The Specificity of Attention Retraining in Traumatic Brain Injury

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Attentional deficits are a very common complaint following traumatic brain injury (TBI). Concentration problems, together with poor memory, are reported to be among the most common post-concussive cognitive complaints (Binder, 1986). It has been suggested that many apparent failures of memory are due to attention dysfunction and that this problem contributes substantially to difficulty with reintegration into independent living and vocational settings (Sohlberg & Mateer, 1989). Brooks and McKinlay (1987) reported that attentional impairment predicts return to work after head injury.

There has been considerable clinical and research interest in the potential for improving attention skills. Attention interventions typically involve administration of a series of cognitive exercises that place increasingly greater demands on the attention system. Research in this area has produced somewhat mixed results. While many studies have provided support for the efficacy of attention training (Sohlberg & Mateer, 1987; Neumann, Ruff & Baser, 1990; Gray & Robertson, 1989; Gray, Robertson, Pentland & Anderson, 1992; Sturm, Willmes, Orgass & Hartje, 1997; Ciccone et al., 2000; Sohlberg, McLaughlin, Pavese, Heidrich & Posner, 2000; Palmese & Raskin, 2000), other authors have found more equivocal results (Gauggel & Neumann, 1996; Park, Proulx & Towers, 1999; Malec, Jones, Rao & Stubbs, 1984; Gansler & McCaffrey, 1991; Ponsford & Kinsella, 1988).

Park and Ingles (2001) conducted a meta-analysis of 30 studies that evaluated the efficacy of attention interventions. They concluded that retraining attention only produces a small, non-statistically significant improvement on outcome measures. However, their study sample included studies evaluating interventions for individuals with stroke and surgical lesions in addition to traumatic brain injury. Differential response for these groups to rehabilitative interventions may have impacted their results. The patients represented in their meta-analysis had primarily severe injuries so their findings cannot be generalized to individuals with injuries of mild to moderate severity. The nature and duration of the interventions evaluated were highly variable. Outcome measures were also highly variable and were analyzed in aggregate and this may also have contributed to the negative findings. In addition, the exclusion criteria described in this meta-analysis were somewhat unclear and excluded frequently cited studies in this area (e.g., Sohlberg & Mateer, 1987).

A significant problem with this body of literature is the fact that attention training tasks and intensity of treatment do vary widely across studies. In addition, an emphasis on training of attention skills is often only one component of a more comprehensive rehabilitation program. The program may also include awareness training and/or psychotherapeutic support to assist the individual in dealing with the emotional consequences of sustaining a brain injury and coping with changes in functioning. Therefore, it remains unclear whether attention training per se is beneficial (Goransen, 1997).

For example, Palmese and Raskin (2000) administered attention training to three adults with mild traumatic brain injury. Following their treatment, the three adults participated in six to seven sessions of brain injury education and a focus on the application of cognitive abilities. This condition was considered to be a no-treatment control. However, all three of the participants showed some change after both the attention training condition and the no-treatment control condition. It is difficult to ascertain if the differences in performance on neuropsychological tasks noted after the no-treatment control were due to carry-over effects of the attention training or to non-specific change related to both conditions because there was no counter-balancing for order. Similarly, other studies have included a psychotherapeutic element as part of the intervention but have not evaluated its impact on outcome (Park, Proulx, & Towers, 1999; Middleton et al., 1991).

In a large meta-analysis, Carney and colleagues (1999) reported no treatment effect when cognitive rehabilitation was compared with another form of treatment. They stated the need to test the differential effects of general stimulation versus cognitive rehabilitation. Similarly, Wilson (1993) has suggested asking questions that tease out the effects of particular rehabilitation procedures as they are applied to particular patient groups.

A few studies do attempt to provide data relevant to this issue. Ruff and colleagues (1989) conducted a randomized group design study aimed at separating specific treatment effects from those of stimulation and social support. In their study two groups of 20 subjects received different treatments. Their control group received sessions focusing on psychosocial adjustment, leisure, activities of daily living, coping skills and health. The experimental group received computerized training in attention, memory, spatial integration, and problem solving. Both groups received 50 minutes of group psychotherapy at the beginning of each day. At post-test, both groups improved significantly on neuropsychological measures in all areas except for spatial integration. The relative efficacy of the two treatments was not demonstrated but statistical trends in the data suggested that the experimental group made
larger gains in almost all areas. Their data suggest that the enriched environment characteristic of the therapeutic milieu yields some benefits, even in the absence of targeted, neuropsychologically based training. Their data also suggest that specific training may have some benefit above and beyond what is provided by a supportive therapeutic situation but this conclusion is tentative. An additional difficulty with this study is the fact that all participants received psychotherapy and the impact of this intervention on outcome was not considered. In a later paper, Ruff and Niemann (1990) reported on the impact of cognitive remediation versus psychosocial day treatment on emotional and psychosocial variables. They predicted an increase in affective distress after participation in cognitive remediation and a decrease after participation in the day program. Using the design described above, they found that their hypotheses were not supported. Both groups demonstrated a reduction in symptoms of psychosocial distress. These findings underscore the importance of considering separately the impact of cognitive rehabilitation and psychosocial interventions in outcome studies.

In a study focused specifically on attention training, Sohlberg, McLaughlin, Pavese, Heidrich and Posner (2000) compared Attention Process Training (APT) (Sohlberg & Mateer, 1987) with a placebo condition of brain injury education using a within and between groups design. Fourteen individuals with brain injury were divided into two groups and received 24 hours of individually administered APT over 10 weeks and 10 hours of brain injury education over 10 weeks in counterbalanced order. Dependent measures were administered at pre-test and after each experimental condition. Outcome measures included neuropsychological tests sensitive to attention dysfunction, cognitive marker tasks (tasks that have been studied by positron emission tomography (PET) and for which there are putative neuroanatomical correlates), self-report questionnaires and a structured interview. Results indicated practice effects and improvement on cognitive tasks after participation in both conditions. However, participants showed greater improvement on cognitive tasks after participation in both APT and the control condition. Their data also suggest that specific training may have some benefit above and beyond what is provided by a supportive, compensatory and adjustment-focused approach.

A secondary goal of this study was to determine if neurophysiological correlates of attention change after attention retraining, implicating the occurrence of underlying neuronal recovery/change. The P300 and N200 event related potentials (ERPs) were recorded because of their association with cognitive processes. The P300 is considered a neurophysiologic index of attention capacity in humans (Deacon-Elliott, Campbell, Suffield & Proulx, 1987; Polich, 1995; Picton, 1992). The N200 is associated with evaluation of stimulus information required for response selection (Gevins & Cutillo, 1971). The P300 has been shown to be both reduced in amplitude and delayed in latency in the TBI population (Heinze, Munte, Gobet, Niemann & Ruff, 1992; Papincolau, Levin, Eisenberg, Moore, Goethe & High, 1984; Campbe, Deacon-Elliott & Proulx, 1986; Rugg et al., 1988; Keren, Ben-Dror, Stern, Goldberg & Grososswasser, 1998).

Researchers have begun to employ these measures to evaluate brain changes following participation in attention retraining with individuals with TBI. Baribeau, Ethier & Braun (1989) assessed auditory ERPs as neurophysiological indices of selective attention before and after an intensive, computer-dispensed cognitive rehabilitation program. They utilized 21 individuals with TBI and also employed a control group of 22 individuals with TBI matched for age, gender and education. They found the neurophysiological indicators to be sensitive to treatment condition; however, there were no changes in error rates or speed. They report reduced N100 latency, increased amplitude of the P1-N1-P2 component and increased amplitude of the Nd for the left ear only for their experimental group. The authors interpreted their results as suggesting no improvement in selective attention but as possibly indicating increased motivation, attentional effort and improved tonal stimulus processing.

Stone and Raskin (1996) used quantified EEG as a measure of efficacy in a rehabilitation study evaluating the efficacy of prospective memory training with two participants with TBI. These participants demonstrated an abnormal frontal distribution of alpha activity prior to training which reverted to a more typical, posterior distribution after training. Raskin (1996) also measured
P300 before and after prospective memory training. The participants demonstrated reduced P300 latency after training. Therefore, there is some preliminary evidence pointing to the possibility of brain related changes, as measured by changes in brain electrical activity, as a consequence of direct interventions and practice on specific cognitive skills.

In the present study it was predicted that both neuropsychological test scores and neurophysiological measures would show significantly more positive change after participation in an attention training condition (using Attention Process Training materials-APT) than after participation in an Active Control condition (AC). With respect to specific ERP components, it was predicted that the P300 and N200 components would show differences after participation in the attention training condition. More specifically, it was predicted that a decrease in latency of the both the P300 and N200 components would be observed. In addition, a decrease in the negativity of the N200 was predicted. It was predicted that P300 amplitude would also show change, but specific hypotheses about directionality of this change were not offered because the P300 component is influenced by both task difficulty and level of certainty (Picton, 1992); therefore we were unclear as to how this might influence our findings.

Method

Participants

Four adults with moderate to severe TBI participated in this study. They were selected from a pool of 21 available participants. Initially, seven participants meeting inclusion criteria were enrolled in the study. However, two participants dropped out and one was not able to attend enough sessions to collect reliable data. Prior to study entry, participants took part in a clinical interview and a brief neuropsychological assessment in order to document their cognitive difficulties. In addition they completed The Depression Scale developed by the Rand Corporation. It is a very short questionnaire that correlates reasonably well with the Beck Depression Scale, r = .70, p < .05. It contains only items of an emotional nature and does not contain any of the vegetative or cognitive items that may be confounded with brain injury symptomatology.

Participants selected were at least one year post injury and evidenced an injury of at least moderate severity as defined by either a Glasgow Coma Scale (GCS) of 8 to 12, loss of consciousness of 30 minutes or more, a period of post traumatic amnesia (PTA) of at least one hour, or evidence of a brain injury documented by neuroimaging studies. Performance on the Paced Auditory Serial Addition Test (PASAT) (Gronwall, 1977) was at least 1.5 standard deviations below the mean. Because of the single case experimental design nature of this study individual variability was of interest. Therefore, participants were not excluded on the basis of seizures or previous TBIs. In addition, participants were not excluded on the basis of a prior history of substance abuse. Alcohol abuse is common in individuals who sustain traumatic brain injuries (Grafman & Salazar, 1987); therefore to exclude participants on this basis would not be representative of the characteristics of the population of interest. However, participants were screened to ensure that they were not currently abusing either alcohol or street drugs. One participant did report a history of alcohol abuse. Participant 1 suffered two significant TBIs. The first was due to a fall from a horse and the second was a bicycle - motor vehicle accident. Participants 2 & 3 were injured in motor vehicle accidents. Participant 4 was assaulted. Participants 2 & 4 showed evidence of depressive symptoms on the Rand Depression Scale. Participant characteristics are displayed in Table 1.

Design and Procedures

A modified single case multiple baseline cross-over design was utilized. Each participant underwent a six-week baseline phase, six weeks participation in Attention Process Training (APT) and six weeks participation in an Active Control (AC) condition. Participants took part in the AC condition together in a group format. Order of administration of the two conditions was counterbalanced (Participants 1 & 2 received APT first; Participants 3 & 4 received AC first). Frequency and intensity of the intervention was identical for the two conditions (twice per week for one hour each session).

Behavioral dependent measures were collected at two-week intervals throughout the study for a total of nine data points per measure. Neurophysiological measures were recorded at two-week intervals during the baseline phase and were collected at the end of each treatment condition for a total of five recordings. Testing was carried out by a research assistant not involved in the provision of the rehabilitation procedures. The therapist was the same for both conditions to control for therapist effect.

Active Control Condition

The Active Control condition was outlined in a manual format and was designed to focus on emotional adjustment and psychoeducation and to control for the effects of general stimulation and therapeutic and social support. Different topics relevant to coping with TBI were discussed for each session.

Table 1

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>TSI</th>
<th>Neuroimaging</th>
<th>LOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Female</td>
<td>58</td>
<td>(1) 26 mos</td>
<td>Subdural hemotoma with midline shift, skull fracture</td>
<td>9 days coma</td>
</tr>
<tr>
<td>2 Male</td>
<td>22</td>
<td>45 mos</td>
<td>n/a</td>
<td>Brief with 3 days PTA</td>
</tr>
<tr>
<td>3 Male</td>
<td>34</td>
<td>12 yrs</td>
<td>Right sided injury with left hemiparesis and blindness</td>
<td>8 wks coma</td>
</tr>
<tr>
<td>4 Male</td>
<td>40</td>
<td>15 mos</td>
<td>n/a</td>
<td>2 days with significant PTA</td>
</tr>
</tbody>
</table>

Note: LOC = loss of consciousness, PTA = post-traumatic amnesia, TSI = time since injury
Topics included: education about brain injury, fatigue, headaches, problem solving, relaxation training, use of compensations, and cognitive restructuring.

Attention Training Condition

The attention retraining module consisted of the Attention Process Training (APT) materials (Sohlberg & Mateer, 1987). The APT materials consist of hierarchically organized treatment tasks for each of the five levels of attention outlined in Sohlberg and Mateer’s componential model of attention: focused, sustained, selective, alternating, and divided attention. The materials include paper and pencil tasks; some exercises are presented on audiotape. Other activities include multi-tasking such as sorting a deck of cards and counting at the same time.

Measures of Attention and Working Memory

Participants completed two versions of a short computerized working memory task (Kerns, 1997; Owens, Morris, Sahakian, Polkey & Robbin, 1996). They were presented with a number of boxes and words on a computer screen. They were required to locate symbols hidden beneath the words or boxes. This involved remembering where the previously seen boxes were located (spatial memory) and which words they had already chosen (verbal memory). Location of the symbols was randomly determined by the computer program. Four trials for each task (box and word) were administered to each participant. They began with four items on the screen and this increased to six items, eight items and twelve items for the fourth trial. Reaction time and error rates were recorded.

Selected subtests of the Test of Everyday Attention (TEA) (Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996) were administered. The TEA has three parallel versions to account for practice effects from repeated administrations. The subtests used in this study demonstrated high test-retest reliability. The Lottery subtest is a ten minute test which requires participants to listen for winning lottery numbers presented on audiotape. The test authors report that this test loads on a sustained attention factor. The Map Search subtest was also administered. It requires participants to search for symbols on a map. They are timed to see how many symbols they can locate in two minutes. This test loads on a visual selective attention factor. Finally, the Auditory Elevator with Distraction subtest was administered. Participants listened to beeping elevator sounds presented on audiotape and were required to count the floors in the presence of a distracting tone. This subtest loaded on an auditory working memory factor and is a measure of selective attention and resistance to distraction.

Neurophysiological Measures

Event related potentials (ERPs) were recorded three times during the baseline phase and once after each treatment phase for a total of five recordings per participant. Brainstem auditory evoked potentials (BAEPs) and checkerboard pattern visual P100 evoked potentials were recorded during the first test session only. This was done to ensure that participants were free from hearing or visual difficulties that could account for any abnormalities noted in later component ERPs. For recording of ERPs, participants engaged in a visual and an auditory oddball task (detecting targets in a sequence of standard stimuli). For the auditory task they listened to a series of tone beeps presented binaurally through earphones and were required to count the number of targets (designated as the higher tone). Standard or non-target tones were 2000 Hz and targets were 1000 Hz. Both tones were presented at an 80 dB level. Targets were presented 15% of the time (p=.15) and non-targets were presented 85% of the time (p=.85). This task is believed to tap working memory and attention processes. For the visual task, participants were presented with blue triangles (non-targets, p=.85) and blue circles (targets, p=.15) on a computer monitor. They were required to press a button whenever a blue circle appeared on the screen. Reaction times were recorded for this task.

ERP Recording

Electrodes were placed on the scalp for 3 response sites (FZ, PZ, CZ - International 10-20 System). These sites are located on the midline and cover the frontal to parietal area. An electrode cap was used. Electrodes placed on the mastoid served as references. Electrode impedance was kept below ten KΩ. ERPs were recorded using a Bio-Logic Brain Atlas (BioLogic Systems). The signal was amplified 50,000 times and filtered with a 60 Hz notch filter with a band pass of 1-30 Hz. Sampling rate was 200 Hz from 100 msec prior to stimulus onset to 924 msec post-stimulus. An automatic artifact rejection system was used to reject trials contaminated with eye blinks, eye movements or excessive muscular activity.

ERP Data Analysis

Waveforms were averaged by the Bio-Logic Brain Atlas system. 30 single sweep waveforms were used to create an average waveform for each task. ERP component wave forms were determined through visual inspection. The most prominent peak occurring for all three electrode sites after the NI-P2-N2 complex was chosen as the P300. Peak amplitude was measured with respect to the mean of the 100 msec pre-stimulus baseline. Latency was measured with respect to stimulus onset and was defined as the time point of maximum positive amplitude.

Case Analyses and Results

Data were analyzed using visual inspection with graphing carried out as suggested by Krishef (1991). The primary researcher was blind to the identity and group membership of the participants during the data analysis phase of the study.

Attention and Working Memory Measures

Because this study utilized alternate forms of the TEA, data were graphed as z scores to account for variability between forms. The tasks selected from the TEA were not as sensitive as expected. They were not challenging enough for a number of participants, who achieved ceiling level performance. The Lottery task was the least sensitive of the three tasks utilized in this study. Two participants did demonstrate improvement on TEA tasks. Participant 2 showed improvement on the Auditory Elevator with Distraction task after APT training (see Figure 1) and improvement on the Map Search task after participation in the
AC condition delivered following APT. Baseline z scores for the Map Search task ranged from -1.5 to -.7 with a post-treatment z score of +1.5. Participant 4 demonstrated improvement on the Lottery subtest after participation in the APT condition (see Figure 2). Improvement on the Auditory Elevator Task was noted during the AC condition delivered prior to APT (see Figure 3). This participant’s performance for the Map Search task showed considerable variability in terms of z scores. The baseline was stable (z = 0) and improvements and decreases in performance were observed during the Active Control condition (z = -1.4 to +2). Considerable improvement was noted for the APT phase (z = +3 and +2.6). However, there was a drop to z = -.4 for the last test session. This corresponds with the drop in scores also observed for the Auditory Elevator with Distraction task.

The computerized working memory task proved to be a more sensitive measure, with participants working at four levels of difficulty for the spatial and verbal tasks. All participants were able to achieve ceiling performance for the four item trials. The data were graphed by collapsing across levels of difficulty for all conditions that did not show ceiling effects or unstable baselines.

Three of the four participants showed some improvement in error rates on this task following participation in APT (Participants 1, 2, 3) (see Figures 4, 5, 6). No participant showed improved performance on the working memory task after the Active Control condition without prior APT participation.

Neurophysiological Measures

Evoked potential data was examined by graphing latency and amplitude values for the P300 and N200 components. Data was graphed for each site individually (FZ, CZ, PZ). It was felt that inspection of amplitude and latency values for individual sites would be more sensitive than collapsing these values across all three sites because site differences in amplitude, latency and the relationship between amplitude and latency have been reported (Ravden & Polich, 1999). Waveforms were examined for target and non-target stimuli. No participants demonstrated abnormalities in their non-target evoked potentials (such as the presence of a large P300 waveform to non-target stimuli), suggesting no difficulty in discriminating between target and non-target stimuli.

All participants showed some change in ERPs. However, there was considerable variability in the changes observed and no clear pattern emerged. Decreased negativity of the N200 was observed in three participants. Two participants showed changes in N200 latency, however they were not consistent; there was one increase and one decrease. Three participants showed decreased latency of the P300 component; no participants showed an increase in P300 latency. Three participants showed increased P300 amplitude and two participants showed decreased P300 amplitude for some tasks. These changes were all noted following participation in APT (see Table 2) with the exception of a decrease in N200 latency observed for the auditory task following the AC condition for Participant 4. Actual amplitude and latency data are presented in Appendix A.

Discussion

In addressing the primary question posed by this study: is there a specific effect for the administration of attention training (APT) above and beyond a supportive, adjustment oriented approach, the data point to APT as being the efficacious ingredient in terms of producing cognitive change. With the exception of Participant 4 showing improvement on the Auditory Elevator with Distraction task of the TEA following the AC
Figure 2. Z scores for the lottery task for Participant 4 for each test session.

Figure 3. Z scores for the auditory elevator with distraction task for Participant 4 for each test session.
condition, and Participant 1 showing an improvement on the working memory task during the AC condition following APT, all participants demonstrated improvement on the cognitive tasks following participation in APT only. For the two participants who received APT prior to the AC condition, changes were maintained during AC. For those who received AC first, changes were not noted until attention retraining was initiated.

The findings provide support for improvement in performance on tasks of working memory and attention following participation in attention retraining. These results are particularly positive in light of the fact that improvements were demonstrated on untrained tasks that were quite different from the training tasks. The outcome measures employed provide stronger evidence of generalization than studies that have used standard neuropsychological tests such as the PASAT, which is often quite similar to training tasks and bears little similarity to functional activities. TEA tasks were different from training tasks and quite similar to training tasks and bears little similarity to functional neuropsychological tests such as the PASAT, which is often sensitive temporal measure of neural activity underlying the processes of attention allocation and immediate memory. It has been associated with superior cognitive performance in normal subjects (Sturm, Willmes, Orgass & Hartje, 1997).

The current findings add to the list of studies that have shown attention retraining to be efficacious for individuals with TBI (Sohlberg & Mateer, 1987; Neumann, Ruff & Baser, 1990; Sturm, Willmes, Orgass & Hartje, 1997; Gray, Robertson, Pentland & Anderson, 1992; Gray & Robertson, 1989; Wilson & Robertson, 1992; Ruff et al., 1994; Nag & Rao, 1999; Franzen & Harris, 1989; Sohlberg et al., 2000; Palme & Raskin, 2000; Cicerone et al., 2000). Our findings also contribute to a very small body of literature that has examined the differential impact of targeted cognitive practice and more general, therapeutic or psychoeducational approaches (Sohlberg et al., 2000; Ruff et al., 1989; Schmitter-Edgecombe et al., 1995; Ruff & Neumann, 1990; Palme & Raskin, 2000). The results suggest that the targeted practice on cognitive exercises is the active ingredient in producing change on cognitive outcome measures and that there may be a differential impact for attention retraining and psychotherapeutic support. However, due to the single case nature of this study, the small number of cases, and the relatively limited research bearing on this question to date, replication and extension of these findings will be important.

It is important to recognize that there were also some changes noted in our data following participation in the AC condition. This is consistent with the findings of others (Sohlberg et al., 2000; Ruff & Neumann, 1990), and suggests that psychotherapeutic interventions can impact outcome variables for some individuals. Clearly, the impact of psychotherapeutic interventions should be considered when assessing the efficacy of specific cognitive rehabilitation techniques. This has been recognized by the National Institute of Health in their consensus statement for the Rehabilitation of Persons with Traumatic Brain Injury (1999). They stated that the findings from efficacy studies of rehabilitation for TBI have been limited by, among other things, the unspecified effects of social contact.

The data also provided support for our second hypothesis, that neurophysiological variables would show the most change after participation in APT. All participants showed some difference in ERPs that was believed to represent positive change. However, there was considerable variability and no clear pattern of change in ERPs emerged. For the two participants who received APT prior to participation in the Active Control condition (Particpants 1 & 2), ERP changes were maintained, or in the case of Participant 1, actually became more pronounced. There was minimal change in ERP variables noted during participation in the AC condition for the participants who received the AC condition first.

The observed ERP changes were generally in the expected direction. However, only one participant showed decreased N200 latency. Participant 2 showed increased N200 latency which was not predicted. Decreased negativity of the N200 component was observed in three participants suggesting that reduced effort was required to complete the task. Two participants showed decreased latency of the P300 component. This is suggestive of improved information processing speed. P300 latency is considered to be a measure of stimulus classification speed or information processing efficiency (Picton, 1992; Clark, 0-Hanlon, Wright & Geffen, 1992). Polich (1998) describes P300 latency as a sensitive temporal measure of neural activity underlying the processes of attention allocation and immediate memory. It has been associated with superior cognitive performance in normal subjects (Sturm, Willmes, Orgass & Hartje, 1997).

There were no hypotheses put forth with respect to directionality of P300 amplitude changes. On the various tasks employed in this study, three participants showed increased P300 amplitude and two showed decreased P300 amplitude. P300 amplitude changes are difficult to interpret because of the complex interactions of the influence of extraneous variables, such as arousal level and task difficulty. Three participants in the current study demonstrated increased P300 amplitude values. Because a reduction in P300 amplitude has been interpreted by many as an indication of reduced cognitive capacity, the increase may reflect improved attentional capacity. It may also reflect greater attention given to the task stimuli, perhaps as a result of improved attention.

The decrease in amplitude observed in two participants can

Table 2. Summary of ERP Changes

<table>
<thead>
<tr>
<th>#</th>
<th>Auditory Task P300</th>
<th>Auditory Task N200</th>
<th>Visual Task P300</th>
<th>Visual Task N200</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Increased amplitude +</td>
<td>Decreased N2 negativity +</td>
<td>Decreased P3 amplitude</td>
<td>Decreased P3 latency +</td>
</tr>
<tr>
<td>2</td>
<td>Decreased P3 latency +</td>
<td>Decreased N2 negativity +</td>
<td>Increased N2 latency</td>
<td>Decreased P3 amplitude</td>
</tr>
<tr>
<td>3</td>
<td>No changes</td>
<td></td>
<td>Increased P3 amplitude +</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Decreased P3 latency +</td>
<td>Decreased N2 latency +*</td>
<td>Increased P3 amplitude +</td>
<td>Decreased N2 neg. +</td>
</tr>
</tbody>
</table>

* indicates ERP differences believed to represent positive change.
* only ERP changed noted following AC.
Figure 4. Participant 1: Errors for working memory task for all non-ceiling conditions combined.

Figure 5. Participant 2: Errors for working memory task for all non-ceiling conditions combined.
also be explained by examining the factors that affect the amplitude of the P300. Theoretically, a decrease in amplitude could also reflect improved attentional abilities. When adequate attention is paid to a task, amplitude and certainty are believed to covary (Picton, 1992). Therefore more certainty of the correct response could be associated with decreased amplitude. In a similar vein, amplitude varies with task difficulty. A less difficult task would produce a smaller amplitude P300. If participants’ attentional abilities have improved, the task may have become easier resulting in a smaller amplitude P300. Conversely, amplitude also varies with arousal level and amount of attention paid to a task. Therefore, poor attention and/or effort could also result in decreased amplitude. Examination of behavioral data for the visual ERP task revealed that participants made few errors during all five administrations of this task. This weakens the notion that reduced amplitude is evidence of reduced task difficulty or greater certainty. The difference in directionality of amplitude changes observed across and within participants (Participant 1) weakens the evidence that bi-directional changes in amplitude reflect valid ERP changes related to the training tasks. Theory predicts that increased amplitude may reflect changes associated with improved attention but decreased amplitude is more likely related to changes in arousal level across test sessions. The findings of the current study add to a very small body of research that suggests that ERP or EEG changes occur after cognitive rehabilitation (Baribeau, Ethier & Braun, 1989; Raskin, 1996).

Examination of the current findings reveals that those participants with the least severe initial injury showed change on the greatest number of behavioral and ERP measures (Participants 2 and 4). Neither of these participants was in coma, however both demonstrated significant periods of post-traumatic amnesia (PTA). Another notable similarity of these two participants was the presence of depressive symptomatology. Clinical lore exists that suggests that depression may be a contra-indicator for treatment because a depressed individual may not have the emotional resources to benefit from a treatment program. Our results suggest otherwise. Involvement of individuals with depressive symptomatology may provide an opportunity for behavioral activation and distraction from or re-focusing of negative beliefs. However, it should be noted that depression was measured in this study using only the Rand depression inventory and was not assessed using specific diagnostic criteria (i.e., the DSM-IV). Therefore, these findings may not hold true for individuals who meet the DSM-IV criteria for a Major Depressive Disorder.

It has been suggested that treatment success is inversely related to time since injury (Franzen & Harris, 1993). However, this finding may be somewhat spurious because numerous studies utilize patients who are still in a period of significant spontaneous, or natural, recovery. In the current study, participants ranged from 15 months to 12 years post-injury, spanning a very wide range of chronicity. Changes were shown by all participants, regardless of time since injury. This suggests that the inverse relationship between time since injury and treatment success may not hold for individuals who have reached a plateau in terms of natural recovery.

Limitations
The present study addresses a number of issues that have
been raised as limitations of previous studies of the efficacy of attention retraining (Park and Ingles, 2001). Repeated baseline measurements and alternate forms were used to control for practice effects and a control condition was employed. The heterogeneity inherent in the population was evaluated and not ignored in this study through its single case design methodology. The issue of nonspecific, psychotherapeutic effects was systematically examined. However, a number of limitations remain and must be discussed in considering the implications of the findings.

As noted previously, ceiling effects on the TEA tasks limited the ability to detect change in the different components of attention. Tasks were selected to represent sustained and selective attention, resistance to distraction, visual scanning and speed of processing. However, because only two participants showed improvements on these tasks it is not possible to address issues relating to the responsivity of different attentional networks to the training tasks. This is an important area for consideration as some authors have suggested that degree of impairment in the vigilance network may impact the outcome of training higher levels of attention (Sturm et al., 1997; Sohlberg et al, 2000).

The duration of the rehabilitation program employed in the current study was relatively short. Participants engaged in rehabilitation activities for one hour sessions twice per week for six weeks. Stronger effects may have been observed for longer or more intense training. Similarly, participants with more severe injuries may have benefited more from a longer duration of treatment. This study is also limited by a lack of follow-up data. This precludes the possibility of drawing any conclusions about the maintenance of treatment effects. Generalization to improvement in real life functioning remains a challenge to rehabilitation researchers. Our participants reported positive changes in their daily lives, however it is only possible to speculate about the role of the rehabilitation activities in these improvements due to the influence of the individual’s psychosocial environment outside of the rehabilitation program.

This study was conducted to attempt to determine the specificity of the efficacy of attention retraining in producing improvements on tests of attention, working memory and neurophysiological measures, above and beyond a supportive, adjustment-oriented approach. Findings support the continued use of attention retraining activities for individuals with TBI who experience attention deficits. Additional research is needed to elucidate specific relationships between patient characteristics, intensity and duration of administration of retraining activities, and treatment approach. Future research utilizing ERPs and other functional neuroimaging techniques may help to elucidate the neural processes underlying recovery after injury. Plasticity in the adult nervous system has potentially far-reaching implications for recovery for various brain based disorders and injuries.

References


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Appendix A: ERP Changes by Participant

Participant 1

Auditory Task:

This participant demonstrated an increase in amplitude of the P300 after APT. The observed increased amplitude continued after the AC condition. Baseline amplitudes for the P300 were 5.2 mV, 1.7 mV, 1.82 mV. Amplitude after APT only was 6.61 mV and after APT and AC was 7.72 mV. P300 latency also demonstrated a decrease; however, it is difficult to interpret this data due to an unstable baseline.

Participant 1 demonstrated decreased negativity of the N200 for the auditory task after APT that continued after participation in the AC condition. Baseline amplitudes for the N2 were -1.69 mV, -2.11 mV, -2.0 mV. Amplitude after APT only was -1.0 mV and after APT and the AC condition was 1.54 mV. Baseline latencies for N2 were not stable.

Visual Task:

Participant 1 did not show corresponding changes for the visual task in the P300 or N200 components, however, some changes were observed. A decrease in P300 amplitude was observed for this task and there was a decrease in P300 latency after APT. Baseline amplitudes for the P300 were 10.77 mV, 18.59 mV, 11.68 mV. Amplitude after APT only was 7.59 mV and after APT and AC was 4.25 mV. Latencies for baseline measurements were 436 msec, 424 msec, 604 msec. Latency after APT only was 316 msec and after the AC condition was 300 msec. Reaction time (RT) for this task also showed a decrease from baseline. Baseline reaction times were 366.5 msec, 358 msec, 391 msec. After APT, RT for the visual task was 341 msec. RT was 341.5 after the AC condition. N2 data could not be interpreted for this task because of unstable baselines.

Participant 2

Auditory Task:

This participant showed two ERP changes for the auditory task after participation in APT. There was a decrease in the negativity of the N200 and an increase in N200 latency following APT. There was no change in amplitude of the P300. There were changes in P300 latency but they were judged to be insignificant.

Baseline amplitudes for the N200 were-2.91 mV, -3.55 mV, -3.36 mV. After participation in APT, N200 amplitude was .47 mV. After participation in the AC condition, amplitude was -.3 mV. Baseline latencies of the N200 were 256 msec, 216 msec, 220 msec. After participation in APT, latency was 288 msec, and was 280 msec after participation in the AC condition.

Visual Task:

Participant 2 showed decreased P300 amplitude after participation in APT. Baseline amplitudes for the P300 were 9.34 mV, 10.49 mV, 9.99 mV. After participation in APT, P300 amplitude was .47 mV. After participation in the AC condition, amplitude was -.3 mV. Baseline latencies of the N200 were 256 msec, 216 msec, 220 msec. After participation in APT, latency was 288 msec, and was 280 msec after participation in the AC condition.

Participant 3

Auditory Task:

This participant showed no changes in either the P300 or the N200 components after participation in either condition for the auditory task.

Visual Task:

Participant 3 showed an increase in P300 amplitude following APT. Only two baseline measurements were available for this participant due to a poor quality recording.

Baseline measures for P300 amplitude were 6.97 mV and 9.25 mV. After participation in the AC condition, amplitude was 8.07 mV. After APT amplitude was 20.53 mV. P300 latency was variable.
Participant 4

Auditory Task:

Participant 4 showed decreased latency for the P300 following APT and decreased latency for the N200 following AC. This participant missed one baseline session; therefore, there are only two data points for baseline data. Baseline measures for latency of the P300 were 616 msec and 392 msec. After participation in the AC condition, P3 latency was 368 msec. After APT, latency was 264 msec. Baseline measures for latency of the N200 were 408 msec, 252 msec. After the AC condition, latency was 204 msec. After APT it was 200 msec. No changes in amplitude of either component were observed.

Visual Task:

This participant showed an increase in P300 amplitude and a decrease in negativity of the N200 for the visual task with no corresponding changes in latency of either component following APT. Baseline measures for P300 amplitude were 4.82 mV, 7.04 mV. After the AC condition, amplitude was 3.83 mV and after APT amplitude was 11.27 mV. Baseline amplitude measures for the N200 were -4.82 mV and -6.33 mV. After participation in the AC condition, amplitude was -6.32 mV. After APT participation, amplitude was -1.78 mV.