– two with a closed head injury, one with an open head injury, and one with an aneurysm. Patients were given training from four to eight weeks with seven to nine training sessions per week. The effectiveness of the training programme was evaluated using a multiple baseline across behaviours design (Barlow & Hersen, 1984), by measuring performance on the paced auditory serial addition task (PASAT) and on a test of spatial relations. Sohlberg and Mateer (1987) hypothesised that training would improve performance on the PASAT because that task requires attention, but would have no effect on the test of spatial relations because that task requires other cognitive functions.

The PASAT is a standard means of assessing attention performance and has been shown to be sensitive to attention deficits following head injury (Gronwall & Wrightson, 1981). It is administered by presenting auditorily a long sequence of digits, one at a time. The participant's task is to add each new number to the immediately preceding number and to say aloud the answer. Thus, if the first four digits presented were 5, 6, 3, 2 the participant should say 11, 9, and 5.

Results showed an improvement in performance on the PASAT after training compared to the scores obtained at baseline. In contrast, scores on the spatial relations test remained constant. Based on these results Sohlberg and Mateer (1987) concluded that the APT programme improved the functioning of specific cognitive processes underlying attention, but did not improve general cognitive functioning.

Other studies have also found specific rather than general effects of training. For example, building on the idea of distinct attention functions, a recent study reported that they developed specific computerised programmes to train each of four types of attention: alertness, vigilance, selective attention, and divided attention. Results showed specific training effects: Performance improved on tasks requiring the specific type of attention practised during training, but tended not to improve on other tasks not requiring that type of attention (Sturm et al., 1997).

On the basis of these findings some investigators have concluded that specific components of attention (Sturm et al., 1997) need specific training, and that with a sufficient amount of appropriate training it is possible to improve the integrity of aspects of attention and other cognitive functions (Gordon & Hibbard, 1991; Mateer, Sohlberg, & Youngman, 1990; Rothi & Horner, 1983; Sturm et al., 1997; Zangwill, 1947). The *improved cognitive function* hypothesis has important implications for rehabilitation because it would mean a treatment programme which improved a damaged function, would yield more effective performance on other tasks requiring that function (Mateer et al., 1990). That is, there should be generalisation following improvement of a damaged cognitive function.

Other investigators have questioned, however, whether the integrity of a damaged cognitive function changes as a result of rehabilitation (e.g. Luria, 1966; Ponsford, 1990; Ponsford, Sloan, & Snow, 1995; Schacter & Glisky, 1986). Instead, it may be possible through rehabilitation to alleviate cognitive problems resulting from brain damage through a process of *learning specific skills*, but not by improving the integrity of a damaged cognitive function.

According to the specific skills orientation, improvement in performance after rehabilitation training results from practice on the outcome measure or, alternatively, from learning specific skills during training that are recruited to perform other tasks after training. Put another way, improved performance is a consequence of learning a skill, not the result of improved functioning of an underlying cognitive process. To clarify the distinction between the functional improvement and specific skills perspectives, consider the study of Sohlberg and Mateer described earlier. That study showed that performance of brain-injured participants on the PASAT improved after APT training. They concluded that "changes in the performance on the PASAT can be attributed to changes in attentional processing ability and not merely alterations in task performance" (Sohlberg & Mateer, 1987, p. 128). In contrast, the specific skills hypothesis proposes that improved performance on the PASAT is the result of improvement during training of specific skills, such as the ease of adding pairs of numbers, a skill required to perform the PASAT, and not to a change in attentional processing ability.

The hypothesis that specific skills are learned as a result of training is consistent with the transfer appropriate processing hypothesis (Kolers & Roediger, 1984; Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989). According to this hypothesis performance on an outcome measure will benefit to the degree that the processing operations on the outcome measure recapitulate or overlap those engaged during prior learning.

The purpose of the present study is to evaluate whether the APT programme improves performance of TBI participants, and if so, whether the improvement in performance is general or specific. Examination of the APT programme showed that all of its exercises required sustained attention because participants always needed to apply a rule to classify a series of several stimuli for an extended period of time. In performing the APT exercises it is unnecessary, however, to remember large amounts of information either in the absence or presence of interfering activity. We therefore postulated that, if there are specific effects, training should improve sustained attention performance, but should have little effect on memory performance. We tested this hypothesis by comparing performance on the PASAT and the consonant trigrams task before and after training, hypothesising that performance on the PASAT should improve after training because this task requires sustained attention. In contrast, performance on the consonant trigrams should not improve because that task requires participants to remember verbal material in the presence of interfering activity, an activity not practised during training. In addition, it has been shown that performance on the consonant trigrams is essentially uncorrelated with measures of working memory (Dobbs & Rule, 1989).

To assess whether performance improves because of improved cognitive function or because of specific learning, we also compared performance of the TBI participants to controls who received the outcome measures two times, but were not given training. If improved performance by patients is attributable to specific practice on the outcome measure, not training, then the controls and TBI participants should improve by a similar amount.

Finally the Beck Depression Inventory (BDI), a standard measure of depression, was administered before and after training to determine whether participation in the training programme improved mood (Beck, 1987). If there was an improvement in mood, the BDI scores could be used to investigate statistically whether improvement in mood, not the training programme, was responsible for improved performance on the outcome measures.

Method

Participants

TBI participants. All 23 participants in the training group received neuropsychological assessment following traumatic brain injury. Participation in the training programme was contingent upon (1) evidence that there had been TBI, (2) a profile of test results suggestive of an attention deficit, (3) clinical judgement that the candidate might benefit from this type of training programme, (4) no outstanding medical problems, and (5) a willingness to participate in the training programme. Mean duration of post-traumatic amnesia (PTA) was 8.3 days ($SE = 3.0$), and so this sample of TBIs would be classified as having had a severe traumatic brain injury (Lezak, 1995). Training typically took place 3 to 4 years after injury ($M = 51.0$ months, $SE = 9.93$; median = 43.5

months) to eliminate spontaneous recovery effects, and to allow time to resolve outstanding medical problems. In 18 cases the training took place at least two years after injury, and in all but two cases at least one year after injury. The training group consisted of 17 women and 6 men. We are not certain why more women than men were in the training programme. We do know that more men than women were referred suggesting that women were more likely to opt for treatment.

Results of psychological tests show that overall cognitive functioning of TBI patients was slightly above average (WAIS-R verbal IQ $M = 105.0$, $SE = 2.99$; and WAIS-R performance IQ $M = 103.5$, $SE = 2.01$). Performance on Trails A and B ($M = 33.8$ seconds, $SE = 3.37$; and $M = 74.3$ seconds, $SE = 7.57$), and on the Wisconsin Card Sort in terms of number of categories ($M = 5.06$, $SE = 0.39$) and number of errors ($M = 25.9$, $SE = 4.27$) was less than 1 standard deviation below matched controls (Heaton et al., 1993; Kennedy, 1981). Performance by TBI patients on one of the outcome measures, the consonant trigrams test was about 2 standard deviations below age-matched controls (Stuss, Stethem, & Pelchat, 1988b), and on the other outcome measures, the PASAT, was less than 1 standard deviation below age-matched controls (Stuss et al., 1988b). A more detailed description of performance on the outcome measure is presented in the Results section.

Control Group. A control group was derived from data collected by Stuss et al., (1988b) who administered common clinical tests of attention including the consonant trigrams test and the PASAT to normal control subjects on two separate occasions separated by a week. The sample of control subjects was selected so that it matched the TBI group in age and education. The ages of the two groups (TBI $M = 37.3$, $SE = 2.66$; control group $M = 37.9$, $SE = 2.55$) and their years of education (TBI $M = 15.1$, $SE = 0.66$; control group $M = 14.4$, $SE = 0.60$) did not differ significantly as assessed by *t*-tests [$t(42) = 0.16$, and $t(41) = 0.82$].

Materials

The APT programme consists of a series of progressively more difficult exercises. Each exercise is designed to provide practice in at least one of the following types of attention: sustained, selective, alternating, or divided. The APT exercises have a common structure. Before each task is given, its requirements are briefly explained. Some tasks are subject-paced, and others are experimenter-paced, but in either case, exercises typically take two or three minutes to complete. The tasks do not have a heavy memory load and usually require the participant to classify stimuli. For example, one task requires a participant to press a buzzer each time he or she hears the number 3 read aloud. In another task, the participant hears the months of the year one at a time and must press a buzzer each time the month just presented is the month that immediately precedes the month presented one back.

Feedback about accuracy and speed of performance (when measured) was provided after each exercise. Other aspects of performance such as patterns of errors were also discussed. As the programme proceeded participants were educated about different types of attention, and parallels between difficulties of daily living and problems performing particular APT exercises were pointed out.

Measures

PASAT. The PASAT was used to assess attention performance because of its sensitivity in measuring attention deficits after closed-head injury and its high test–retest reliability (Gronwall, 1977; Gronwall & Wrightson, 1981). Two versions of the PASAT were used. In one version there were a total of 49 responses possible on each of 4 different lists presented at 2.4, 2.0, 1.6, and 1.2 second rates. In a second version, there were 60 possible responses to a single list presented at the same rates as the first version.

The PASAT is a complex task requiring several different cognitive skills. Two different types of attention appear to be necessary: sustained attention, needed to apply the same rule repetitively over a 2 minute time period; and a second type of attention needed to identify errors and regain "set". To gain a more detailed understanding of the PASAT, the following performance measures were used: (1) The *total number of correct responses* over the entire list is an aggregate measure of performance, and is the traditional measure of performance on the PASAT; (2) the *number of consecutively correct responses from the start of a list until the first error* is a measure of sustained attention; (3) the *average number of consecutively correct responses* is the average length of runs of consecutively correct responses over the entire list and also measures sustained attention; (4) the *mean run length of consecutively incorrect responses* over the entire list is calculated by determining the average length of runs of consecutively incorrect responses. This measure provides an estimate of how long it takes a subject to regain set after an error.

Consonant trigrams. The consonant trigrams or Brown–Peterson task assesses memory performance under conditions of distraction. This task is a sensitive measure of cognitive impairments suffered after a head injury (Stuss et al., 1985). In this task participants hear three consonants, then a number, and are instructed to count backwards by threes for 3, 9, or 18 seconds. When signalled to stop, the participant attempts to recall the three consonants. The version of the Brown–Peterson task used in this study is similar to the one developed by Edith Kaplan, and it consists of a total of 20 trials (Lezak, 1995). On the first five trials, participants are presented three consonants and then are asked to recall the consonants immediately. In the remaining 15 trials, participants are presented five trials at each delay (3, 9, or 18 seconds). The list is constructed so that each successive set of three trials has one trial at each delay.

Beck Depression Inventory (BDI). The BDI is a widely used 21-item scale used to determine the presence and intensity of depression. The scale has been shown to have reasonable concurrent validity (Spreen & Strauss, 1991) and test–retest reliability (Kazniak & Allender, 1985).

Procedure

The APT training programme was designed to last for 40 hours, and although there was some variability in its actual duration, the median number of hours of training was 40 ($M = 35.5$, $SE = 1.84$). The scheduling and duration of training was flexible, but a common pattern was 20 sessions ($M = 20.6$, $SE = 1.62$), each session lasting about two hours ($M = 1.8$, $SE = 0.10$). Prior to training and at its completion the PASAT, consonant trigrams, and BDI were administered to TBI participants. Mean duration of training and means duration between successive administrations of the outcome measures was 7.2 months ($SE = 0.88$).

The primary training consisted of the APT programme. The APT exercises were graduated in difficulty. Upon completion of each exercise the trainer, a psychologist, reviewed the performance of the participant, discussed errors, and pointed out the relation between difficulties performing the training exercises and attentional problems encountered in daily living. Exercises in which a participant made three or more errors were repeated with the goal of improving performance until the participant made no more than two errors.

In addition to the APT training, adjunct counselling was given to address salient clinical issues. These problems varied from patient to patient, but included issues such as stress, pain management, and ways of restructuring activities at home or at work to reduce attention requirements.

RESULTS

Beck Depression Inventory (BDI)

Scores on the BDI of TBI participants were consistent with a mild to moderate depression with somewhat elevated subscores on both the first 13 and last 8 items ($M = 9.6$ and 7.1, respectively). There was, however, no statistically significant change in BDI scores [$t(15) = 1.19$, n.s.) when the scores after the programme ($M = 15.9$, $SE = 1.98$) were compared to the scores prior to the programme ($M = 17.6$, $SE = 2.46$).

PASAT

As previously noted, two different versions of the PASAT were used with the TBI group in this study. We will report results of our analyses of the PASAT only from TBI participants who were given lists of the same length, either 49 responses ($n = 4$) or 60 responses ($n = 12$), before and after training. TBI participants, who received lists of different lengths before and after training, were not included because of the difficulty of interpreting the results. Before performing these analyses, we determined whether the composition of the TBI sample changed by comparing the sample of TBI given PASATs of equal length pre- and post-training to the control group. Results showed that the age and education of the reduced TBI sample was almost unchanged (mean age = 36.1, $SE = 3.02$; mean years of education = 14.9, $SE = 3.11$) and was not statistically different from the control group. For this reason we made no changes to the composition of the control group.

Table 1 presents the total number of correct responses made on the PASAT before and after training for the TBI and control groups. The scores on the 49-item PASAT lists were multiplied by 60/49 to make them comparable to the 60 item PASAT scores. We analysed this aggregate measure of performance for the TBI group data using a repeated measures ANOVA with list type entered as a between subjects factor. The primary finding was that performance was significantly higher after training than before [$F(1,10) = 13.96$, $P < .01$]. The analysis also showed that performance declined at faster rates of presenta-

TABLE 1
Mean Total Number of Correct Responses on PASAT for the TBI and Control Groups on Test 1 and Test 2

	Rate (seconds)			
Condition	*2.4 (SE)*	*2.0 (SE)*	*1.6 (SE)*	*1.2 (SE)*
TBI group[a]				
Pre	41.5	35.8	29.7	21.8
	(2.94)	(2.11)	(2.77)	(2.23)
Post	49.9	44.7	37.8	29.3
	(2.62)	(2.93)	(2.44)	(2.57)
Control group				
Test 1	45.0	41.0	34.8	25.7
	(2.45)	(2.56)	(2.67)	(2.52)
Test 2	52.8	49.6	44.9	36.4
	(2.10)	(2.35)	(2.57)	(2.72)

[a]The scores of the 49-item PASAT lists were multiplied by 60/49 to make them comparable to the 60-item lists.

tion [$F(3,30) = 6.72$, $P < .001$] and that rate interacted significantly with test order [$F(3,30) = 3.39$, $P < .05$]. No other factors were statistically significant.

A similar pattern of results was found for the control group. Performance improved significantly on test 2 versus test 1 [$F(1,21) = 17.72$, $P < .001$], performance declined at faster rates of presentation [$F(3,63) = 12.77$, $P < .001$], and rate interacted significantly with test order [$F(3,63) = 3.04$, $P < .05$].

A further analysis compared performance on test 2 versus test 1 at each different rate of presentation using Bonferroni t-tests. As one might expect from inspection of Table 1, both groups improved significantly on test 2 versus test 1 at all four rates.

Number of consecutively correct responses from start of trial. The mean run length of consecutively correct responses from the start of the trial until first error, a measure of sustained attention, was determined. Performance on this measure increased substantially after training for the TBI group. The means on this measure of performance prior to training (standard errors are in brackets) were 8.3 (2.42), 3.9 (0.62), 4.3 (1.24), and 2.6 (0.46) at the 2.4, 2.0, 1.6, and 1.2 second rates of presentation, respectively. The corresponding figures after training are 15.8 (4.96), 8.4 (1.70), 5.2 (1.29), and 3.6 (0.72). A repeated measures analysis of variance design of the TBI group data with list type entered as a between subjects factor, showed performance was significantly higher after training [$F(1,10) = 13.96$, $P < .01$], performance declined at faster rates of presentation [$F(3,30) = 6.72$, $P < .001$], and that these two factors interacted significantly [$F(3,30) = 3.39$, $P < .05$].

The control group data showed a similar pattern of performance. Mean number of consecutively correct responses from the start of the trial test on test 1 (standard errors are in brackets) were 12.2 (2.18), 12.3 (2.16), 7.5 (1.37), and 5.0 (1.00) at the 2.4, 2.0, 1.6, and 1.2 second rates of presentation. Corresponding figures for test 2 were 28.1 (4.83), 20.3 (3.93), 17.0 (3.84), and 10.1 (1.90). Results of an ANOVA showed significant effects of test order [$F(1,21) = 17.72$, $P < .001$], rate [$F(3,63) = 12.77$, $P < .001$], and rate by test order [$F(3,63) = 3.04$, $P < .05$].

The next analysis determined whether the improved performance of the TBI group after training depended upon the specific rate of presentation. Although the pattern of findings suggest that there was an improvement, particularly at the slower rates, the differences were not statistically significant using Bonferroni t-tests. Results from the control group were more robust, probably because of their larger sample size. Using Bonferroni t-tests, we found significantly higher performance on test 2 versus test 1 at all rates: 2.4 second rate [$t(21) = 3.43$, $P < .01$]; 2.0 second rate [$t(21) = 2.80$, $P < .05$]; 1.6 second rate [$t(21) = 3.07$, $P < .05$]; 1.2 second rate [$t(21) = 3.32$, $P < .05$].

Mean run length of consecutively correct responses over entire list. A second measure of sustained attention is the mean run length of consecutively correct responses over the entire PASAT list. Performance on this measure improved after training for the TBI group on both versions of the PASAT. Mean performance prior to training (standard errors in brackets) for the TBI group receiving 60 item lists prior to training was 2.7 (0.53), 2.3 (0.30), 1.9 (0.39), and 1.2 (0.58) from the slowest to the fastest rate of presentation. After training mean performance increased to 7.2 (2.10), 4.0 (1.14), 2.7 (0.49), and 1.64 (0.21) at the corresponding rates of presentation. Results of a repeated measures ANOVA with list type as a between subjects factor, showed significantly higher performance after training than before [$F(1,10) = 14.12$, $P < .01$], a decrease in the mean run length of consecutively correct responses at faster rates of presentation [$F(3,30) = 22.79$, $P < .001$], and a significant interaction between these two factors [$F(3,30) = 7.17$, $P < .001$]. In addition, there was a significant interaction between length of the list studied and rate [$F(3,30) = 3.13$, $P < .05$].

Control group performance also increased from test 1 to test 2. On test 1 mean performance (standard errors in brackets) was 5.8 (0.96), 4.2 (0.51), 3.2 (0.4), and 2.3 (0.20) from the slowest to fastest rate of presentation. The corresponding results on test 2 were 11.7 (1.48), 9.2 (1.35), 7.0 (1.28), and 4.0 (0.58). Results of an ANOVA showed that the mean run length of consecutively correct responses was significantly higher on test 2 than on test 1 [$F(1,19) = 29.70$, $P < .001$], run lengths were shorter at faster rates of presentation [$F(3,57) = 27.48$, $P < .001$], and that there was a significant interaction between these two factors [$F(3,57) = 6.93$, $P < .001$].

Bonferroni *t*-tests were performed to determine whether the pattern of improved performance varied with rate of presentation. For the TBI group, performance improved significantly at all but the fastest rate of presentation: 2.4 second rate $t(11) = 3.33$, $P < .05$; 2.0 second rate $t(11) = 3.24$, $P < .05$; and 1.6 second rate $t(11) = 3.30$, $P < .05$. The improvement in performance on test 2 versus test 1 for the control sample was significant at all rates of presentation: 2.4 second rate $t(19) = 4.83$, $P < .01$; 2.0 second rate $t(19) = 4.87$, $P < .01$; 1.6 second rate $t(19) = 3.99$, $P < .01$; and 1.2 second rate $t(19) = 3.84$, $P < .01$.

Mean run length of consecutively incorrect responses. The TBI group improved in its ability to regain "set" after making an error after training as measured by the mean run length of consecutively incorrect responses over the entire list for both versions of the PASAT. That is, the mean run length of consecutively incorrect responses decreased with training. Mean performance (standard errors in brackets) of the TBI group presented PASAT lists of 60 items prior to training was 1.7 (0.16), 1.6 (0.10), 2.1 (0.19), and 3.1 (0.34) consecutively incorrect responses at 2.4, 2.0, 1.6, and 1.2 second rates of presentation. The corresponding results after training were 1.6 (0.17), 1.6 (0.13), 1.8

(0.16), and 2.3 (0.13). Results of a repeated measures analysis of variance with list type as a between subjects factor showed that performance improved significantly after training [$F(1,7) = 8.31$, $P < .05$], and that the mean run length of consecutively incorrect responses increased significantly at faster rates of presentation [$F(3,21) = 15.90$, $P < .001$].

Performance of the control group also improved from test 1 to test 2. Mean performance on test 1 (standard errors are in brackets) was 1.6 (0.12), 1.9 (0.14), 2.1 (0.23), and 2.8 (0.28) from the slowest to fastest rates of presentation, and 1.3 (0.09), 1.5 (0.18), 1.8 (0.20), and 2.3 (0.20) on test 2. Results of an ANOVA performed on the control group data showed significant improvement in performance on test 2 versus test 1 [$F(1,14) = 7.71$, $P < .05$] and a significant increase in the mean number of consecutively incorrect responses at faster rates of presentation [$F(3,42) = 24.42$, $P < .001$].

Consonant trigrams

Table 2 presents performance by the TBI group on the consonant trigrams test before and after training at delays of 3, 9, and 18 seconds and shows that performance declines at longer delays. We analysed these data using an ANOVA in which the three factors were delay (3, 9, or 18 seconds), test type (pre or post), and study position (1, 2, 3, 4, or 5). Study position 1 designates the first three consonant trigrams studied, study position 2 designates the second three consonant trigrams studied, and so on. Each study position consists of three consonant trigrams, one tested at each delay.

Analysis of these data revealed that performance declined with increases in delay [$F(2,26) = 36.35$, $P < .001$], and study position [$F(4,52) = 6.61$, $P < .001$]. In terms of the central question of the study, performance was higher after training than before [$F(1,13) = 14.87$, $P < .01$]. Mean performance by study position (standard errors are in brackets) prior to training was 5.3 (0.50), 5.6 (0.54), 4.3 (0.32), 4.4 (0.51), and 4.9 (0.50) for study positions 1 through 5,

TABLE 2
Mean Consonant Trigram Scores for TBI Group, Pre and Post training by Delay

	Test Type	
Delay	*Pre (SE)*	*Post (SE)*
3	11.4 (0.32)	13.1 (0.34)
9	7.7 (0.88)	9.5 (0.77)
18	5.4 (0.93)	6.8 (0.84)

respectively. After training the corresponding figures were 7.1 (0.40), 6.4 (0.47), 5.4 (0.31), 4.7 (0.54), and 5.8 (0.50). Multiple comparisons using Bonferroni t-tests found that, in spite of some variability in the data, performance improved significantly only at a 3-second delay [$t(13) = 6.85$, $P < .05$], and only at study position 1 [$t(13) = 4.00$, $P < .05$].

Table 3 shows performance on consonant trigrams by control participants. Results are presented at 9 and 18 second delays but not at a 3 second delay because that delay was not tested in the control group. In common with the TBI data, performance declined significantly with delay [$F(1,21) = 4.56$, $P < .05$]. However, in contrast to the data from the TBI group, performance did not change significantly from test 1 to test 2 [$F(1,21) = 2.11$, n.s.], and there was no evidence of a decline in performance by study position [$F(4,84) = 0.73$, n.s.].

Intrusions, or incorrect responses on the consonant trigrams task, were analysed according to whether or not the intruded response had been experienced previously (either as a stimulus or a response), and if experienced, how recently. Intrusions from the immediately preceding trial were classified as lag 0 intrusions, those from one trial back were lag 1 intrusions, and so on. Analysis of intrusions made by the TBI group showed no statistically significant change in intrusion rate pre- and post-training [$F(1,13) = 2.98$, n.s.]. Averaged across administrations, single letter intrusions occurred most frequently at lag 0 ($M = 5.46$, $SE = 0.60$), and dropped sharply for all other lags– lag 1 ($M = 1.29$, $SE = 0.32$), lag 2 ($M = 0.61$, $SE = 0.14$] and lag > 2 ($M = 0.96$, $SE = 0.25$). Intrusions of non-experienced items were uncommon and averaged 0.29 ($SE = 0.11$) across lists.

The control group made about half as many intrusions as the TBI group (control $M = 7.91$, $SE = 1.57$; TBI $M = 16.14$, $SE = 2.0$), a statistically significant difference [$t(34) = 3.25$, $P < .01$. As with the TBI data, intrusions for the control group occurred most frequently at lag 0, ($M = 2.82$, $SE = 0.56$] and dropped off sharply for the other lags (lag 1, $M = 0.59$, $SE = 0.19$; lag 2, $M = 0.41$, $SE = 0.13$; and lags > 2, $M = 0.27$, $SE = 0.10$). Intrusions of non-presented items were uncommon ($M = 0.09$, $SE = 0.06$).

TABLE 3
Mean Consonant Trigram Scores for Control Group on Test 1 and Test 2 by Delay

	Test Type	
Delay	*Test 1 (SE)*	*Test 2 (SE)*
9	12.1 (0.59)	12.6 (0.57)
18	10.9 (0.68)	11.7 (0.72)

The finding that the control group made about half as many intrusions as the TBI group was investigated further to determine whether the greater intrusion rate could be attributed solely to the overall lower performance by the TBI group. Regression analyses in which the criterion variable was the number of intrusions showed a significant negative relation between the total number of intrusions and the total number of correct responses [$r^2 = .34$, $F(1,34) = 47.06$, $P < .001$] and between the total number of intrusions and group membership [$r^2 = .24$, $F(1,34) = 10.58$, $P < .01$]. Results showed that group membership did not contribute significantly to the cumulative R^2 (incremental $r^2 = .01$) after the total number of correct responses had been entered into the equation. Thus, although the data are correlational, the lower level of overall performance by the TBI group may be responsible for their higher intrusion rate.

Outcome scores and relation to other measures. This section analyses the relation between the two primary outcome measures, their relation to other measures, and patterns of performance on these two measures at the individual patient level. The two outcome measures investigated were performance on the consonant trigrams and the total number of correct responses at the 2.4 second rate of presentation for the PASAT. This rate was selected because of missing data at faster rates of presentation.

We began by investigating the relation between the PASAT and the consonant trigrams to determine whether, as hypothesised, the two tests measure different cognitive functions. We computed separate correlation coefficients between scores on the PASAT and the consonant trigrams before and after training. Results showed that PASAT and consonant trigram performance were not significantly correlated with each other, although pre- and post-training performance on the PASAT ($r = .67$, $P < .01$) and consonant trigrams ($r = .65$, $P < .05$) were significantly related. We also examined whether a common factor underlies the improvement in performance on the PASAT and consonant trigrams by correlating the change in performance (post-training score–pre-training score) on the PASAT to the change in performance on the consonant trigrams, and found no statistically significant relation between these two variables.

The next analysis investigated the degree to which the outcome scores change from pre- to post-training for the TBI group. Our primary purpose in performing this analysis was to investigate whether the training programme had different effects on different TBI participants. On the PASAT score performance improved in 18 cases and deteriorated in 4. In 7 cases the degree of improvement was more than 1 standard deviation of the pre-training scores. To determine whether this pattern of improvement differed from the control group we examined the distribution of scores by classifying the TBI and control scores into three categories: scores that either deteriorated or improved by less than 0.25 to 1 standard deviation; and scores that improved by more than 1 standard deviation. The results of this classification, analysed using a chi-square test showed that the distribution of scores between the two groups did not differ significantly. A similar analysis performed on the consonant trigram scores showed a tendency on the part of TBIs to improve to a greater degree than controls on test 2, but a chi-square test was non-significant.

Next we analysed the TBI data and calculated the correlation between these two outcome measures and a series of assessment test results (WAIS performance and verbal IQ, WAIS digit symbol, Trails A and B, and errors and categories in the Wisconsin card sort), demographic variables (age and education), injury-related variables (elapsed timed between injury and start of training, and mean duration of PTA), and the score of the outcome variable prior to training. The only two variables correlating significantly with the score on the PASAT after training were Trails B ($r = -0.63$, $P = .004$) and the PASAT scores prior to training ($r = 0.67$, $P = .001$). Next, we performed a stepwise regression analysis in which the PASAT score after training was the criterion measure, and the assessment measures, demographic variables, and other measures just described were the predictor variables. Results of this analysis showed that only the PASAT score prior to training was entered into the regression analysis with the level to enter variables set at .05. This finding shows that partial correlations between the post-training PASAT measure and all other variables controlling for the pre-training PASAT score were statistically non-significant.

A similar set of analyses showed that the only two measures correlating significantly with the consonant trigrams score after training were age ($r = -.54$, $P = .04$) and the consonant trigram score prior to training ($r = .65$, $P = .01$). A stepwise regression analysis showed that, with the level to enter new variables set at .05, the only variable entered into the equation was performance on the consonant trigram measure administered prior to training. Thus, no other variables were significantly correlated to the after-training consonant trigram score controlling for the score obtained on the consonant trigram score prior to training.

In summary, this section investigated performance on the outcome scores. Results showed that performance on the PASAT and consonant trigrams were not significantly correlated. This finding suggests that these two tests measure the performance of different cognitive functions, a conclusion also suggested by other work (Dobbs & Rule, 1989). We also found that although there was considerable variation in the degree of improvement on both the PASAT and consonant trigrams after training, the distribution of scores did not differ between TBIs and controls. Further analysis of the post-training scores failed to identify factors significantly related to the criterion measure once the pre-training score had been entered into the equation.

SUMMARY AND DISCUSSION

This study evaluated whether the APT training programme improved the performance of TBI participants. The effectiveness of the APT programme was assessed using PASAT and consonant trigrams as outcome measures with the BDI administered to assess the impact of the APT programme on mood. Table 4 summarises the primary findings from this study.

The BDI results show that the TBI participants in this study were moderately depressed before and after training. Other investigators have also found that depression is a common and persistent problem following head injury (e.g. Brooks et al., 1986). More relevant to the central question of the study, however, is the finding of no significant change in BDI scores. Thus, in terms of this measure, there is no support for the idea that APT improved the mood of TBI participants, or that mood changes were responsible for their improved performance after training.

On the consonant trigrams task, performance by the TBI group improved after training with the improved performance statistically significant at the shortest delay and study position 1 only. In contrast the control group showed no change in performance from test 1 to test 2. We had hypothesised that the training programme would not improve consonant trigram performance because the training exercises do not require the storage and retrieval of large amounts of information under conditions of interference.

The difference in the pattern of performance on the consonant trigrams between controls and TBIs from test 1 to test 2 suggests that some aspects of the training programme, not practice on the consonant trigram task itself, affected performance of TBIs. One possibility is that TBI participants learned to perform the consonant trigram task more effectively, at least at short delays, as a result of practice on the alternating attention exercises during training. In these exercises participants alternate between performing two tasks just as in the consonant trigrams task. Before beginning an alternating attention exercise the two tasks are briefly described. When the exercise begins the participant is instructed to switch back and forth between the two tasks when signalled to do so.

TABLE 4
Pre and Post Performance of TBI and Control Groups on Different Tasks

Task	*TBI*	*Controls*
Beck Depression Inventory	No change	Not administered
Consonant trigrams	Improved[a]	No change
Total number of correct responses on PASAT	Improved	Improved
Number of correct responses to first error on PASAT	Improved	Improved
Mean length of consecutively correct responses on PASAT	Improved	Improved
Mean length of consecutively incorrect responses on PASAT	Improved	Improved

[a]Limited to study position 1 and 3-second delay.

Perhaps as a result of performing these exercises TBI participants learn a strategy such as covertly rehearsing the requirements of one task while carrying out the other, and this strategy is useful at least during short delays in the consonant trigrams task.

Another notable finding is that performance on the consonant trigrams declined by study position for the TBIs, but not for the controls. We interpret this to mean that TBIs are more susceptible to interference effects than normal controls. Finally, TBIs were impaired in their performance before and after training relative to the control group, and in comparison to published norms of performance by normal controls in the same age group (Stuss, Stethem, & Pelchat, 1988a).

As shown in Table 4 performance on the PASAT by the TBI group was considerably higher after training than before regardless of the measure used to assess performance. This improvement in performance on the PASAT might lead one to conclude that the training programme was effective, and that the results support the improved cognitive function hypothesis outlined in the Introduction. According to that hypothesis, performance should have improved on the PASAT, but not on the consonant trigrams task because the APT programme was hypothesised to provide practice on cognitive functions underlying the PASAT, but not on functions underlying the consonant trigrams task.

The finding that the control group showed precisely the same pattern of performance on PASAT as the TBI group suggests, however, that the pattern of performance observed in the TBI group may be a consequence of specific practice on the PASAT, not the training programme. This conclusion is contrary to the one drawn by Sohlberg and Mateer (1987). However, there are some reasons to question their interpretation. First, in their study, which used a multiple baseline design across behaviours, performance on the PASAT was not stable, but actually improved prior to training during a very brief baseline period of between two and four observations. Second, performance on the PASAT also improved while one subject received visual processing training, a task which did not provide practice on attention, and hence should not have improved performance on the PASAT according to their hypothesis. Finally, studies have reported that performance on the PASAT improves over several administrations, even without training (Stuss, Stethem, Hugenholz, & Richard, 1989).

In addition to practice on the test it is quite possible that performing training exercises resembling the PASAT could be important in determining performance on the outcome measure after training. In the present study and in the Sohlberg and Mateer study, which employed the same training materials, many of the training exercises involve the perception of numbers and their manipulation (e.g. addition, subtraction, and judgement of order) raising the possibility that the improved performance on the PASAT after training is partly attributable to practice on the test itself, and partly to practice on tasks similar to the PASAT during training.

We investigated this possibility further by reviewing other published studies that have reported positive effects of cognitive rehabilitation on treatment. We wanted to determine whether the beneficial effects of the training programme were specific and whether these effects could be attributed plausibly to transfer appropriate training rather than to improved cognitive function. A randomised group attentional retraining study (Gray, Robertson, Pentland, & Anderson, 1992), reported greater improvement in performance on the arithmetic sub-test of the WAIS-R and the PASAT at six-month follow-up for the treatment versus a control group of people with acquired brain damage. Based on this result the authors concluded that the treatment improved attentional function. However, as they pointed out, some of the training material involved the storage and manipulation of numerical information, and one task required mental arithmetic under time pressure. Thus, it is possible that participants in the treatment group became more skilled in mental arithmetic, and this improved skill, not improved attention, aided performance on the arithmetic sub-tests of the WAIS-R and on the PASAT. This hypothesis gains plausibility because none of the other measures of attention improved significantly after training, including measures of working memory (forward and backward digit span), other tests of attention (letter cancellation, picture completion, and time estimation), and tests of frontal function. A similar interpretation can be given to a series of case studies (Gray & Robertson, 1989).

The study by Niemann and his colleagues can be interpreted similarly (Niemann et al., 1990). In this study one group received attention training first while a second group received memory training first. It was postulated that the group receiving attention training first would improve significantly on tests of attention but not on tests of memory when tested immediately after attention training while the group receiving memory training first would show the opposite pattern of results when tested immediately after memory training. Focusing only on the attention tests, results showed that performance improved significantly on Trails B for both groups, but improved to a greater degree for the attention group. There was no improvement on the other three measures of attention. The finding that performance on this measure improved significantly for both groups suggests that at least part of the improvement in Trails B may be attributable to practice on the test itself. The greater improvement of the attention group relative to the memory group may be a consequence of the similarity between some of the attention training exercises and the Trails B test. One series of training exercises required participants to alternative attention between different stimulus dimensions. We were unable to evaluate other studies (Ruff et al., 1994; Sturm et al., 1997) because the training tasks were not described in enough detail to determine the similarity between the training exercises and the outcome measures.

An alternative interpretation of the present study is that the failure to find a positive effect of training is attributable to a limitation of the design of the study or of the training procedure. Perhaps there was an insufficient amount of training, there were too few TBI participants, or the composition of the sample was unusual. Alternatively, it may be that the training exercises or feedback were not helpful. Other important limitations of the current study include the use of normals as controls and the substantial difference in the elapsed time between successive administrations of the PASAT and the consonant trigrams between the two groups. Although all of these possibilities cannot be decisively ruled out, the 40 hours spent on training and the 23 TBI patients participating in this study are comparable to other published studies that have reported positive effects of training. Thus, the study by Gray and colleagues (1992) provided 17.5 hours of training to 14 patients, the study by Niemann et al. (1990) provided 36 hours of training to 29 patients, the study by Ruff et al. (1994) provided up to 20 hours (maximum) of training to 15 patients, and Sturm and his colleagues (1997) provided 28 hours of four different types of training to four groups ranging in number from 8 to 12 patients. In addition, although the length of time between successive tests of the outcome measures is longer for patients than controls, patients spent a considerable amount of time while in training performing exercises that resembled the PASAT in that they involved manipulating and remembering numbers.

The functional improvement and specific skills hypotheses differ in their views about generalisation. According to the specific skills hypothesis learning will be specific and will not tend to generalise. In contrast, the functional improvement hypothesis proposes that cognitive functions are improved during training, and therefore that there should be generalisation, provided the training is appropriate and the tasks used to measure generalisation require the cognitive function improved during training.

It is important for future cognitive rehabilitation studies to investigate explicitly the relation between training tasks and outcome measures, and the degree to which training generalises across tasks, situations, and time. The relation between training tasks and outcome measures is often not reported in rehabilitation studies, and the question of generalisation has received little attention (Robertson, 1990) making it difficult to be certain whether a specific skills or a functional improvement hypothesis is more plausible. In addition, if future studies paid more attention to these issues, it would help investigators assess the clinical usefulness of the rehabilitation intervention being reported.

REFERENCES

Barlow, D.H., & Hersen, M. (1984). *Single case experimental designs: Strategies for studying behaviour change*. Oxford: Pergamon Press.

Beck, A.T. (1987). *Beck Depression Inventory.* San Antonio, TX: The Psychological Corporation.

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

Brooks, D.N., Campsie, L., Symington, C., Beattie, A., & McKinlay, W. (1986). The five-year outcome of severe blunt head injury: A relative's view. *Journal of Neurology, Neurosurgery, and Psychiatry, 49,* 764–770.

Dobbs, A.R., & Rule, B.G. (1989). Adult age differences in working memory. *Psychology and Aging, 4,* 500–503.

Gordon, W.A., & Hibbard, M.R. (1991). The theory and practice of cognitive remediation. In J.S. Kreutzer & P.H. Wehman (Eds.), *Cognitive rehabilitation for persons with traumatic brain injury: A functional approach* (pp. 13–22). Baltimore: Paul H. Brookes Publishing Co.

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

Gray, J.M., Robertson, I., Pentland, B., & Anderson, S. (1992). Microcomputer-based attentional retraining after brain damage: A randomised group controlled trial. *Neuropsychological Rehabilitation, 2,* 97–115.

Gronwall, D. (1977). Paced auditory serial addition task: A measure of recovery from concussion. *Perceptual and Motor Skills, 44,* 367–373.

Gronwall, D. (1987). Advances in the assessment of attention and information processing after head injury. In H.S. Levin, J. Grafman, & M. Eisenberg (Eds.), *Neurobehavioural recovery from head injury* (pp. 355–371). New York: Oxford University Press.

Gronwall, D., & Wrightson, P. (1981). Memory and information processing capacity after closed head injury. *Journal of Neurology, Neurosurgery and Psychiatry, 44,* 889–895.

Heaton, R.K., Chelune, G.J., Talley, J.L., Kay, G.G., & Curtiss, G. (1993). *Wisconsin Card Sorting Test manual.* Odess, FL: Psychological Assessment Resources.

Kazniak, A.W., & Allender, J. (1985). Psychological assessment of depression in older adults. in G.M. Chaisson-Stewart (Ed.), *Depression in the elderly: An interdisciplinary approach.* New York: Wiley.

Kennedy, K.J. (1981). Age effects on trail making test performance. *Perceptual and Motor Skills, 52,* 671–675.

Kolers, P.A., & Roediger, H.L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behaviour, 23,* 425–449.

Lezak, M.D. (1995). *Neuropsychological assessment.* (3rd edn.). New York: Oxford.

Luria, A.R. (1996). *Human brain and psychological processes* (Haigh, B., Trans.). New York: Harper and Row.

Malec, J., Jones, R., Rao, N., & Stubbs, K. (1984). Video game practice effects on sustained attention in patients with craniocerebral trauma. *Cognitive Rehabilitation, 2,* 18–23.

Mateer, C.A., Sohlberg, M.M., & Youngman, P.K. (1990). The management of acquired attention and memory deficits. In R.L. Wood & I. Fussey (Eds.), Brain damage behaviour and cognition: *Developments in clinical neuropsychology* (pp. 68–95). London: Taylor & Francis.

Morris, C.D., Bransford, J.D., & Franks, J.J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behaviour, 16,* 519–533.

Niemann, H., Ruff, R.M., & Baser, C.A. (1990). Computer-assisted attention retraining in head-injured individuals: A controlled efficacy study of an outpatient program. *Journal of Consulting and Clinical Psychology, 58,* 811–817.

Ponsford, J. (1990). The use of computers in the rehabilitation of attention disorders. In R.L. Wood & I. Fussey (Eds.), *Cognitive rehabilitation in perspective* (pp. 48–67). New York: Taylor and Francis.

Ponsford, J. & Kinsella, G. (1998). Evaluation of a remedial programme for attentional deficits following closed head injury. *Journal of Clinical and Experimental Neuropsychology, 10,* 693–708.

Ponsford, J.L., Sloan, S., & Snow, P (1995). *Traumatic brain injury: Rehabilitation for everyday adaptive living*. Hove, UK: Lawrence Erlbaum Associates Ltd.
Robertson, I. (1990). Does computerized cognitive rehabilitation work? A review. *Aphasiology, 4,* 381–405.
Robertson, I., Gray, J., & McKenzie, S. (1988). Micro-computer-based cognitive rehabilitation of visual neglect: Three multiple baseline single-case studies. *Brain Injury, 2,* 151–163.
Roediger, H.L., Weldon, M.S., & Challis, B.H. (1989). Explaining dissociations between implicit and explicit measures of attention: A processing account. In H.L. Roediger & F.I.M. Craik (Eds.), *Varieties of memory and consciousness: Essays in honor of Endel Tulving* (pp. 3–41). Hillsdale, NJ: Erlbaum.
Rothi, L.J., & Horner, J. (1983). Restitution and substitution: Two theories of recovery with applicatio to neurobehavioral treatment. *Journal of Clinical Neuropsychology, 5,* 73–81.
Ruff, R., Mahaffey, R., Engel, J., Farrow, C., Cox, D., & Karzmark, P. (1994). Efficacy study of THINKable in the attention and memory retraining of traumatically head-injured patients. *Brain Injury, 8,* 6–14.
Schacter, D.L. & Glisky, E.L. (1986). Memory remediation, restoration, alleviation, and the acquisition of domain-specific knowledge. In B. Uzzell & M. Gross (Eds.), *Clinical neuropsychology of intervention* (pp. 257–282). New York: Martinus Nijhoff.
Sohlberg, M.M., & Mateer, C.A. (1987). Effectiveness of an attention training program. *Journal of Clinical and Experimental Neuropsychology, 9,* 117–130.
Spreen, O., & Strauss, E. (1991). *A compendium of neuropsychological tests.* (3rd edn.). New York: Oxford University Press.
Sturm, W., Willmes, K., Orgass, B., & Hartje, W, (1977). Do specific attention deficits need specific training? *Neuropsychological Rehabilitation, 7,* 81–103.
Stuss, D.T., Ely, P., Hugenhotz, H., Richard, M.T., LaRochelle, S., Poirer, C.A., & Bell, I. (1985). Subtle neuropsychological deficits in patients with good recovery after closed head injury. *Neurosurgery, 17,* 41–47.
Stuss, D.T., Stethem, L.L., Hugenholz, H., & Richard, M.T. (1989). Traumatic brain injury: A comparison of three clinical tests, and analysis of recovery. *The Clinical Neuropsychologist, 3,* 145–156,
Stuss, D.T., Stethem, L.L., & Pelchat, G. (1988a). Three tests of attention and rapid information processing: An extension. *The Clinical Neuropsychologist, 2*, 246–250.
Van Zomeren, A.H. (1981). *Reaction time and attention after closed head injury.* Lisse: Swets Publishing Services.
Van Zomeren, A.H., Brouwer, W.H., & Deelman, B.G. (1984). Attentional deficits: The riddles of selectivity, speed, and alertness. In N. Brooks (Ed.), *Closed head injury: Psychological, social, and family consequences* (pp. 74–107). New York: Oxford University Press.
Wood, R.L.I. & Fussey, I. (1987). Computer-based cognitive retraining: a controlled study. *International Disability Studies, 9,* 149–153.
Zangwill, O.L. (1947). Psychological aspects of rehabilitation in cases of brain injury. *British Journal of Psychology, 37,* 60–69.

Manuscript received September 1997
Revised manuscript received September 1998