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Visual Reaction Time and Its Relationship to Neuropsychological Test Performance

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The purpose of this study was to investigate the relationship between simple and choice reaction time (RT) measures and neuropsychological test performance (as assessed by the Impairment Index of the Halstead-Reitan Neuropsychological Test Battery). Both median RT scores and intraindividual variability of RT scores were evaluated in three groups: impaired TBI, nonimpaired TBI, and normal controls. In all three groups, there was a statistically significant correlation between both reaction time measures and level of cognitive functioning. In addition, SRT, speed of information processing (as measured by CRT), and intraindividual variability of RT scores continued to be impaired in many brain-damaged individuals who, according to the Impairment Index, had fully recovered from their cognitive deficits. Median RT scores were better able to discriminate between impaired TBI patients and normal controls; but intraindividual variability of RT scores was better able to discriminate between nonimpaired TBI patients and normal controls. It was concluded that, by adding the two short RT tests to the neuropsychological test battery, more accurate predictions can be made about a patient's level of cognitive functioning and the nature of treatment needed for continued recovery.

With the growth of cognitive psychology, reaction time (RT) has become conceptualized as a measure of speed of information processing; and, as such, it has been used extensively to study a wide variety of mental activities in both normal and neurologically impaired populations (Margolin, 1992a; Posner and McLeod, 1982). As a result of such research, it has been repeatedly demonstrated that these chronometric measures give important information about cognitive efficiency, thus, providing useful information for predicting the patient's ability to cope with the complexities of both occupational and social settings (Gronwall & Wrightson, 1974; Miller, 1970). For this reason, RT tasks promise to be a valuable supplement in neuropsychological assessment (Blackburn & Benton, 1955; DeRenzi & Faglioni, 1965; Elsass, 1986).

Because it has been well-documented that RT is impaired in head-injury patients, it seems logical that a measure of simple response time and of more complex speed of information processing would provide valuable information about cognitive functioning. In fact, as early as 1971, Bruhn and Parsons wrote that "this deficit in information processing is so

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consistent that the simple reaction time test has merit as a diagnostic tool equivalent to that found in more sophisticated and complex psychological tests" (p. 278). In 1989, Braun, Daigneault, and Champagne stated, "There is no longer any doubt that reaction time is severely impaired as a result of closed head injury, establishing reaction time as a quick, simple, and valid tool for gauging such patients' functional status" (p. 167). A measure of intraindividual variability of response time would also provide useful information about efficiency of processing time.

Despite its potential usefulness, however, there has been little research investigating the relationship between RT and neuropsychological test performance. One of the few studies in the area found a linear relationship between intellectual impairment and RT performance; those who were the most impaired demonstrated the slowest RTs (Elsass & Hartelius, 1985). These researchers concluded that not only was RT a valuable supplement to neuropsychological assessment, but that it also was especially sensitive to progressive cerebral disease. One of the problems with this study is that Elsass and Hartelius used Willanger's (1970) procedure for classifying impairment, and it is unclear how this method relates to more common measures of neuropsychological impairment (such as the Halstead-Reitan Impairment Index).

Because of the lack of research in this area, many questions remain about the relationship of RT measures to the Halstead-Reitan Battery (HRB). This is unfortunate because the HRB is probably the most researched neuropsychological assessment instrument (Goldstein, 1990; Reitan & Wolfson, 1985), and it is also the most widely used neuropsychological assessment battery in North America and perhaps in the world (Goldstein, 1990). However, because research has established that RT and the HRB Impairment Index are both highly sensitive to brain damage (Margolin, 1992b; Reitan & Wolfson, 1985), it seems likely that they would be significantly related to each other as well.

If RT was only highly correlated with the HRB Impairment Index and assessed the same abilities, then there would be little reason to add this test to an already lengthy battery. However, it is theorized that RT scores would provide additional information about speed and efficiency of information processing which would increase HRB accuracy. The reason for this is simple. Even though other HRB subtests assess processing abilities to varying degrees, none of them represent "pure" measures. The Tactual Performance Test (TPT), for instance, is a timed complex integrative test that requires information processing skills; but performance on this test is also affected by a variety of other abilities such as psychosensory, tactile form discrimination, manual dexterity, coordination of movement, visual-spatial skills, and problem-solving (Reitan & Wolfson, 1985). Though it can be affected by other factors, RT is generally a much more "pure" (or direct) measure of speed of information processing and cognitive efficiency. The degree of this "pureness" is greatly affected by the complexity of the RT task. The most simple RT tasks appear to be little affected by other factors such as differences in strategy or knowledge. The more complex the task, the more the individual's response times will be affected by these other factors (Miller, 1970). For this reason, using both simple and complex RT measures provides much useful information about both processing speed and efficiency. This provides important information for predicting a person's ability to perform in the everyday world (Gronwall & Wrightson, 1974; Van Zomeren, 1981). And, because RT is a quantifiable measure, statements can be made about the individual's degree of impairment as compared to the general population.

A more direct investigation of the relationship between RT measures and the Halstead-Reitan Battery investigated 426 individuals with multiple etiologies (Western & Long, in press). Subjects were classified as impaired or not-impaired based on the Impairment Index and were given the same simple reaction time (SRT) and choice reaction time (CRT) measures that are used in this study. These researchers found that RT measures correctly discriminated groups with 70% accuracy. In that study, however, all subjects either had some underlying CNS pathology or were psuedoneurologic controls (i.e., patients who were experiencing difficulties with cognitive functioning even though no specific neurological problem could be detected). A comparison of individuals who are clearly with or without documented CNS pathology should provide an even better picture of the relationship between RT scores and the HRB Impairment Index.

The present study investigated this presumed relationship between RT and neuropsychological test performance, making procedural adjustments to deal with the previously mentioned problems. First, SRT and CRT measures were correlated with two levels of cognitive functioning (history of brain damage and cognitively impaired vs. no history of brain damage and not cognitively impaired), with level of cognitive functioning being measured by a modified Halstead-Reitan Impairment Index. Second, cut-off scores were established and used to determine how well each of the RT procedures was able to discriminate between the two previously described groups; SRTs & CRTs were compared to determine which was the best predictor of neuropsychological test performance. Third, the same cut-off scores were used to see if the RT procedures could discriminate between a group of individuals who do not have a history of brain damage and are not cognitively impaired (as measured by the modified Impairment Index) and a group of patients who have a history of brain damage and are not impaired on the modified Impairment Index. Fourth, a discriminant analysis was performed on half the sample to determine if RT would be selected as a predictor variable for discriminating between brain-damaged and non-brain-damaged subjects. A cross-validation was performed on the other half of the sample.

It was hypothesized that:

1. There would be a statistically significant correlation between RT measures and level of cognitive functioning (as measured by the HRB Impairment Index) and that CRT would show the higher correlation because of its increased complexity.
2. RT measures would discriminate between patients who have a history of brain damage and are cognitively impaired and those who do not have a history of brain damage and are not impaired on their neuropsychological test performance.
3. Speed and efficiency of information processing would continue to be impaired in many individuals who, according to the Impairment Index, had fully recovered from their cognitive deficits. RT measures were expected to reflect these processing deficits and, thus, be able to discriminate between individuals who are brain-damaged but not cognitively impaired (according to the modified Impairment Index) and subjects who have no reported history of brain damage and are not cognitively impaired.
4. RT would be selected as a predictor variable, and classifications utilizing RT measures would be more accurate than classifications based on Impairment Index tests alone.

METHODS

Subjects

Three groups of subjects were used in this study: (a) traumatic-brain-injury (TBI) patients who were impaired on the Impairment Index; (b) TBI patients who were not impaired on the Impairment Index; and (c) normal controls (who had no history of brain damage and who were not impaired on the Impairment Index).

The subjects for the first two groups were medical outpatients who were referred for neuropsychological assessment by private physicians, neurosurgeons, psychologists, and the Department of Rehabilitation Services. The original subject pool consisted of 229 consecutive referrals who: (a) had at least a 10th grade education, (b) were between the ages of 16 and 49, and (c) had a documented history of head trauma. Individuals who had not completed all Impairment Index and RT tests were eliminated from this group. Also excluded from the subject pool was anyone who had a history of hospitalization for psychiatric disorder or a prior history of head trauma, cerebral disease, epilepsy, or any other disorder associated with brain damage. This left a total of 94 medical patients, 47 in each group.

The third group (normal controls) was composed of students at The University of Memphis who participated in the experiment for course credit. Fifty-one students were initially tested, but three had to be dropped from the study: two because of prior history of neurological problems and one because of an inability to understand sufficient English to complete the required tests. This left 48 students in the normal control group.

Comparisons were made to ensure that there were no significant age or education differences among the three groups. (See Table 1 for group composition.)

Design and Procedure

The neuropsychological testing consisted of a pretesting interview (during which a detailed history was obtained), the Halstead-Reitan Battery (except for the Category Test), and Trail Making Test — Part B. Classification of subjects as cognitively impaired or nonimpaired was based on a revised form of the Impairment Index, a general measure of cortical integrity: Finger Tapping (dominant hand), Speech Sounds Perception Test, Seashore Rhythm Test, Tactual Performance Test (Total Time), Tactual Performance Test (Memory), Tactual Performance Test (Location), and the Trails B Test. (The Category Test was not included because we do not routinely administer it in our test battery; instead, the patient's score on Trail Making Test — Part B is calculated into our modified Impairment Index.) The Impairment Index score was determined by dividing the number of test measures on which the subject was impaired by the total number of Impairment Index measures (7). Subjects with an Impairment Index rating above .5 were considered impaired; ratings below .4 were considered nonimpaired. Subjects who were borderline impaired (i.e., had an Impairment Index of .5 to .4) were not included in the study because a dichotomous impaired vs. nonimpaired comparison should be better able to assess the sensitivity and specificity of the RT measures.

RT testing was administered via a Zenith laptop computer. The program was written in Turbo Pascal with machine language components that allowed response times to be measured in milliseconds.

The first test was modeled after Elsass's (1986) SRT task. Subjects were instructed to rest the fingers of their dominant hand lightly on the computer space bar and then to press the bar as fast as possible when a solid (filled in) dark blue circle (1.5 mm in diameter)

TABLE 1
Group Composition

	Impaired TBIs	Non-Impaired TBI	Normal Controls
History	Head Trauma	Head Trauma	No neurological or psychiatric problems
Impairment Index	above .5	below .4	below .4
Age	16–46	16–49	18–46
Mean age	30.28	29.70	29.04
SD	8.36	9.35	7.58
Education (years)	12–16	10–17	12–14
Mean Education	12.64	13.06	13.13
SD	.97	1.63	.41

appeared in the center of the screen. The circle was always the same color, the same size, and in the same position. For this task, no warning signal was presented. Subjects received five practice trials and 50 experimental test trials.

In the CRT task, subjects were presented with the outlines of four 1.5 mm circles, aligned in a horizontal row, and they were told to press the bar as quickly as possible if any two of the four circle outlines were filled in (i.e., were a solid dark blue rather than just an outlined circle). This test had five practice trials and 30 test trials (18 of which were correct trials). A warning signal of two beeps was sounded before each stimulus presentation.

The choice procedure is more complex than the SRT task because it has more stimuli and the probability of a positive trial is 60%. This CRT procedure is different from the CRT procedures typically reported by other researchers (e.g., Benton & Joynt, 1958; Blackburn & Benton, 1955; Miller, 1970). Their CRT procedures present a certain number of stimuli with a corresponding number of responses (e.g., two lights with two corresponding microswitches). The problem with these tasks is that they increase the motor demands on the subject, and more variability enters into the RT values. Although procedures exist to control for this problem (e.g., computing movement time vs. RT), our version of the CRT procedure seems a better solution because it increases the cognitive demands of the task but maintains the same motor response used in the SRT test. In addition, because the subject only presses the bar when any two circles are filled in with a solid dark blue (but does not press the bar when one, three, or four circles are filled in with a solid dark blue), this procedure has a go/no-go component that has been found to aid classificatory precision (Braun et al., 1989).

On both the SRT and CRT tasks, feedback for incorrect responses was given with a "buzzer sound" that lasted for approximately 1 second. The intertrial interval for these two tasks varied between 1 and 5 seconds. The two tasks collectively took about 10 minutes to administer when RT performance was in the normal range; the time required by other individuals depended on their level of impairment. Individual RTs were calculated in milliseconds by taking the median of RT scores.

RESULTS

Mean Reaction Times and Intraindividual Variability

RTs for the two brain-damaged groups were both slower and more variable than those of the normal controls. Group means of the individual median SRT scores were: impaired TBI (538 ms, SD = 186), nonimpaired TBI (491 ms, SD = 210), and normal controls (310 ms, SD = 38). Group means of the individual median CRT scores were: impaired TBI (1088 ms, SD = 293), nonimpaired TBI (838 ms, SD = 235), and normal controls (574 ms, SD = 121). Results of a one-way ANOVA and associated post hoc tests indicate that SRTs for both the impaired TBI and nonimpaired TBI groups are significantly different from the normal controls ($p < .01$), but they are not significantly different from each other. However, all three groups' CRTs are significantly different from each other ($p < .01$).

The three groups were then compared on the basis of intraindividual variability. (It should be noted that response times faster than 150 ms were not used in these computations because these were believed to be anticipatory responses rather than true response-to-stimuli. Response times longer than 2,600 ms were also excluded because they appeared to be influenced by other factors [e.g., difficulty staying on task] in addition to speed and efficiency of information processing.)

After the SD (intraindividual variability) was determined for each subject's SRT and CRT performances, group means were determined. The mean SDs for the groups on the SRT task were: impaired TBI (295 ms, *SD* = 198), nonimpaired TBI (238 ms, *SD* = 169), and normal controls (75 ms, *SD* = 53). On the CRT task, group means for intraindividual variability were: impaired TBI (395 ms, *SD* = 161), nonimpaired TBI (340 ms, *SD* = 157), and normal controls (240 ms, *SD* = 166). Results of a one-way ANOVA and associated post hoc tests showed that, for both the *SRT-SDs* and *CRT-SDs*, the impaired and nonimpaired TBI groups were significantly different from the normal controls; but they were not significantly different from each other.

Relationship Between Reaction Time and the Impairment Index

The mean Impairment Index scores for the three groups were: impaired TBI (.73, *SD* = .17), nonimpaired TBI (.21, *SD* = .10), and normal controls (.15, *SD* = .12). It should be noted that the mean Impairment Index score for the nonimpaired TBI group is well within the normal range.

When RT scores were correlated with the Impairment Index, the findings were as follows: $r = .40$ for SRT, $r = .60$ for CRT, and $r = .59$ for SRT & CRT combined. All three correlations are statistically significant ($p < .01$), demonstrating a positive relationship between RT and level of impairment demonstrated on the neuropsychological tests.

Intraindividual *SDs* were also correlated with the Impairment Index scores. The findings for this analysis were: $r = .40$ for *SRT-SDs*, $r = .27$ for *CRT-SDs*, and $r = .43$ for *SRT-SDs* and *CRT-SDs* combined.

Sensitivity and Specificity of Reaction Time Measures

Sensitivity refers to a test's ability to correctly classify patients with a known diagnosis; proper classification of patients who do *not* have a given diagnosis is called *specificity* (O'Donnell, Reynolds, & DeSota, 1984). To examine the sensitivity and specificity of the RT procedures, cut-off scores for mean values of the two RT procedures were calculated so as to maximize each procedure's ability to discriminate between the impaired and nonimpaired levels of neuropsychological test performance (i.e., the ability to discriminate between the impaired TBI group and normal controls). The selected cut-off scores were 380 ms for SRT and 780 ms for CRT.

When the established cut-offs were used with the mixed group of impaired TBI patients and normal controls, SRT correctly classified 89.5% of the mixed group; CRT correctly classified 92.7%. To look at the issue of sensitivity, these cut-offs were exclusively applied to the impaired TBI group. SRT accurately discriminated 83% of these individuals; CRT was far more effective with a 91.5% hit rate. Specificity was examined by using the cut-offs solely with the normal controls. In this case, the correct classification rates were 95.8% for SRT and 93.8% for CRT.

Chi-square analyses of the hit-rates revealed that both the SRT and CRT procedures were able to discriminate between the two groups; but CRT yielded the best classification rate. This difference was not statistically significant, however.

The above analyses were repeated for the intraindividual *SDs*. The selected cut-off scores which maximized each procedure's ability to discriminate between groups were 90 ms for the *SRT-SDs* and 270 ms for *CRT-SDs*. When these cut-off scores were used with the mixed group of impaired TBI patients and normal controls, the *SRT-SDs* correctly classified 88.4% of the mixed group; the *CRT-SDs* correctly classified 66.3%. When these cut-off scores were exclusively applied to the impaired TBI group, SRT-SD accurately discriminated 93.6% of this group, and CRT-SD had a lower hit rate (78.7%). When the cut-offs were used exclusively with the normal controls, the correct classification rates were 83.3% for *SRT-SD* and 45.8% for *CRT-SD*.

These findings suggest that the SRT and CRT cut-off scores are more effective than *SRT-SDs* or *CRT-SDs* for discriminating between impaired and nonimpaired subjects. However, it is possible that the intraindividual *SDs* would have been equally or more effective if the outlying scores (< 150 ms and > 2600 ms) had not been excluded from computations.

Residual Reaction Time Deficits in "Recovered" TBI Patients

The previously selected cut-off scores (380 ms for SRT and 780 ms for CRT) were then used with the nonimpaired TBI group and normal controls. It should be remembered that, according to Impairment Index scores, all of these individuals were once again functioning well within the normal range of cognitive abilities. If the nonimpaired TBI group and the normal controls really do belong to the same population of normal-range cognitive abilities, then the RT cut-off scores should not be able to discriminate between the two groups.

However, when the SRT and CRT cut-off scores were used, only 69.5% of the mixed group had SRTs below the cut-off score of 380 ms, and only 66.3% had CRTs below the cut-off score of 780 ms. In other words, 30.5% of the mixed group was classified as having impaired SRTs, and 33.7% had impaired CRTs. When the nonimpaired TBI group was considered alone, 57.4% still had impaired SRTs, and 61.7 % still had impaired CRTs.

When the *SRT-SDs* and *CRT-SDs* cut-off scores (90 ms and 270 ms) were used with the mixed group of nonimpaired TBI patients and normal controls, only 52.6% of the mixed group had *SRT-SDs* below the cut-off score of 90 ms, and only 46.3% had *CRT-SDs* below the cut-off score of 270 ms. In other words, 47.4% of this mixed group had impaired *SRT-SDs*, and 53.7% had impaired *CRT-SDs*. When the nonimpaired TBI group was considered alone, 78.7 % still had impaired *SRT-SDs*, and 61.7% still had impaired *CRT-SDs*.

It is interesting to note that it is the *SRT-SDs* and *CRT-SDs* (rather than the SRT and CRT scores, themselves) that do the better job of discriminating between the nonimpaired TBI group and the normal controls.

Using Reaction Time Scores to Increase Predictive Accuracy

The purpose for the final set of analyses was to determine whether or not classifications (of brain-damaged vs. not brain-damaged) utilizing RT measures would be more accurate than classifications based on the Impairment Index alone. For this reason, the impaired TBI group and the normal controls were each divided into two subgroups: Impaired-TBIs-A, Impaired-TBIs-B, Controls-A, and Controls-B. This was done by computer random assignment. A discriminant analysis was then performed on half the sample (Impaired-TBIs-A/Controls-A) to determine if RT would be selected as a predictor variable for discriminating between the groups.

In the discriminant analysis, the variables used for possible inclusion in the prediction equation were SRT, CRT, *SRT-SD*, *CRT-SD*, and a dichotomous impaired/not impaired rating based on the HRB Impairment Index. The actual Impairment Index score was not used because it (along with neurological history) was part of the criteria for group selection and would, therefore, be automatically selected as a major predictor variable. In addition, in clinical settings, the exact Impairment Index score is used mainly to make a decision about "impaired" versus "not impaired." Once the determination is made, it is this classification that is normally referred to (rather than a specific Impairment Index figure). It is our contention that RT scores are sensitive to cognitive deficits that are overlooked by this impaired/not-impaired classification based on the Impairment Index alone. If this is the case, then the RT scores should be selected as predictor variables in addition to the dichotomous Impairment Index rating. ("Normal distribution" is one of the assumptions of discriminant analysis. Therefore, because the SRT and CRT scores for all three groups were positively skewed, logarithmic transformations were used.)

In the stepwise discriminant analysis, the following variables were selected (in the order listed): CRT, *SRT-SD*, and *CRT-SD*. At this point, the computation was terminated. SRT and the dichotomous impaired/not-impaired ranking (based on the Impairment Index) were not selected for the equation because they exceeded the tolerance level. In other words, they could add nothing to the prediction equation; all of the variance that could have been explained by the SRT and the dichotomous Impairment Index classification was already accounted for by the previously selected variables.

These selected variables (CRT, *SRT-SD*, and *CRT-SD*) correctly classified 93.75% of the sample. Wilk's Lambda was equal to .30654, showing that the RT scores accounted for 69% of the variance ($p < .01$). In a cross-validation analysis, the derived prediction formula ($D_1 = -8.7195468 + 10.4882345$ (CRT) + 2.55980794E-03 (*SRT-SD*) + (–3.05648531E-03 (*CRT-SD*)) was used on the other half of the mixed group (Impaired-TBIs-B/Controls-B) and resulted in the correct classification of 97.87% of the subjects. Only one of 47 subjects was misclassified.

The above prediction equation indicates that RT scores may bring additional information to the assessment process and make possible more accurate statements about a patient's level of cognitive functioning. To demonstrate this, the prediction formula was used to classify all members of the three groups. The results were as follows. In the impaired TBI group, 43 of 47 patients were correctly classified as brain-damaged (a 91.48% hit-rate). In the nonimpaired TBI group, 28 of 47 patients were classified as impaired (59.6%). In the normal controls, 48 of the 48 subjects were correctly identified as not impaired (100%).

It should be remembered that all of the individuals in the nonimpaired TBI group had Impairment Index scores well in the normal range and, therefore, would be considered to have cognitive functioning in the normal range. However, the above prediction equation classified 28 of the 47 nonimpaired TBI subjects as being impaired in their cognitive functioning. It should be noted that 10 of the 19 individuals from the nonimpaired TBI group who were not classified as impaired by the RT prediction equation had PTA $\leq$ 1 day and ranged from 5–84 months postinjury. Previous research (Van Zomeren & Deelman, 1978) indicates that RT should be back in the normal range for these individuals; therefore, these would not be considered misclassifications.

DISCUSSION

The results of the current study are consistent with previous studies indicating that both SRTs and CRTs are significantly impaired in brain-damaged individuals. Impaired TBI subjects had SRTs and CRTs that were significantly longer than those of the normal controls, indicating deficits in both simple response time and speed of information processing. RT's sensitivity to brain damage was also demonstrated by its ability (using previously established cut-off scores) to discriminate between the impaired TBI patients and normal controls. These findings are consistent with the findings of Blackburn and Benton (1955), Braun et al. (1989), and Margolin (1992b).

Researchers such as Jensen (1992) have found that brain-damaged subjects tend to have increased variability in their response times. This was also found to be true in the current study. The *SRT-SD*s and the *CRT-SD*s of the impaired TBI subjects were both significantly greater than those of the normal controls, indicating deficits in efficiency of processing. *SRT-SD* and *CRT-SD* cut-offs were able to discriminate between the two groups, but not as well as the SRTs and CRTs themselves.

Previous research (e.g., Hicks & Birren, 1970) has also demonstrated that RT deficits tend to be nonspecific in their effects and reflect impairment of some generalized (rather than strictly localized) cognitive ability. Miller (1970) proposed that RT deficits reflected impaired speed of information processing and decision making. Deficits in cognitive speed would presumably result in impaired performance on other cognitive measures (especially timed tests); therefore, it would be expected that RT scores would be highly correlated with neuropsychological test performance. This relationship was demonstrated in the current study. There was a statistically significant correlation between both SRT and CRT measures and level of cognitive functioning (as measured by a modified version of the Halstead-Reitan Neuropsychological Test Battery's Impairment Index). CRT showed a much higher correlation. These findings are consistent with Elsass and Hartelius' (1985) findings that there is a positive relationship between RT and level of impairment on neuropsychological tests.

Consideration of the relationship between the nonimpaired TBI subjects and the normal controls raises some interesting issues, however. According to the Impairment Index, all of the individuals in the nonimpaired TBI group were once again functioning well within the normal range of cognitive abilities. If these nonimpaired TBI subjects and normal controls really do belong to the same population, their RTs should reflect this. This was not the case. The nonimpaired TBI subjects were significantly different from the normal controls on SRTs, CRTs, *SRT-SD*s, and *CRT-SD*s. Cut-off scores for SRT and CRT were able to discriminate between the two groups; however, this time it was the *SRT-SD* and *CRT-SD* cut-off scores that did a better job of classifying subjects. This is an interesting finding. While *speed* of processing (as measured by SRT and CRT) was better at discriminating between impaired TBI patients and normal controls, it appears that *efficiency* of processing (as measured by *SRT-SD*s and *CRT-SD*s) is better at discriminating between the more borderline group (non-impaired TBI subjects) and normal controls. This suggests that both of these RT measures could provide useful information in clinical settings where such distinctions are to be made.

Not only did the results of this study indicate that the nonimpaired TBI patients and normal controls are significantly different from each other (and, therefore, belong to different populations), but it also demonstrated that the nonimpaired TBI subjects were, in their reaction times, still very similar to the impaired TBI patients. There was not a significant difference between the SRTs, *SRT-SD*s, or *CRT-SD*s of these two groups. The only significant difference was in their CRTs. This is extremely thought-provoking because, according to the Impairment Index rating, the nonimpaired TBI group is functioning within the normal range of cognitive abilities and, therefore, should be more similar to the normal controls than to the impaired TBI group. Thus, in the clinical setting, a large portion of these nonimpaired TBI patients would have been told that they were "fully recovered" when, in fact, they were still experiencing speed and efficiency of processing deficits.

Another interesting finding is that the prediction equation for group classification consisted of CRT, *SRT-SD*, and *CRT-SD*. The stepwise discriminant analysis did not select SRT and the dichotomous impaired/not impaired ranking (based on the Impairment Index) for the equation because they exceeded the tolerance level. This is somewhat surprising because the exact Impairment Index score was part of the criteria for group selection; therefore, it would have been able to discriminate between the impaired TBIs and normal controls with 100% accuracy. Because it was part of the selection criteria, however, it could not be included as one of the possible predictor variables in the discriminant analysis. If it had been, it would have been the first predictor selected. Because the dichotomous impaired/not-impaired rating was based on the Impairment Index, it was expected that this, too, would figure strongly in the prediction equation. But this was not the case. It was not even selected. This dichotomous ranking could add nothing to the prediction equation; all of the variance that it could have explained was already accounted for by the combined CRT, *SRT-SD*, and *CRT-SD* scores.

When the prediction equation was used to classify members of all three groups, 43 of 47 impaired TBI patients (91.48%) and 48 of 48 normal controls (100%) were correctly classified. These findings were quite similar to the Impairment Index rankings. When the RT prediction formula was applied to the nonimpaired TBI group, however, the classifications were quite different from Impairment Index classifications. Even though all members of this group had a history of brain damage, none of them were still cognitively impaired according to the Impairment Index. They were fully recovered and, once again, functioning in the normal range. The RT prediction formula, on the other hand, classified 28 of these 47 individuals (59.6%) as still being cognitively impaired. This, once, again indicates that these individuals were having speed and efficiency of processing problems which were not detected by the Impairment Index.

The above findings have some important clinical implications. First of all, reaction time scores bring additional information to the assessment process; they are sensitive to residual speed and efficacy of processing deficits that are overlooked by the Impairment Index tests. Secondly, the fact that TBI patients achieve normal-range scores on Impairment Index tests does not necessarily mean that they are, in all ways, functioning within the normal range of cognitive abilities. It is perhaps with this borderline group that RT measures can be most useful. Even though there remain many questions about the exact nature of the deficits reflected by these RT measures, it does not change the fact that residual cognitive impairment is still evident.

The results of this study indicate that, when Impairment Index test scores alone are used to make a statement about level of cognitive functioning, some patients will be classified as "recovered" when they actually are still experiencing deficits in simple reaction time and in speed and efficiency of information processing. Told that they are now functioning in the normal range of cognitive abilities, they will expect that they should be able to function as they did pretrauma. Family members and employers will expect the same. When, in fact, the patient cannot maintain his or her former quality and pace due to slowed thinking processes and cognitive inefficiency, numerous problems are apt to develop: psychologically, socially, and occupationally. By adding the two short RT tests to the neuropsychological test battery, more accurate predictions can be made about a patient's level of cognitive functioning. This will help clinicians make better treatment recommendations and also enable them to help their patients better understand and work with their residual deficits.

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