INFORMATION PROCESSING AND ATTENTION DEFICITS FOLLOWING SEVERE HEAD TRAUMA

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PREFACE

According to the National Head Injury Foundation, traumatic brain injury leaves 50,000 people permanently disabled each year. Roughly $4 billion is spent annually on hospitalizing brain-injured patients. Although facilities for rehabilitating brain-injured patients are springing up all around the country, these programs are in their infancy. Practitioners who work with this population are constantly in need of recommendations for dealing with the multitude of problems they encounter with brain-injured patients. This dissertation examined a common area of difficulty for brain-injured patients: the ability to attend and respond quickly to visual stimuli. Brain-injured subjects showed significant deficits in attentional processes on a paced continuous performance signal detection task. Hit rates and false alarm rates were examined as diagnostic measures of different underlying attentional events. This task was found to differentiate brain-injured from control subjects on a variety of experimental variables, including vigilence, impulsivity, and fatigability. It was also effective in assessing improvement at different points of recovery in the brain-injured group. Possible physiological explanations and recommendations for rehabilitation professionals were offered based on this investigation.

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CHAPTER I

INTRODUCTION

Practitioners in the field of clinical neuropsychology and cognitive rehabilitation have noted that brain-injured patients exhibit various symptoms of attentional deficits which affect performance on rehabilitation tasks. As early as 1904, Meyer described victims of serious head trauma as unable to concentrate their attention on any type of occupation. Conkey (1934) administered a battery of 30 tests to brain-injured patients and concluded that the most significant deficits were memory impairment, loss of power to sustain attention, difficulty shifting from one activity to another, and fatigue. Attentional deficits were also cited by Ruesch (1944) to explain the poor performance of brain-injured patients on a variety of tasks. Miller (1961) described a syndrome which he labeled "accident neurosis" characterized by difficulty concentrating, distractibility, and anxiety. Prigatano and Fordyce (1984) note that attentional deficits, poor concentration, distractability, and fatigability impact many of the brain-injured patient's cognitive abilities and adaptive behaviors. Ben-Yishay, Rattoh, Ross, Lakin, Silver, Thomas, and Diller (1982) also recognized the impact of attentional disturbances on general functioning, and developed a remediation program to address these problems.

Brain-injured patients also subjectively report difficulties with attention, concentration, distractibility, impulsivity, and fatigue as persistant, disturbing symptoms which occur even after mild concussions (Rosenthal, 1983; Van Zomeren, 1981). Thus, practitioners and brain-injured patients agree that attentional deficits are often a major problem in rehabilitation. Difficulties arise, however, when one attempts to arrive at a precise definition of "attention," and to identify specific behavioral deficits which contribute to the attentional problems noted in brain-injured patients.

Attention is a construct which is assumed to have a profound impact upon intellectual operations, although it is not directly observable. Broadbent (1958) began to actively investigate and measure components of attention, and hypothesized a structural information processing model for which "attention" acted as a filtering mechanism in an early stage of processing. Stimulated by this early investigation, other researchers have demonstrated that attentional mechanisms operate at several points in the information processing sequence (Treisman, 1964; Broadbent, 1971). Niesser (1967) postulated a dichotomy of pre-attentive and attentive processing, and demonstrated that complex tasks which initially require a great deal of attention may become automatic with practice. Others (La Berge & Samuels, 1974; Shiffrin & Schneider, 1977; 1984) have described other attentional components, which they labeled "automatic" and "controlled" processes.

Posner and Boies (1971) discuss attention in terms of three components: alertness (general receptivity to stimuli), selectivity (focusing on relevant characteristics of a stimulus), and limited processing capacity. Lezak (1983) observed that:

> "Brain damage affecting these components can result in slowed reaction times, inattentiveness or difficulty screening out impinging stimuli, and restricted range of awareness. Generally, defects in attention will involve all three components, although only one may be noticably impaired" (Lezak, 1983, p. 35).

The present investigation attempts to further elucidate the nature of the attentional deficits observed in brain-injured patients.

For many years, investigators have used reaction time as a way of quantifying and studying mental operations (Donders, 1969; Sternberg, 1969; Sanders, 1980; Logsdon, Hochhaus, Williams, Rundell, & Maxwell, 1984). Because slowed speed of processing was observed in brain-injured patients, reaction time investigations were incorporated in early investigations of this population. Ruesch (1944) reported that patients with head injuries showed prolonged reaction times and required longer tachistoscope exposure times to respond to stimuli. Benton and Blackburn (1957) found highly significant differences between brain-injured and control subjects on both simple and choice reaction time tasks. Other researchers (Carson, Carson, and Tikofsky, 1964; Miller, 1970) found that differences between head injured and control subjects increased as the complexity of the reaction time task increased. Miller (1970), Gronwall and Sampson (1974), and Van Zomeren and Deelman (1976) were able to demonstrate convincingly that movement time was <u>not</u> a source of difference in reaction time between their brain-injured and control groups, and concluded that central processing time is significantly increased following head injury.

Van Zomeren and Deelman (1976) investigated the effects of severity of injury (based on length of coma) on simple and choice reaction time. They found a highly significant relationship between length of coma and complexity of the task that was apparent up to two years post-injury. Further longtitudinal investigation of reaction time (Van Zomeren & Deelman, 1978) of brain-injured patients at six different points in their recovery revealed that reaction time was significantly affected by severity of injury, complexity of the task, and length of time since injury. Severity and complexity also produced a significant interaction, as had been observed in the 1976 investigation, and an interaction between complexity and time since injury was also significant. They concluded that in terms of information processing theory, the complexity effect indicated that head injury influenced channel capacity, or rate of information transmission in the central nervous system. They noted that this capacity seemed to be reduced in proportion to the severity of the injury and observed that in severe cases, recovery seemed to continue even beyond the two year duration of their investigation.

Van Zomeren (1981) reported further investigations of attentional deficits in patients with closed head injuries. In a reaction time investigation which incorporated an incompatible response distractor, he found that irrelevant stimuli had a much stronger effect on reaction times of head-injured subjects than on controls. In examining possible causes of this increase in reaction time in the distraction task, he discovered that the distractor effect is present only when time pressure is involved. Given an unlimited amount of time, brain-injured subjects were not adversely affected by the presence of irrelevant stimuli. Based on his review of attention and reaction time literature, and on his own investigations of the effects of task complexity and distraction on reaction time, Van Zomeren concluded that at this time, evidence suggests that the attentional deficit noted in brain-injured subjects appears to be a result of an impairment in the aspect of attention which Posner and Boies (1971) identified as "limited processing capacity." Attention is affected in the sense that the ability to deal quickly and efficiently with information is limited.

As described above, many investigations of attentional deficits in brain-injured subjects have incorporated reaction time as a behavioral measure of attentional processes. Pachella (1974) notes that reaction time has become the dependent variable of choice in the study of basic psychological processes. He asserts, however, that reaction time measures have sometimes been used as much for convenience as for theoretical reasons. He describes a number of factors which have been shown to account for variation in reaction time without regard for specific experimental paradigms and substantive problems. Distribution of stimuli, distribution of responses, intertrial intervals, and error rates all have systematic effects on reaction time, and will affect the conditions and procedures under which reaction times can be collected most reliably and interpreted most reasonably.

Errors, according to Pachella, are an important limiting factor on the interpretability of reaction time. Even low error rates which are dismissed as inconsequential by experimenters may lead to serious problems in interpretation when they are a result of subjects trying to respond a little more quickly than they normally would. Pachella points out that even small differences in error rates can lead to large differences in reaction time, particularly for the range of 90 to 100 percent accuracy typically found in reaction time experiments. In investigations of brain-injured subjects, trials on which the subject commits an error are generally not included in the reaction time analysis. Error rates are typically either not reported or dismissed as inconsequential. Examining correct and incorrect responses under different experimentally imposed time limits may be one way of further understanding differences in information processing in brain-injured and control subjects.

A few investigations of deficits in brain-injured patients have used a paced continuous performance task to examine attentional deficits. This type of task has the advantage of incorporating time limits for performance. Bruhn and Parsons (1971) investigated attentional problems and fatigue among a heterogenous group of brain damaged subjects. They used an experimenter-paced continuous performance reaction time task to determine the effects of fatigue upon reaction time and variability of brain damaged subjects' performance. Stimuli in this experiment were presented at the rate of one every 2.5 seconds. Although the brain damaged group was significantly slower and more variable than the control group, Bruhn and Parsons found no performance decline over 40 minutes of testing, nor was there a systematic increase in variability over time. Gronwall and Wrightson (1974; 1975) and Gronwall (1977) report significant differences in performance (measured as per cent correct) of post-concussion patients, depending on the rate of presentation of stimuli.

Paced continuous performance tasks have also been used to investigate attentional deficits in children with a medical diagnosis of "minimal brain dysfunction." These children committed more errors and showed less responsiveness than control subjects (Dykman, Ackerman, Clements, and Peters, 1971; Messer, 1976). This has been interpreted as an inability to maintain vigilence and/or inhibit inappropriate responses in learning disabled children (Bryan & Bryan, 1978).

The aim of the present investigation was to further explore the nature of attentional deficits found in brain-injured patients. Included in the design were measures of vigilence, impulsivity, and fatigue, because these variables may contribute to observed differences in performance of brain-injured and control subjects. In order to assess the impact of these variables, the present investigation compared the hit rates and false alarm rates of brain-injured and control subjects on a five-minute continuous performance test. The test consisted of a series of "X's" and "O's" to which the subject responded by pressing a button if the stimulus was an "X" and doing nothing if the stimulus was an "O." A hit occurred when the subject correctly pressed the button for an "X," a miss occurred if the subject failed to press the button when an "X" appeared. A false alarm occurred if the subject pressed the button when the stimulus on the screen was an "O," and a correct rejection occurred when the subject saw an "O" and did not press the button. The hit rate was calculated by dividing the number of hits by the total number of "X's". The false alarm rate was calculated by dividing the number of false alarms by the total number of "O's".

The hit rate was evaluated as a measure of attention and vigilence to the task. Errors, or misses, indicated an attention deficit. A high hit rate indicated that the subject was attending to the task. Control subjects, since they were assumed to have adequate attentional capacity, were expected to achieve hit rates near 100%. Brain-injured subjects were expected to obtain lower hit rates due to their reported attention deficits. Due to their increased susceptibility to fatigue, brain-injured subjects' hit rates were expected to decrease over time on task, reflecting a vigilence deficit in this population. The false alarm rate provided an assessment of impulsive responding. A high false alarm rate indicated that the subject was responding before processing the stimulus and/or was unable to inhibit an inappropriate response. If the false alarm rate increased as the subject performed the task, fatigue would also have seemed to have a negative effect on his/her ability to inhibit an inappropriate response. Control subjects were expected to achieve very low false alarm rates, demonstrating their ablity to process the stimulus and inhibit their response within the time constraints of the task. Brain-injured subjects were expected to be less able to process the stimuli and inhibit their responses, thus their false alarm rates were predicted to be higher than those of the controls. In addition, since fatigue has been observed to be a problem for patients with brain injuries, their false alarm rates were expected to increase across trials during the continuous performance test.

It should be noted that this was not a standard type of signal detection analysis. The usual analysis recommended by signal detection theorists involves computing "d-prime," based on a combination of the hit rate and the false alarm rate. By combining the two measures, researchers have shown that a measure of attention and vigilence can be obtained (Spoehr & Lehmkuhle, 1982). Pilot data (see Appendix A) for this investigation indicated that the hit rate and false alarm rate were each important measures of attention, and that each measured a different component of attention. One of the goals of this investigation was to investigate these different components of attention. The continuous performance test was used in an atypical signal detection analysis to make detailed predictions about the performance of brain-injured subjects on an attentional task. Separate performance indicators (hit rate and false alarm rate) were hypothesized to be diagnostic measures of different underlying attentional events.

A second issue which was addressed in this investigation was the implication of the attentional deficit(s) examined in the first part of the research for treatment of brain-injured patients. If performance was found to decline significantly over 5 minutes, this must be taken into consideration in the design of treatment strategies. This issue was further explored by incorporating a second task into the investigation. The digits forward portion of the Digit Span test, which is believed to be a measure of immediate memory and attention/distractability (Kaufman, 1979) was administered to each subject prior to the continuous performance test. Four different Digit Span trials were given to obtain a "baseline" for this task. Following the continuous performance test, Digit Span was immediately re-administered to evaluate performance under conditions of fatigue. If performance on Digit Span was at the same level as the baseline established prior to the continuous performance test, this might indicate that the attentional deficits were due in part to motivational problems, and might be dealt with by frequently changing the type of task the patient is required to perform. This was expected to occur in the case of control subjects. If, on the other hand, performance on Digit Span was below the baseline level, attentional problems could be attributed to fatigue. Brain-injured subjects were expected to show greater fatigue effects than controls.

The third and final area that was addressed in this investigation was how performance changed over recovery. Brain-injured subjects were tested at 3 different points of recovery, all within 6 months of their injury, and were expected to show improvement in all areas. At the third testing, performance on the continuous performance test was expected to be significantly improved over the initial testing, as indicated by increased hit rates and decreased false alarm rates, and by smaller performance decrements over trials. Significant improvement in performance on the Digit Span task over the three test times was also expected.

This investigation adds empirical support to observations that brain-injured patients are more susceptible than normal individuals to various attentional problems. The continuous performance test provided an objective measurement of different types of attentional deficits. In addition, treatment recommendations for patients in cognitive rehabilitation programs were made based on conclusions drawn from the results of this investigation.

In summary, reaction time investigations have often been used to study attentional deficits observed in brain-injured patients. Slowed processing speed is widely documented in these patients, and it has been demonstrated that the more complex the stimuli, the greater the difference in processing speed between patients and controls. Van Zomeren (1981) has also demonstrated that distraction (stimulus-response incompatibility) had a much greater impact on the reaction times of brain-injured subjects than on controls. Thus, research indicates that reaction time of brain-injured patients is influenced disproportionally by two variables: number of stimulus alternatives and stimulus-response incompatibility. Both of these variables appear to impact primarily Posner and Boies' (1971) "limited capacity" aspect of attention.

Pachella (1974) questioned the validity of drawing conclusions about mental operations based solely on reaction times, and suggested that differences in reaction time may be produced by a variety of variables inherent in the experimental task, rather than by mental processes. A particularly important question he raised is whether differences in error rates may account for differential reaction times. When comparing brain-injured vs. control subjects, one must question whether the two groups use comparable speed-accuracy criteria, and whether reaction time is measuring the same process for each of the two groups. One way of addressing this question is to examine the differences in numbers of correct vs. error responses in brain injured and control groups with a predetermined rate of stimulus presentation.

The present investigation provided an alternative way of studying attentional deficits in brain-injured patients. It used a continuous performance signal detection task, and compared correct and error responses of brain-injured and control subjects. It provided information as to the nature of the attentional deficits observed in patients with closed traumatic head injuries, and the impact of fatigue and impulsivity on the performance of these patients. Further, it measured each of these variables at three different points in the recovery process. Results of this investigation were evaluated to determine whether they support previous reaction time research or whether they provide alternative explanations of brain-injured patients' attentional deficits.

CHAPTER II

METHOD

Subjects

The experimental group consisted of ten patients (6 male and 4 female) in a head injury rehabilitation program at a midwestern teaching hospital. Each patient had a recent history of severe closed traumatic head injury (incurred in motor vehicle accidents) resulting in neurological impairment consistent with acceleration-deceleration insult and multifocal brain damage. Galveston Orientation and Amnesia Test scores (Levin, O'Donnell, and Grossman, 1979) at initial testing were at least 80, to rule out patients who were still in an acute Post Traumatic Amnestic state. Patients agreed to be tested at approximately monthly intervals for a total of 3 tests, while they participated in a cognitive rehabilitation program. Initial testing occurred within 4 months of injury, and final testing was completed within 6 months post injury. Length of time between injury and initial testing averaged 5.3 weeks, with a range of 3-9 weeks. All subjects were comatose for at least 7 days following their injury, and average length of Post Traumatic Amnesia was 3-4 weeks. Average age of experimental subjects was 19.8 years, with a range of 13 to 35 years. Average years of education was 10.8 years (ranging from 6 years to 16 years).

Ten control subjects, matched for age, education, and sex, with no history of concussion/head injury, neurological impairment, psychiatric disorder, and drug or alcohol abuse were tested on one occasion only. These subjects were recruited among friends and relatives of experimental subjects, and additional volunteers were recruited from a rural area near the teaching hospital. Subjects were matched for whether they lived in rural or urban areas. Control subjects were screened using a self-report health questionnaire and interview, and participated voluntarily. Average age of control subjects was 21.7 years (ranging from 13 to 33 years), and average years of education was 10.9 (ranging from 6 to 16 years).

Procedure

Demographic and medical data were collected through personal interviews, questionnaires, and/or review of hospital records. All subjects were screened, interviewed and tested by the author. In the initial test sessions, the Galveston Orientation and Amnesia Test was administered to experimental subjects. Testing was begun only after the subject was able to obtain a score of at least 80 on this test, to insure that post traumatic amnesia had resolved. For control subjects, a medical history questionnaire was completed. Subjects were accepted only if their histories were negative for significant head injury, neurological or seizure disorder, psychiatric disorder, and heavy or extended alcohol or drug use.

Four different trials of the Digit Span Task (Digits Forward), as described on the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981), were administered, to obtain a baseline performance level for each subject. These trials were obtained from the Digit Span Task of the WAIS-R and the WISC-R, and each trial consisted of a different sequence of digits to eliminate the possibility of subjects' learning the sequence from one trial to the next. Then a continuous performance task was administered to each subject. The task consisted of a series of "X's" and "O's" visually presented to subjects on an APPLE Computer monitor. The task was designed to meet several criteria. The first consideration was simplicity. Since subjects were to be tested as soon as possible after their injury, it was necessary to minimize necessary instructions and use nonverbal as well as verbal presentation of the instructions. The need for higher cognitive functions such as memory and reasoning was eliminated as much as possible. Stimuli were designed to be large enough (5 cm tall and 3.125 cm wide) to counteract visual acuity problems and they were presented on an APPLE IIE monitor in the center of the subject's visual field on every trial to minimize the effects of impaired visual scanning or other perceptual deficits. Motor movement

required for the response was minimal, requiring only the ability to press a button. The simplicity of the task was intended to facilitate its usefulness with patients in an acute care, inpatient rehabilitation program. (See Appendix A for a description of a pilot investigation which influenced the development of the task.) Three hundred stimuli (50% "X's" and 50% "O's") were presented in a random sequence at the rate of one stimulus per second for a total of 5 minutes. Stimuli were presented by an APPLE II microcomputer, which also recorded subjects' responses.

Subjects were instructed that they would see either an "X" or an "O" on the APPLE monitor. They were told to respond by pressing the <Space Bar> for an "X" and to do nothing if the letter was an "O." Following the verbal instructions, subjects were given a practice block of 10 stimuli. If the subject was able to perform the practice trials correctly, he/she proceeded to the continuous performance test. If the subject did not perform the practice trials correctly, the trials were repeated up to 2 more times. If the subject was unable to perform the practice trials perfectly at this point, but did indicate an understanding of the task, he/she was given the test. For one brain-injured subject who seemed never to understand the instructions or demands of the task, testing was discontinued and he was replaced with a different subject.

Immediately after completing the continuous performance test, subjects were retested on the Digit Span test. Subjects were given no feedback during testing, to avoid confounding the testing with distracting stimuli. After the testing was complete, however, subjects were given feedback as to their performance. Total testing time was about 20 minutes, and the experimenter was present throughout administration of the tests.

This procedure was completed once for control subjects. Brain-injured subjects repeated the procedure (except that the Galveston Orientation and Amnesia Test was given only on the first occasion) on three occasions: the first within 4 months of injury, the second about one month later, and the third about 2 to 3 months after the first testing. Due to the constraints of the cognitive rehabilitation program, most subjects were discharged from the inpatient rehabilitation center between the second and third testing, and the third testing was conducted when they returned for outpatient follow-up services.

CHAPTER III

RESULTS

Continuous Performance Test

Two separate analyses of variance were performed to evaluate hit rates and false alarm rates of brain-injured and control subjects during the 5-minute continuous performance test. For brain-injured subjects, data from the initial test period were used in this analysis, since control subjects completed only one test period. A hit was scored when a subject correctly pressed a button when an "X" appeared on the computer monitor screen. Hits for brain-injured vs. control subjects were compared across the 5 one-minute blocks of trials. Control subjects scored significantly more hits than brain-injured subjects throughout the entire continuous performance test, $F(1,18) = 15.72$, $p < .001$. Although hit rate appeared to decline somewhat over testing, no significant differences were noted in hits across blocks. Table 1 shows hit rates for each group during each of the 5 one-minute blocks. Overall hit rate was 96% for the control group and 74% for the brain-injured group. For individual subjects, hit rates ranged from 89% to 100% for controls and from 33% to 90% for brain-injured subjects.

INSERT TABLE 1 ABOUT HERE

A false alarm was scored when a subject incorrectly pressed the button when the stimulus letter was an "O." False alarms for controls vs. brain- injured subjects were analyzed in the same manner as that described for hits. Brain-injured subjects scored significantly more false alarms than control subjects across all 5 blocks of the continuous performance test, $\underline{F}(1,18) = 21.29$, $\underline{p} < .0005$. Overall false alarm rates were 3.98% for control subjects, and 24.26% for brain-injured subjects. Additionally, false alarm rate was significantly affected by block, $\underline{F}(4,72) = 5.79$, $\underline{p} < .0005$, and a group by block interaction, $\underline{F}(4,72) = 2.38$, $\underline{p} < .059$ approached significance. Table 2 shows false alarm rates for each group during each of the 5 one-minute blocks. False alarm rates of control subjects ranged from 0.6% to 8.2%, while false alarm rates of brain-injured subjects ranged from 7.6% to 46%.

INSERT TABLE 2 ABOUT HERE

Figures 1 and 2 illustrate the comparison of hit rate and false alarm rate for experimental and control groups across the 5 blocks.

INSERT FIGURES 1 & 2 ABOUT HERE

Analyses of variance were also performed on the hits and false alarms of the brain-injured subjects across the 5 blocks and 3 testing periods (over recovery). Subjects' hit rates improved with recovery, producing a significant period effect, $\underline{F}(2,18) = 14.98$, $\underline{p} < .0001$. Mean hit rates for each period were 74.28, 85.24, and 89.24 respectively. Subjects also showed significantly improved performance across periods (recovery) with regards to false alarm rate, $\underline{F}(2,18) = 10.53$, $\underline{p} < .001$. False alarm rates averaged 24.26 at the first test period, 17.4 at the second, and 12.26 at the third testing. These are illustrated in Figure 3.

INSERT FIGURE 3 ABOUT HERE

Hit rates also changed significantly across blocks, $\underline{F}(4,36) = 5.71$, $\underline{p} < .001$. Hit rates by block across all 3 periods were: 87.73, 83.13, 83.03, 78.73, and 81.97 respectively. False alarm rates were also significantly affected across blocks, F(4,36) = 11.81, $p < .0001$. False alarm rates by block across all three periods were: 14.5, 17.63, 14.37, 16.60, and 26.77. No significant interaction between periods and blocks was found, indicating that the general pattern of the block effect remained consistent over recovery for both hit rate and false alarm rate. Block effects on hit rate and false alarm rate are shown in Figure 4.

INSERT FIGURE 4 ABOUT HERE

Figures 5 and 6 illustrate the hit rates and false alarm rates of the brain-injured group across all 5 blocks at the 3 different test periods (control subjects' data from their first and only test period is presented for comparison). These data are presented as a summary of the pattern of results over blocks and over recovery. Note again, overall block and recovery effects are significant for hit rate and false alarm rate, and no interactions are present.

INSERT FIGURES 5 & 6 ABOUT HERE

Because of the observed variability in the performance of the brain-injured subjects, it was decided to evaluate standard deviations for significant differences between the experimental and control groups. This analysis did, indeed, show a significant group effect, both for hit rate, $\underline{F}(1,18) = 13.63$, $\underline{p} < .005$, and for false alarm rate, $\underline{F}(1,18) = 17.03$, $\underline{p} < .001$. Thus, significantly more variability was found among brain-injured subjects than among control subjects. Brain-injured subjects' variability was then examined more closely to determine whether it was differentially affected by different experimental conditions. No systematic changes in variability occured as a result of recovery, nor was there a systematic block effect on variance. Thus, the difference in variance observed between the control and experimental groups appears to result from variability among the brain-injured subjects themselves, rather than any of the independent variables used in the experiment. In light of the variation between subjects, significant results are particularly remarkable. Finally, an analysis of "d'," which combines hit rate and false alarm rate was performed on the continuous performance test data for both control and brain-injured subjects. The d' has been determined by signal detection theorists to represent a more accurate measure of attention and fatigue than either hit rate or false alarm rate alone. This analysis revealed a significant difference in d-prime between control and brain-injured groups, $\underline{F}(1,18) = 23.33$, $\underline{p} < .0001$. Also, significant period, $\underline{F}\ (2,18) = 25.39$, $\underline{p} < .0001$ and block, $\underline{F}\ (4,36) = 5.74$, $\underline{p} < .001$, effects were found. These significant effects are consistant with and further reinforce the differences in hit rates and false alarm rates in the earlier ANOVA. They indicate that the main effects are significant even when hit rate and false alarm rate are combined in a traditional signal detection analysis.

Digit Span

The digits forward portion of the Digit Span test was incorporated into this investigation to evaluate fatigue and/or motivational factors which might influence brain-injured and control subjects differentially. An analysis of variance comparing the two groups' performances on the task before and after the continuous performance test was performed. This analysis revealed no significant differences between groups either before or after the continuous performance test, nor was before/after performance significant when groups were combined. Average number of digits recalled by control subjects was 6 before the continuous performance test and 6.2 after the continuous performance test. Averages for brain-injured subjects were 5.27 and 5.35, respectively, before and after the continuous performance test. Analysis of Digit Span results before and after the continuous performance test for brain-injured subjects across the 3 test periods again yielded non-significant results. Brain-injured subjects were able to repeat about 5.4 digits regardless of whether they were tested before or after the continuous performance test, and regardless of recovery.

CHAPTER IV

DISCUSSION

Results of this investigation demonstrate that the continuous performance task developed for the study of attentional deficits in brain-injured patients is a sensitive discriminator of brain injury. It was found to differentiate brain-injured from control subjects on a variety of experimental variables, including vigilence, impulsivity, and increased impulsivity with time-on-task. It was also effective in assessing improvement at different points of recovery in the brain-injured group.

Hit rates were evaluated as an indication of attention and vigilence on the task. Control subjects achieved significantly higher hit rates than brain-injured subjects, supporting the observation among rehabilitation professionals and brain-injured patients that patients have difficulty maintaining attention on tasks. This finding is consistent with reaction time studies which demonstrate that brain-injured patients have a deficit in attention which interferes with their ability to deal quickly and efficiently with information. It was hypothesized that the hit rate of the brain-injured group would decline relative to the control group over the 5 minutes of the continuous performance test, due to increased susceptiblity to fatigue. This was not supported, as hit rates showed a slight (nonsignificant) decline which was equally evident in both groups. When brain-injured subjects' hit rates across recovery were examined, however, a significant decline over time-on-task was found. False alarm rates were believed to measure impulsive responding, or inability to inhibit an inappropriate response. As expected, results showed the brain-injured group to experience much more difficulty inhibiting the response when it was inappropriate. Observation of the subjects as well as subjects' remarks during and after the task indicate that most subjects were aware that they had responded incorrectly by pressing the button for the wrong stimulus, but they were unable to inhibit the response in time to prevent the error. Control subjects, on the other hand, were able to achieve very low false alarm rates, demonstrating the ability to quickly process the information and respond with appropriate inhibition. False alarm rates of brain-injured subjects increased significantly during the task, indicating that impulsivity or disinhibition was adversely affected by time-on-task in these subjects.

On both hit rate and false alarm rate, brain-injured subjects showed significant improvement over recovery. This investigation provides evidence that brain-injured patients can be expected to show gains in attentional capacity and ability to inhibit inappropriate responses for at least six months following their injury. On the analysis of hit rate across recovery, which evaluated data from the brain-injured subjects' performance at three different points in recovery, a significant decline in performance over the 5 minutes of the task was found. This differs from the results reported when both groups were compared on the first test period, where time-on-task was not found to significantly affect hit rate. This discrepancy may be due to the greater number of trials on the recovery analysis, and/or to the possiblity that combining control and brain-injured subjects for the first analysis may have masked some of the differences in the brain-injured group. At any rate, brain-injured subjects showed impaired ability to attend to the task for the entire 5 minutes when data across three periods of recovery were combined. These may represent fatigue effects, and they showed a consistent pattern relative to hit rate over recovery.

False alarm rates of brain-injured subjects decreased markedly over recovery, indicating that as patients recovered from their brain injuries, they became less impulsive and more able to inhibit inappropriate behavior. Although their overall performance improved over the three test periods, the tendency to respond more impulsively as subjects performed the task remained evident.

Brain-injured subjects' performance on this task was found to be significantly more variable than control subjects', but the variance was not systematically related to any of the experimental variables. Bruhn and Parsons (1971) also found significant variability in performance of patients with brain dysfunction. Consistent with the present data, they found no significant effect of fatigue on variability. In the present investigation, variability was not found to decrease significantly over recovery, indicating that brain-injured patients' inability to consistently perform a task may be a relatively long-term impairment.

When hit rate and false alarm rate were combined in an analysis of d', results were consistent with the separate analyses. This analysis showed that when they were forced to perform a task at a fixed rate, brain-injured and control subjects do not demonstrate comparable hit rates or false alarm rates. Interestingly, brain-injured subjects' hit rates and false alarm rates varied significantly with time-on-task as well as with recovery. As Pachella (1983) warned, these differences in error rate may affect reaction times among different groups under investigation. Careful consideration must be given to differences in error rates, and inferences about information processing in brain-injured patients based on studies with non-brain-injured subjects must be evaluated carefully.

No significant differences in Digit Span performance were found. Control and brain-injured groups performed about equally, and their performance was not affected by having performed the continuous performance test immediately preceding testing. It was hoped that conclusions about fatigue could be drawn from the inclusion of the Digit Span task. The data fail to support a generalized fatigue effect in either the control or brain-injured group; instead, the increase in false alarm rate appears to be due to some task specific factor in the continuous performance test. Alternatively, the lack of difference in pre/post Digit Span performance may simply indicate that the Digit Span test is not sensitive to the effects of fatigue. At any rate, it can be concluded that, as Lezak (1979) suggested, Digit Span is not very sensitive to the effects of brain damage, despite its purported effectiveness in detecting deficits in attention and concentration. Nor is it a good indicator of recovery, as it did not change with recovery in the current investigation.

Neural Systems

Posner (1982) states that: "There is evidence that findings at the level of performance, subjective experience, and neural systems can be linked, even though they are not yet reducible to a single theory" (Posner, 1982, p.168). The investigation of the behavioral correlates of brain injury provides an opportunity to make tentative connections between behavior and areas of the brain which are likely to be damaged. In the case of acceleration-deceleration trauma, a number of lesions may be present, but the most common areas of impairment are the frontal and temporal areas which are adjacent to the walls of the anterior and middle cranial fossae. Because of the movement of the brain within the skull and dural envelope, these bony structures typically damage the tips of the temporal and frontal lobes and the orbital surface of the frontal lobe. Laceration and contusion of these areas may result in swelling, intracranial hemorrhage, distortion, and shifting of the brain (Miller, 1983). Other damage which is common in closed head trauma includes widely scattered shearing of axons within their myelin sheaths (white matter), local lesion at the site of impact, and "contra-coup" lesion where the brain impacts the skull opposite the primary site of impact.

Luria (1973) discusses attentional deficits and related brain structures.

> Any complex form of attention, involuntary or, more especially voluntary, requires the provision of other conditions, namely the possibility of <u>selective recognition of a particular stimulus</u> and inhibition of responses to irrelevant stimuli, of no importance in the current situation. This contribution to the organization of attention is made by other brain structures located at a higher level: in the <u>limbic cortex</u> and in the <u>frontal region</u>. (p. 271)

Luria relates lesions in the limbic system, more specifically in the hippocampal structures, to a breakdown of selectivity of behavior. Lesions in this area result in instability of selective responses, marked fatigability, and distractability which may be compensated by the introduction of verbal instructions. Lesions in the frontal lobes have a different impact on attention. "Inability to concentrate on an instruction and to inhibit responses to irrelevant stimuli becomes apparent" in frontal lobe patients (p.274). Frontal lobe lesions may result in impulsive orienting to irrelevant stimuli. Environmental manipulation, rather than verbal mediation has been found most effective in working with patients with frontal lobe lesions.

The subjects in the current investigation all demonstrated behavioral deficits associated with frontal lobe lesions. This is consistent with the type of injury they had incurred, and with results of current testing. The elevated false alarm rates, in particular, are consistent with Luria's description of impulsivity and inability to inhibit responses to irrelevant stimuli.

Implications for Rehabilitation

One of the purposes of this investigation was to learn more about attentional deficits related to brain injury. This issue has been addressed in the discussion thus far. Another purpose discussed early in the introduction, was to provide information relevant to rehabilitation which might be useful to service providers. Several suggestions may be offered based on the research presented here. Although the simple task used in this investigation may seem far removed from complex tasks of every-day life, it does bear some striking similarities. The ability to make decisions and perform under time pressure is often required in daily activities. Although responses are typically so automatic that time pressure frequently goes unnoticed, the brain-injured patient has often lost this capacity to respond automatically. Driving an automobile is a complex activity that requires a number of constant quick judgements. Cooking a meal, answering a telephone, and even simply conversing all contain elements of timing and quickness. This investigation has shown that the brain-injured person's ability to attend to stimuli and to inhibit inappropriate responses are considerably impaired when he/she must respond at a rate which may seem quite slow to an unimpaired person. If a brain-injured person has difficulty on a particular task, it may be helpful to switch to a less stressful task for a while, and to break the more difficult task down into small steps which can be presented one at a time at a slowed rate. Additionally, before releasing a patient to return to driving and/or operating complicated machinery, the task described in this investigation could be used as a brief screening device to assess whether the patient is able to handle information quickly and efficiently. Two subjects in the current investigation were able, at the third testing, to perform the task as well as the control subjects, indicating their readiness for more extensive training in complex tasks (i.e., driver training).

It was also found in this investigation that fatigue effects may be detected in both decreased attention and increased impulsivity after only 5 minutes of intense concentration. This task was rather stressful because of the time pressure, and subjects may be expected to respond to other stressors in similar ways (i.e., fatigue, attentional problems, impulsivity, or disinhibition). Such behaviors may be diagnostic of stress, and provide cues that something in the environment or task being performed needs to be modified, and/or that the patient needs a rest period. Stress appears to be a critical factor in fatigue among brain-injured patients, as other investigators who did not incorporate time pressure into their task report no evidence of unusual fatigue among brain-injured subjects (Bruhn & Parsons, 1971).

Practitioners often comment on the variability of brain-injured patients' performance from day to day and week to week. This variability was also noted on a shorter term basis in the present investigation and in that of Bruhn and Parsons (1971). Variability appears to be a characteristic of brain-injured patients, and no factor examined thus far appears to affect it systematically. At this time, it can be pointed out that practitioners should expect variability in performance to continue through at least the first 6 months of recovery. In testing it will be helpful to take repeated measures to determine both an average level of performance and to assess variability in the individual patient's performance. At this time, there is no research which suggests ways of remediating variability, but perhaps future investigation will shed more light on this problem.

Summary

Although attentional deficits have been widely observed and acknowledged in patients who have suffered acceleration-deceleration closed traumatic head injury, relatively little is known about the specific nature of those deficits. This investigation was developed to study more specifically the nature of attentional deficits in these patients. A paced continuous performance task allowed a comparison of correct and error responses of brain-injured and control subjects. It provided evidence that brain-injured patients experience a number of problems in maintaining attention to a task, including deficits in vigilence, fatigability, and impulsivity. Further, this investigation demonstrated that these deficits improve significantly during the first six months of recovery. Increased variability in the performance of brain-injured subjects was also observed in this study, and it did not seem to improve significantly during the first 6 months of recovery. Differences in the error rates of control and brain-injured subjects were found, and it was found that, for brain-injured subjects, hit rates and false alarm rates changed over time on task and also with recovery. Finally, physiological correlates of attentional deficits were discussed, and recommendations for rehabilitation practitioners based on this investigation were presented.

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Table 1

Hit Rates for Control and Brain-Injured Subjects Over Five 1-Minute Test Blocks

	Block Number				
	1	2	3	4	5
Control	97.7	96.3	95.5	94.6	97.0
Brain-Injured	78.4	73.4	72.7	71.6	75.3

Table 2

False Alarm Rates for Control and Brain-Injured Subjects Over Five 1-Minute Test Blocks

	Block Number				
	1	2	3	4	5
Control	3.2	3.7	2.4	4.3	6.3
Brain-Injured	19.0	23.3	21.2	23.0	34.8

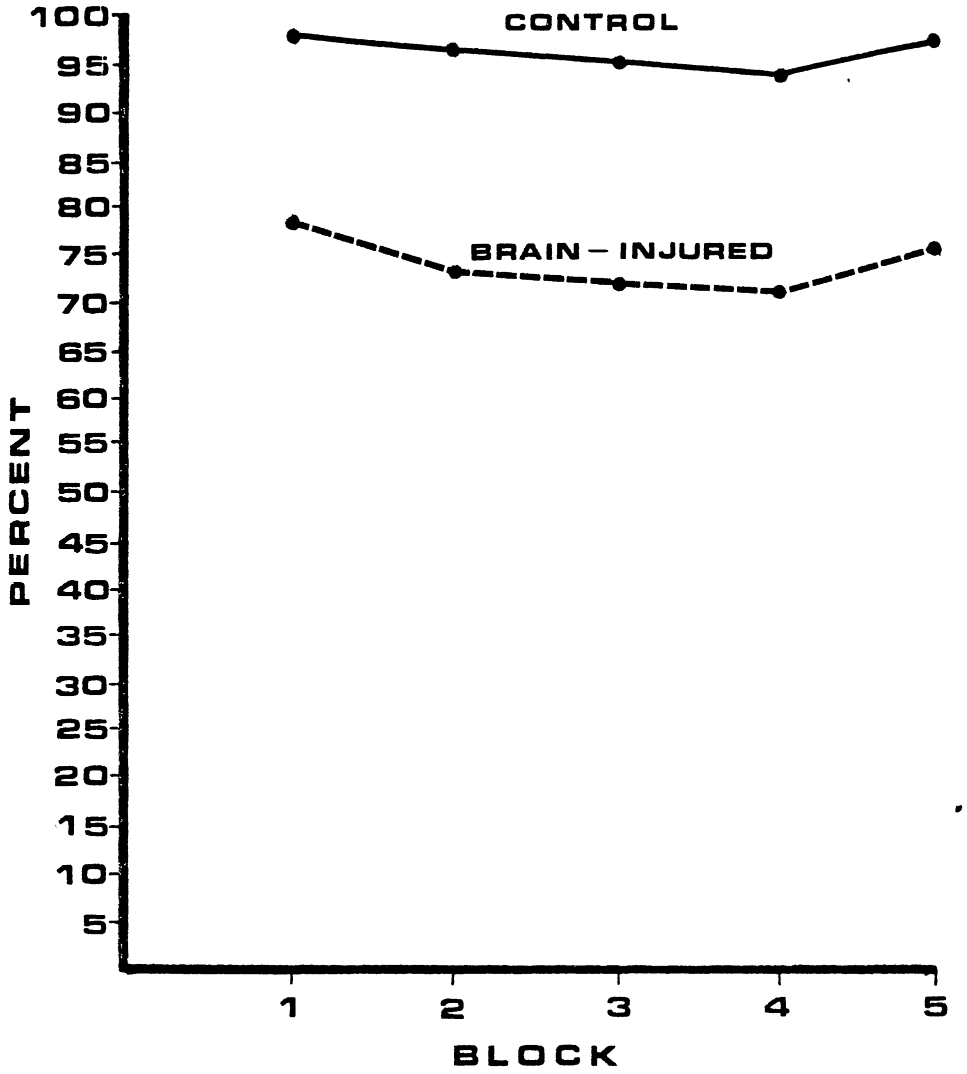

Figure 1. Hit rate of brain-injured and control subjects across five 1-minute blocks of the continuous performance task.

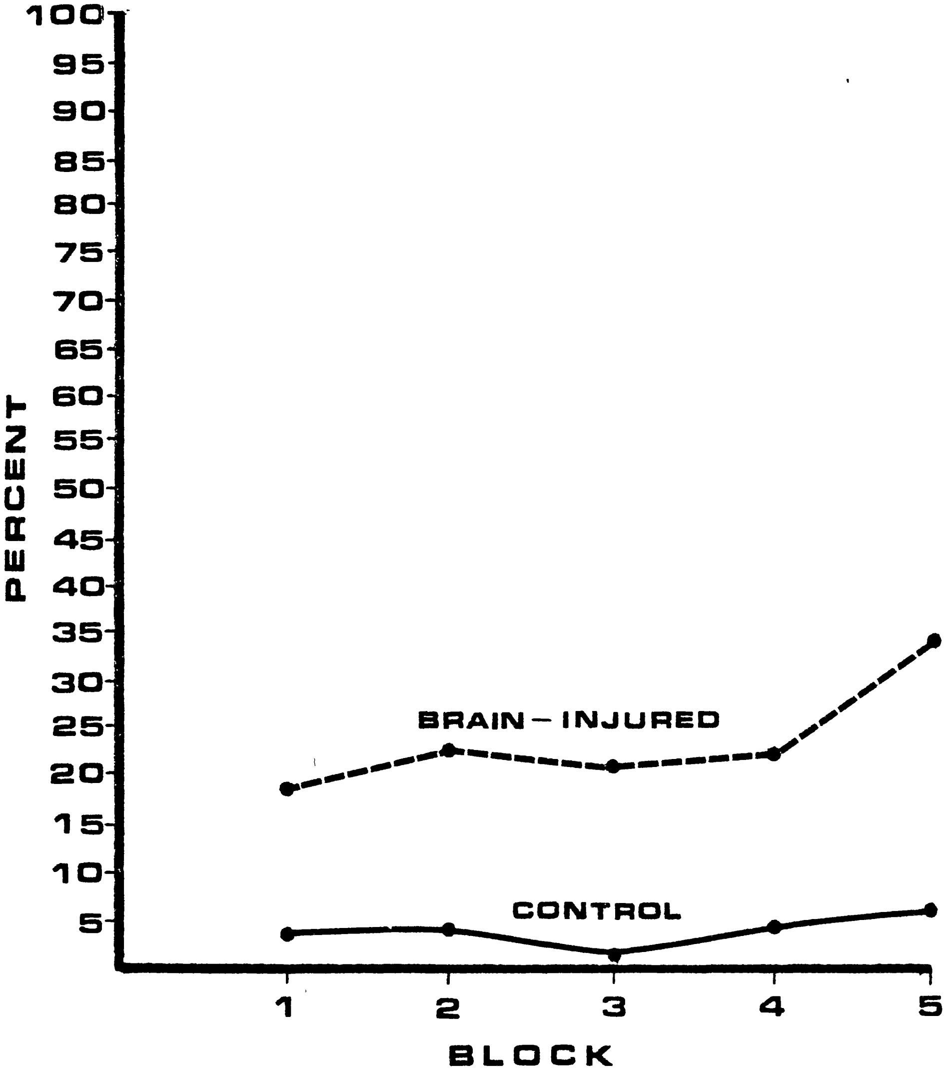

Figure 2. False alarm rate of brain-injured and control subjects across five 1-minute blocks of the continuous performance task.

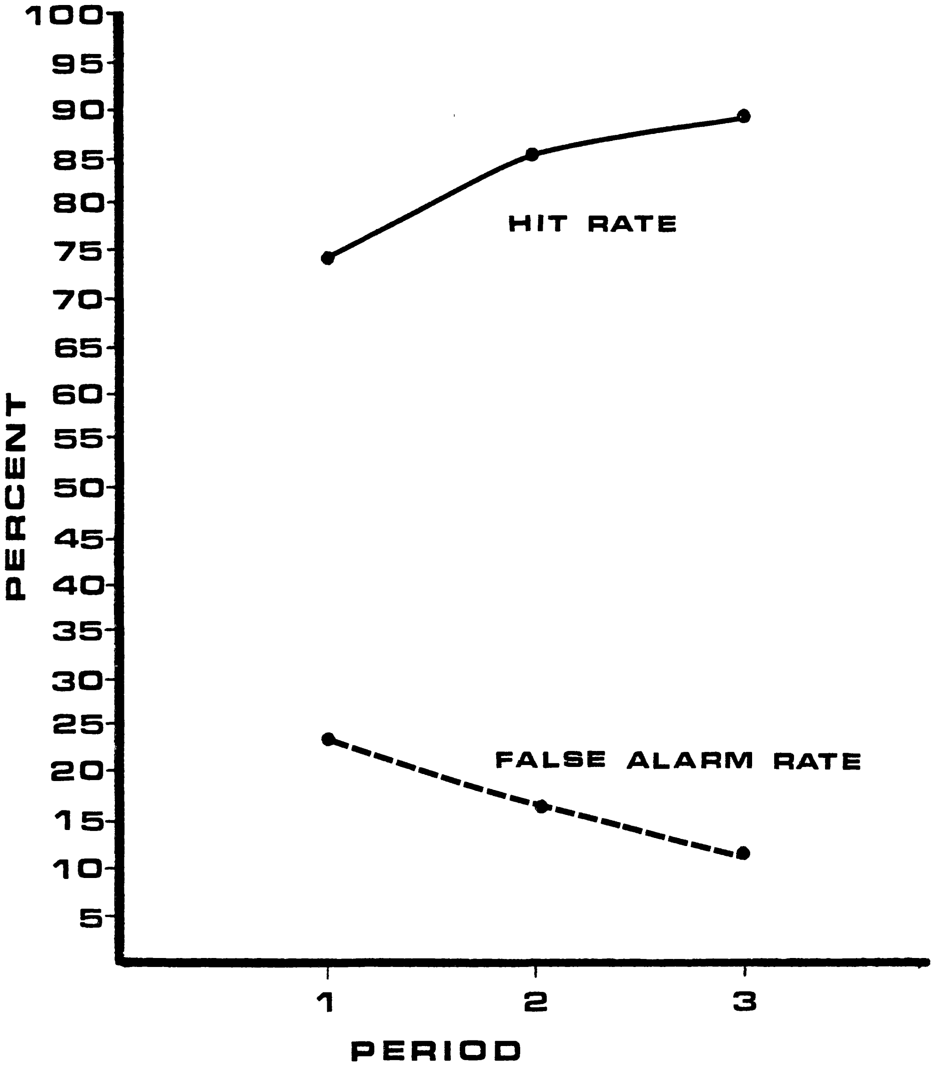

Figure 3. Hit rate and false alarm rate of brain-injured subjects over 3 recovery periods.

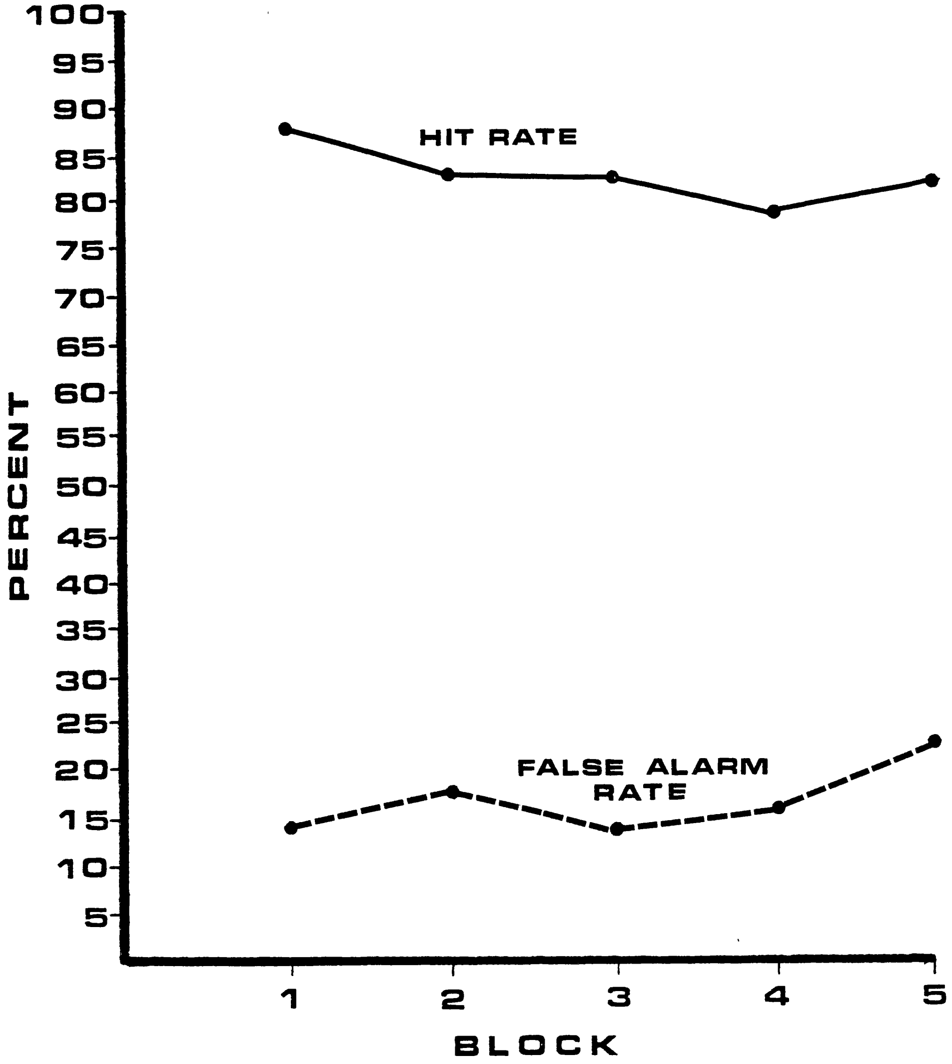

Figure 4. Hit rate and false alarm rate of brain-injured subjects across five 1-minute blocks of the continuous performance task (averaged over 3 points in recovery).

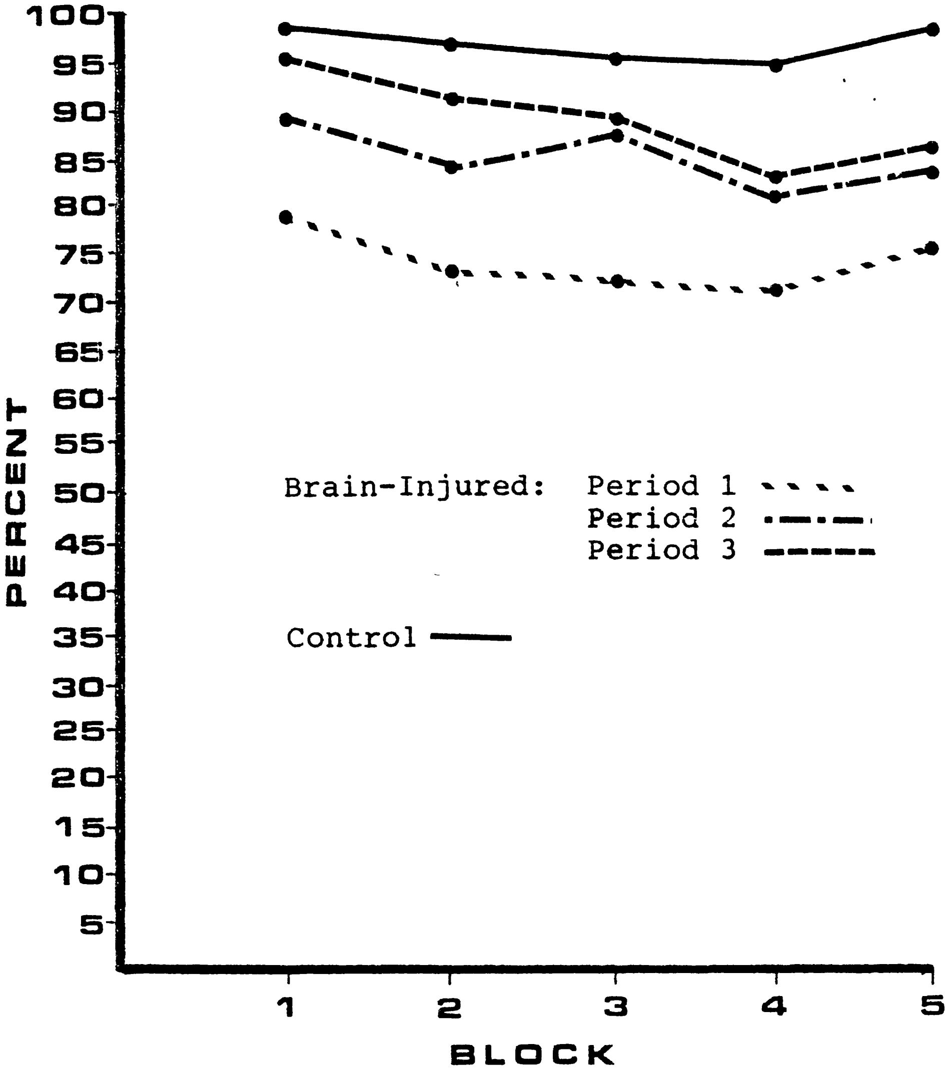

Figure 5. Hit rates of brain-injured subjects across five 1-minute blocks of the continuous performance task at 3 periods in recovery. Hit rates of control subjects at their single test period are included for comparison.

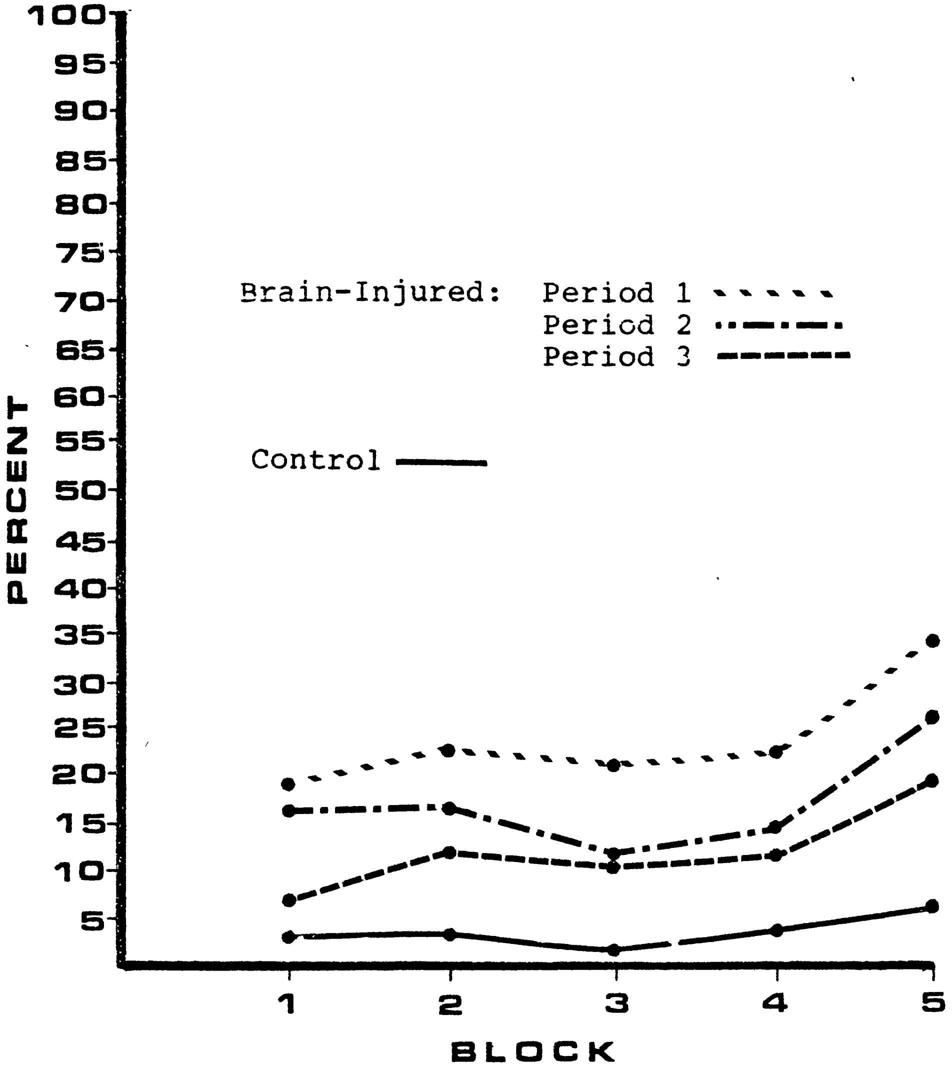

Figure 6. False alarm rates of brain-injured subjects across five 1-minute blocks of the continuous performance task at 3 periods in recovery. False alarm rates of control subjects at their single test period are included for comparison.

APPENDIXES

APPENDIX A

PILOT INVESTIGATION

COMPUTERIZED TEST OF VISUAL PROCESSING
FOR BRAIN-INJURED PATIENTS

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In the rehabilitation of brain-injured clients, a frequently asked question is, "how quickly can this person process information with which he/she is presented?" Slowed response latency is a common deficit among these clients. Golden (1978) and Lezak (1983) include speed of processing as an important issue in neuropsychological assessment, and Benton (1975) describes speed of response as one of the basic abilities represented in the brain. At this time, however, we have no adequate standardized measure of processing speed. Tasks which are currently being used to informally assess speed of processing are typically fairly complex, involving components of memory and channel capacity as well as processing speed.

In reaction time investigations of the performance of brain-injured subjects on information processing tasks it has generally been found that brain-injured subjects' performance is significantly slower than that of control subjects. Their performance also improves more slowly with practice than the performance of normal subjects (Miller, 1970; Van Zomeren & Deelman, 1978; Benton & Blackburn, 1957; Bruhn & Parsons, 1971). A task that could objectively measure speed of processing of brain-injured patients in the early stages of their recovery would have both theoretical and practical relevance in the fields of neuropsychology and information processing.

As patients with closed traumatic head injuries begin to recover from the initial trauma to the brain, their pattern of impairment often changes dramatically. As researchers study the stages of recovery for different types of lesions, more and more is learned about the behavioral correlates of such lesions. By including a measure of processing speed in investigations, valuable information may be provided about the function of different areas of the brain in information processing and the regulation of behavior. Posner (1982) discusses the importance of linking neural systems with phenomena at the level of performance and subjective experience. Investigations of subjects with documented brain damage will assist in making such connections.

Psychologists who work with brain-injured clients are becoming more and more interested in devising cognitive retraining and rehabilitation programs which are effective and efficient for particular individuals. Golden (1978) defines the role of the neuropsychologist as follows:

> The neuropsychologist attempts to design rehabilitation techniques which will prepare the patient to maximally benefit from training given by physical therapists, occupational therapists, speech pathologists, and other rehabilitation workers. (p. 191)

Diller and Gordon (1981) emphasize the need for diagnostic information which can be directly related to treatment. Therapists working with the patient need to know how to provide the best possible environment for the client's assimilation and understanding of the material they are presenting. A basic area of concern is the rate of presentation of material which is optimal for the client. This optimal rate of presentation may be generally defined as the individual client's "speed of processing."

This investigation is part of a pilot project which attempts to further isolate and measure attention and speed of processing in a visual-perceptual task. The task was designed to meet several criteria. The first consideration was simplicity. Since it is desirable to begin rehabilitation as soon after the trauma as possible, it was necessary to make instructions as simple as possible and use nonverbal as well as verbal presentation of the instructions. The need for higher cognitive functions such as memory and reasoning was eliminated as much as possible. Stimuli were designed to be large enough to counteract visual acuity problems and were presented in the center of the visual field on every trial to minimize effects of impaired visual scanning or other perceptual deficits. Motor movement required for the response was minimal, requiring only the ability to press a button. The simplicity of the task was intended to facilitate its usefulness with patients in an acute care, inpatient rehabilitation program. Another criterion was that the task had to gather necessary information in as short a time as possible at each testing, to reduce the impact of attentional problems and fatigue upon test results. Finally, the task had to provide a measure of speed of processing, or the speed at which the client could accurately perceive and appropriately respond to simple visual stimuli.

The purpose of the present investigation was to examine the performance of control and brain-injured subjects on a visual perceptual task at differing rates of presentation. It was hypothesized that the brain-injured subjects would commit significantly more errors than control subjects. Further, brain-injured subjects' performances were expected to be more impaired at the faster rates of presentation, reflecting a speed of processing deficit in these subjects.

Method

Subjects

Subjects for this investigation included six brain-injured clients in a cognitive rehabilitation program at a midwestern teaching hospital. Experimental subjects had a history of severe closed traumatic head injury, resulting in neurologic impairment consistent with an acceleration-deceleration insult and multifocal brain damage. Each brain-injured subject was comatose for at least seven days following injury. Each was participating in a cognitive rehabilitation program and each was tested within six months of his/her injury.

Six control subjects were matched for age and educational level. Brain-injured and control subjects' ages ranged from 18 to 45 years (mean age was 26 years), and educational levels ranged from 10th grade to Master's Degree (mean educational level was about 14 years).

Procedure

The task consisted of a series of "X's" and "O's" (75% "X", 25% "O") presented in 20 s blocks at fixed rates. Interstimulus intervals of 1, 2, and 4 s were chosen to measure the rate at which subjects could correctly identify and respond to the stimulus letter. Sixty trials at each rate were presented to each subject. Trials were divided into 20 s blocks to reduce fatigue and attentional problems. Thus, subjects performed 3 blocks of 20 trials at the 1 s rate of presentation, 6 blocks of 10 trials at the 2 s rate of presentation, and 12 blocks of 5 trials at the 4 s rate of presentation. The blocks were arranged in a random sequence of presentation, with a rest period of at least 10 s between each block. The experimenter was present throughout administration of the test, and total test time was about 20 minutes for each subject. Stimuli were presented by an APPLE II microcomputer which also recorded subjects' responses.

Subjects were instructed that they would see either an "X" or an "O" on the APPLE screen. They were told to respond by pressing the <Space Bar> for an "X" and by doing nothing if the letter was an "O." Following the verbal instructions, subjects were given 3 practice blocks (one at the 4 s rate, one at the 2 s rate, and one at the 1 s rate.)

Results

Hit rates and false alarm rates were calculated separately for each of the two groups at each of the three rates of presentation. Control subjects performed the task virtually perfectly at each rate of presentation. Brain-injured subjects achieved a mean hit rate of 94.4% and a mean false alarm rate of 25.0% at the 1 s rate of presentation. When the number of hits and the number of false alarms were analyzed in a two-tailed *t*-test, brain-injured subjects did not differ significantly from controls on number of hits $t = 2.79$, $p > .05$, but did differ on false alarms $t = 2.79$, $p < .02$. At the 2 s presentation rate, brain-injured subjects were able to achieve a mean hit rate of 99.0% and a mean false alarm rate of 5.6%. The difference between false alarms of controls vs. brain-injured subjects approached significance ($t = 2.00$, $p < .07$). At the 4 s rate of presentation, brain-injured subjects obtained a hit rate of 99.3%, and a false alarm rate of 6.9%. Neither of these differed significantly from the control group's performance.

Discussion

The task described in this investigation was proposed as an objective measure of speed of processing in brain-injured patients. Such a task would provide information as to the patient's ability to understand and respond to material presented at different rates. This information would assist rehabilitation professionals in altering their presentation of educational and therapeutic material according to the abilities of their patients. Further, the task was designed to be useful with patients in the very early stages of recovery, when reduced speed of processing is most frequently noted to be a problem. Fatigue and attentional deficits were minimized as much as possible, to determine how quickly the patient could process simple visual information under optimal conditions.

By computing hit rates and false alarm rates separately, it was possible to determine whether subjects were capable of responding to stimuli presented at the three different speeds (1, 2, and 4 s), and to make observations as to the types of errors they made. As noted in the results, control subjects were able to respond perfectly at each rate. Brain-injured subjects were also able to respond nearly perfectly at each rate--a hit rate of 94.4% at the 1 sec presentation rate was not significantly different from the 100% hit rate obtained by controls. Differences were noted in false alarm rates between brain-injured and control subjects at the 1 s rate of presentation.

Observation of the subjects and empirical data from studies of learning disabled children (Dykman, Ackerman, Clements, & Peters, 1971; Messer, 1976; Kagan & Kogan, 1970), suggest that the high false alarm rate for brain-injured subjects may be an indication of impulsive responding. When subjects responded before fully processing the stimulus or when they were unable to inhibit an inappropriate response, the result was a false alarm--the subject saw a stimulus, but did not determine what it was before responding. The task, therefore, succeeded in differentiating controls from brain-injured subjects on this construct.

Since hit rates were not a valid discriminator between control and brain injured subjects, it is not posssible to draw general conclusions about speed of processing from this investigation. Minimizing the effects of attention and fatigue, may have eliminated some variables which are components of processing speed (Van Zomeren, 1981). Future investigations of speed of processing might do well to include measures of attention and fatigue as part of the experimental manipulation.

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APPENDIX B

COMPUTER PROGRAM:
CONTINUOUS PERFORMANCE TASK

```
10  DIM S$(300)
20  FOR J = 1 TO 150
30 S$(J) = "X"
40  NEXT J
50  FOR J = 151 TO 300
60 S$(J) = "O"
70  NEXT J
80 D$ =  CHR$ (4)
90  FOR I = 1 TO 2: FOR J = 1 TO 2: READ A(I,J): NEXT J,I
100  DATA  129,252,131,163
110  PRINT D$;"BLOAD OX"
120  FOR I = 1 TO 300
130 R =  INT (( RND (1) * 300) + 1)
140 T$ = S$(I)
150 S$(I) = S$(R)
160 S$(R) = T$: NEXT
170  PRINT "TO BEGIN, PRESS ANY KEY"
180  POKE  - 16368,0: GET A$: HOME
190  FOR D = 1 TO 770: NEXT D
200  FOR I = 1 TO 300
210  POKE  - 16368,0
220 L = 1: IF S$(I) = "X" THEN L = 2
230  GOSUB 500
240  IF  PEEK (49152) > 127 THEN R$ = "Y"
250  IF  PEEK (49152) < 128 THEN R$ = "N"
260 S$(I) = S$(I) + R$
270  NEXT I
280  POKE  - 16289,0
290  TEXT
300  VTAB 3: PRINT "F I N I S H E D"
310  VTAB 10
320  PRINT "** REMOVE ATT.EXP DISK &"
330  PRINT "** INSERT ATT.DATA DISK"
340  PRINT : INPUT "ENTER INITIALS:";I$
350  PRINT : INPUT "ENTER TEST NUMBER:";A$
360  HGR : TEXT
370 F$ = "ATT." + I$ + A$
380  PRINT D$;"NOMON I,O"
390  PRINT D$;"OPEN";F$
400  PRINT D$;"WRITE";F$
410  FOR I = 1 TO 300: PRINT S$(I): NEXT
420  PRINT D$;"CLOSE";F$
430  END
500  REM  GRAPHICS SUBROUTINE
510  HGR : HCOLOR= 3: ROT= 0: SCALE= 1
520  POKE 232,A(L,2): POKE 233,A(L,1)
530  DRAW 1 AT 139,79
540  PRINT G$
550  FOR D = 1 TO 335: NEXT D
560  RETURN
```

```
10 D$ =  CHR$ (4)
20  DIM S$(300)
30  INPUT "FILENAME?";F$
40  PRINT D$;"NOMON I,O"
50  PRINT D$;"OPEN";F$
60  PRINT D$;"READ";F$
70  FOR I = 1 TO 300: INPUT S$(I): NEXT
80  PRINT D$;"CLOSE";F$
90  FOR I = 1 TO 300
310  IF S$(I) = "XY" THEN H = H + 1
320  IF S$(I) = "XN" THEN M = M + 1
330  IF S$(I) = "OY" THEN F = F + 1
340  IF S$(I) = "ON" THEN C = C + 1
350  NEXT I
400  HOME : VTAB 5
410  PRINT F$
420  PRINT "H = ";H
430  PRINT "M = ";M
440  PRINT "F = ";F
450  PRINT "C = ";C
460 HR =  INT ((H / (H + M)) * 100 + .5)
470 FAR =  INT ((F / (F + C)) * 100 + .5)
480  PRINT : PRINT "HIT RATE= ";HR
490  PRINT "FALSE ALARM RATE= ";FAR
500  END
```

VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: INFORMATION PROCESSING AND ATTENTION DEFICITS FOLLOWING SEVERE HEAD TRAUMA

Major Field: Psychology

Biographical:

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