Reaction time: An alternative method for assessing the effects of multiple sclerosis on information processing speed

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Abstract

The ability of a newly developed measure of information processing to detect deficits in cognitive functioning associated with multiple sclerosis (MS) was investigated. The Computerized Tests of Information Processing (CTIP; Tombaugh, T., & Rees, L. (1999). Computerized Tests of Information Processing (CTIP). Unpublished test. Ottawa, Ontario, Canada: Carleton University) was administered to 60 clinically definite MS patients and 60 healthy controls. MS patients responded significantly slower than controls on the reaction time tests composing the CTIP. Moreover, as the CTIP tests became more difficult (i.e. as processing demands increased), the difference between the performances of the two groups progressively increased. These results suggest the CTIP is sensitive to the cognitive deficits observed in MS and that this measure has the potential to serve as a viable alternative to traditional measures of information processing speed currently in use with MS patients.

Convergent evidence gathered from a variety of neuropsychological measures suggests that the primary cognitive deficit in MS is an impaired ability to process information as quickly as healthy individuals (e.g., Archibald & Fisk, 2000; DeLuca, Chelune, Tulsky, Lengenfelder, & Chiaravalloti, 2004; Demaree, DeLuca, Gaudino, & Diamond, 1999; Denney, Lynch, Parmenter, & Horne, 2004; Kail, 1997, 1998; Rao, St. Aubin-Faubert, & Leo, 1989). Deficits in information processing speed (IPS) represent a significant impairment because they may negatively impact various other cognitive abilities. This premise has been formalized by DeLuca \textit{et al.} (2004) in their Relative Consequence Model which proposes that the fundamental difficulty in processing speed experienced by MS patients consequently affects other cognitive functions, such as working memory. That is, inefficiencies in a variety of cognitive processes are a by-product of slowed IPS. This view is consistent with that of Salthouse (1996), who concluded that an age-related deficit in IPS is one of the major causes of cognitive decline in the elderly.

Unfortunately, the clinical assessment of deficits in IPS is burdened by the fact that relatively few neuropsychological tests effectively measure this capacity. Of these, the Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977) is generally acknowledged to be the most sensitive (DeLuca, Johnson, & Natelson, 1993; Rao, 1986; Tombaugh, 2006). The PASAT involves the aural presentation of a series of single digit numbers and the test-taker must add the two most recent numbers and provide a verbal response during the inter-stimulus interval (ISI). Traditionally, four
trials consisting of 61 digits are administered with each successive trial utilizing a shorter amount of time between the presentations of the digits (i.e. shorter ISIs). The rationale being that as progressively faster rates of stimulus presentations are introduced the individual’s information processing system will be “pushed” until the individual is no longer able to efficiently respond. The inter-stimulus intervals commonly used are 2.4, 2.0, 1.6, and 1.2 s. Typically, the number of correct responses decline as the ISI becomes shorter. A specific version of the PASAT employing a 3.0 s ISI has been selected by the National Multiple Sclerosis Society Clinical Outcomes Assessment Task Force (Rudick et al., 1997) to measure neuropsychological function in the Multiple Sclerosis Functional Composite (MSFC). The MSFC is an outcome measure commonly used in MS clinical trials, and the PASAT is the only cognitive task included.

The effectiveness of the PASAT as a clinical measure may be restricted by several factors. Perhaps the most significant of these being that the PASAT is often reported to be a very frustrating and aversive task for most individuals, regardless of cognitive status (Lezak, 2004; McCaffrey et al., 1995; Tombaugh, 2006). A second potential disadvantage of the PASAT is that the test is prone to robust practice effects across a wide variety of neurological populations (Tombaugh, 2006). Additionally, performance on the PASAT is affected by various demographic variables such as age, education, and mathematical ability (Chronicle & MacGregor, 1998; Crawford, Obonsawin, & Allan, 1998; Sherman, Strauss, & Spellacy, 1997; Tombaugh, 2006). Also, some authors have noted the tendency of participants to implement a “chunking” strategy where any attempt to add consecutive digits is abandoned and instead an “alternate answer” approach of adding two numbers, skipping one, adding two numbers, skipping one, etc., is adopted (Fisk & Archibald, 2001; Snyder, Cappelleri, Archibald, & Fisk, 2001). This strategy can result in an inflated score.

In view of the above, it is important that alternative methods for evaluating processing speed are investigated. The current study aimed to evaluate the ability of a newly developed reaction time (RT) measure to assess information processing deficits in MS patients. The Computerized Tests of Information Processing (CTIP; Tombaugh & Rees, 1999) is composed of three RT tasks that measure the speed at which an individual responds to various types of stimuli. Time to respond is assumed to reflect the speed of various cognitive processes involved in completing each task. This approach is similar to those commonly used in cognitive psychology involving a variety of reaction time procedures to measure cognitive processes.

The potential value of including RT tests in clinical assessments comes from a variety of sources suggesting that simple and choice reaction time procedures provide a quick, yet easy and valid, method that often reveals cognitive impairment even when normal performance is obtained on traditional neuropsychological tests (Bleich, Hälpern, Reeves, & Daniel, 1998; Braun, Daigneault, & Champagne, 1989; Ferraro, 1996; Kujala, Portin, Revonsuo, & Ruutuainen, 1994). Further support for the clinical use of RT tests is provided by reports of relatively high test–retest reliability coefficients and split half coefficients (Godefroy, Lhullier, & Rousseaux, 1994; Hetherington, Stuss, & Finlayson, 1996; Stuss, Pogue, Buckle, & Bondar, 1994; Stuss et al., 1989). The clinical utility of RT measures rests not only with initial assessment for level of impairment but also with tracking recovery. RTs have revealed that recovery of function occurs in cross sectional and longitudinal research, over short (3–6 months) and extended time periods (5 years versus 10 years), in individuals with both mild and severe traumatic brain injury (TBI) (Felmingham, Baguley, & Green, 2004; Hetherington et al., 1996; Hugenholtz, Stuss, Stethem, & Richard, 1988; MacFlynn, Montgomery, Fenton, & Rutherford, 1984; Spikman, Timmerman, van Zomeren, & Deelman, 1999; van Zomeren & Deelman, 1978; Zwaaghstra, Schmidt, & Vanier, 1996). Finally, the lack of practice effects observed for most RT tests make them ideal for serial examinations.

The three RT tests composing the CTIP progressively increase the amount of information to be processed. The most basic test, Simple RT, is often viewed as a pure IPS measure and can serve as a baseline for the other two tests, which represent choice procedures. The second task, Choice RT, involves concrete or literal processing where two choice stimuli remain the same over all trials. The third procedure, Semantic RT, involves conceptual processing where the items are varied between trials and a semantic or lexical search is required to respond. Unlike the PASAT, practice effects have not been observed with the CTIP, it is not anxiety provoking nor is performance affected by mathematical ability (Baird, 2004; Royan, Tombaugh, Rees, & Francis, 2004; Tombaugh, Rees, Stormer, Harrison, & Smith, in press). Past research has shown that the CTIP is sensitive to the effects of TBI (Rees & Tombaugh, 2001; Tombaugh, Rees, & Royan, 2001; Tombaugh et al., in press). Taken together, the factors listed above suggest that the CTIP may offer a viable alternative with which to study cognitive functioning in patients with MS.

The goal of the present study was to determine the sensitivity of the CTIP to cognitive deficits associated with MS. Two hypotheses were proposed. First, it was expected that MS patients would respond significantly slower than controls on the CTIP tests. Secondly, it was hypothesized that a complexity effect would emerge. That is, the more
complex CTIP tests would be more sensitive to slower processing speeds than the simpler tests. This complexity effect was expected to be greater for MS patients than for healthy control participants.

1. Method

1.1. Participants

Sixty adults with a diagnosis of clinically definite MS were recruited from the MS Clinic of the Ottawa Hospital. Patients were asked to sign a consent to disclose personal health information form in order to obtain Expanded Disability Status Scales (EDSS; Kurtzke, 1983) scores and disease durations from their hospital records. Sixty healthy individuals were recruited from social groups, places of employment, shopping centres, university classes, and by word of mouth. English was the first language for all participants.

1.2. Procedure

Before testing began, participants were asked to read and sign an informed consent form and were given a structured interview designed to provide basic demographic and background information. MS participants were also asked to complete the Beck Depression Inventory II (BDI-II; Beck, Steer, & Brown, 1996) to assess their level of depression. The CTIP was administered within the context of a brief neuropsychological battery which included, in order of administration, the CTIP, Trails A and B (Reitan & Wolfson, 1985), Digit Span Forward and Backward from the Learning and Memory Battery (LAMB; Tombaugh & Schmidt, 1992), and Digit Symbol from the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997) or the Symbol Digit Modalities Test (Smith, 1991).

1.3. Materials

1.3.1. Computerized tests of information processing

For each of the RT tests, the 30 testing trials were preceded by 10 practice trials.

1.3.1.1. Simple RT. This test measures the amount of time required to process and react to a simple stimulus and served as a baseline measure for the other RT tests. On each of 30 trials participants were instructed to press the space bar as soon as a single stimulus (“X”) appeared in the centre of the computer screen.

1.3.1.2. Choice RT. This test measures the amount of time required to process one of two stimuli and respond differentially by presenting participants with either the word “DUCK” or “KITE” on each of 30 trials and requiring them to press one of two keys [“DUCK” = right key (?); “KITE” = left key (Z)] in response.

1.3.1.3. Semantic search RT. This test measures the amount of time required to decide whether a word belongs to a specific semantic category or not. On each of 30 trials the name of one of four categories (Weapon, Furniture, Bird, or Fruit) was randomly presented on a computer screen and remained on the screen for either 2.5, 3.0, 3.5, or 4.0 s. Following this a word appeared below the category name and participants were instructed to press the right key (?) if the word represented a member of the category and to press the left key (Z) if the word did not represent a member of the category.

2. Results

2.1. Demographics

Of the 60 healthy control participants, 31 individuals were male and 29 were female. These participants ranged in age from 18 to 81 years with a mean age of 39.83 years (S.D. = 23.13). Of the 60 MS patients, 19 were male and 41 were female. The difference in frequencies of males and females between the groups was significant, \( \chi^2 (1, N = 120) = 4.94, p = .026 \). The patients ranged in age from 28 to 75 years with a mean age of 48.88 years (S.D. = 11.67). The difference in age between the groups was also significant, \( F(1, 118) = 7.32, p = .008 \). Thirty-five of the patients were diagnosed...
Table 1
Percentage (number) of individuals falling at or below cut-offs for the neuropsychology tests

<table>
<thead>
<tr>
<th>Test</th>
<th>50th percentile</th>
<th>10th percentile</th>
<th>5th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Controls</td>
<td>MS</td>
<td>Controls</td>
</tr>
<tr>
<td>Trails A</td>
<td>52 (31)</td>
<td>73 (43)*</td>
<td>13 (8)</td>
</tr>
<tr>
<td>Trails B</td>
<td>55 (33)</td>
<td>71 (42)</td>
<td>22 (13)</td>
</tr>
<tr>
<td>Digit Span Forward</td>
<td>42 (25)</td>
<td>43 (26)</td>
<td>7 (4)</td>
</tr>
<tr>
<td>Digit Span Backward</td>
<td>57 (34)</td>
<td>47 (28)</td>
<td>12 (7)</td>
</tr>
<tr>
<td>Digit Symbol/Symbol Digit</td>
<td>53 (32)</td>
<td>56 (33)</td>
<td>13 (8)</td>
</tr>
</tbody>
</table>

* $p < .05.$

as having MS of the relapsing-remitting type, 19 as secondary-progressive, 5 as primary-progressive, and 1 as benign. The percentages of individuals scoring at or below certain cut-offs on the tests administered aside from the CTIP are presented in Table 1 for each group.

Recent EDSS scores were available for 57 of the patients and ranged from 0 to 6.5 with a mean of 3.2 (S.D. = 2.0). Disease durations were available for 58 of the patients and ranged from 1.6 to 457.4 months with a mean of 117.7 months (S.D. = 104.2). Disease durations were calculated from the date of initial diagnosis. Scores for MS patients on the BDI-II ranged from 0 to 46 with a mean of 10.27 (S.D. = 10.09). Based on the classification criteria included in the BDI-II manual (Beck et al., 1996), 43 of the patients would be classified as having minimal depression (0–13), 8 as having mild depression (14–19), 5 as having moderate depression (20–28), and 4 would be classified as severely depressed (>28).

2.2. CTIP

The median RT score for each individual was used to minimise the effects of outliers. The mean of the median scores computed over all 30 testing trials was employed in the CTIP analyses. Fig. 1 compares the performances of the MS and Control groups. A repeated measures ANOVA with CTIP tests as the within-subjects variable and group membership as the between-subjects variable revealed significantly longer RTs for the MS group (Group: $F(1, 118) = 37.34, p < .001, \eta^2_p = .24$) with RTs progressively increasing for all participants as the tasks became more complex, Test: $F(2, 236) = 533.98, p < .001, \eta^2_p = .82$. Furthermore, as task difficulty increased across the three tests, the RTs of MS patients progressively diverged from that of the controls, Test × Group: $F(2, 236) = 22.25, p < .001$, $\eta^2_p = .24$. 

![Fig. 1. Reaction times (ms) on the CTIP tests for MS and Control groups.](image-url)
A series of one-way ANOVAs revealed that MS patients obtained significantly longer RTs than controls on each test, SRT: $F(1, 118) = 28.39$, $p < .001$; CRT: $F(1, 118) = 29.99$, $p < .001$; SemRT: $F(1, 118) = 31.98$, $p < .001$.

Because significant differences in sex and age were found between the groups, the repeated measures analysis was repeated with these variables entered as covariates. With sex and age controlled, results obtained were similar to those reported above, Group: $F(1, 116) = 22.20$, $p < .001$, $\eta_p^2 = .16$; Test: $F(2, 232) = 5.23$, $p = .006$, $\eta_p^2 = .043$; Test $\times$ Group: $F(2, 232) = 12.34$, $p < .001$, $\eta_p^2 = .096$. The results were also analyzed to determine the degree to which depression may have affected the performance of MS patients. A separate repeated measures ANOVA compared the scores for the Control group to those obtained by the 43 MS patients who were classified on the basis of the BD-II as having minimal depression. This analysis yielded results very similar to those previously reported for the entire MS sample, Group: $F(1, 101) = 21.62$, $p < .001$, $\eta_p^2 = .176$; Test: $F(2, 202) = 481.25$, $p = .006$, $\eta_p^2 = .827$; Test $\times$ Group: $F(2, 202) = 11.89$, $p < .001$, $\eta_p^2 = .105$.

In order to control for any generalized effects of motor dysfunction scores from the choice and semantic task were converted to percent change (%change) scores using Simple RT as the baseline condition (Fig. 2). A repeated measures ANOVA on these %change scores yielded results similar to those obtained for the RT scores. Significant main effects of group membership [Group: $F(1, 118) = 6.95$, $p = .010$, $\eta_p^2 = .056$] and CTIP test [Test: $F(1, 118) = 413.84$, $p < .001$, $\eta_p^2 = .78$] were obtained. Again, a significant test by group interaction emerged, Test $\times$ Group: $F(1, 118) = 9.04$, $p = .003$, $\eta_p^2 = .071$. A one-way ANOVA revealed that the groups did not significantly differ on CRT %change from baseline, $F(1, 118) = 1.84$, $p = .18$. However, a significant change did occur for the semantic task, $F(1, 118) = 7.43$, $p = .007$.

To determine if practice effects occurred over the 30 testing trials, the RT scores were divided into three, 10-trial blocks. Repeated measures ANOVAs were carried out for each CTIP test. RTs were consistent across the three blocks for the SRT and SEM RT tests indicating the lack of practice effects, SRT: $F(2, 236) = 1.22$, $p = .30$; SemRT: $F(2, 236) = .17$, $p = .85$. In contrast, RTs significantly differed between blocks of CRT trials, CRT: $F(2, 236) = 4.95$, $p = .008$, $\eta_p^2 = .040$. This was due to the fact that the RTs of controls stayed relatively consistent across the three CRT blocks while the mean RTs of MS patients became slightly longer on each successive block of trials, Group $\times$ Block: $F(2, 236) = 3.12$, $p = .046$, $\eta_p^2 = .026$.

Past research on RT and discrimination judgements has found a robust phenomenon of longer response latencies being associated with “different” judgements as compared with “same” judgements (e.g., Entus & Bindra, 1970; Proctor, 1981; Tombaugh et al., in press). Similar results occurred in the present study (Fig. 3), Category: $F(1, 118) = 39.82$, $p < .001$, $\eta_p^2 = .25$; Category $\times$ Group: $F(1, 118) = 10.64$, $p = .001$, $\eta_p^2 = .083$. To determine whether scores on the
“different” trials alone could account for all of the difference in RTs between the groups on the semantic task, one- way ANOVAs were run for the same and different categories individually. These analyses revealed that MS patients responded significantly slower than controls for both categories, Same: $F(1, 118) = 23.21, p < .001$; Different: $F(1, 118) = 33.50, p < .001$.

2.3. Sensitivity

The following analyses were performed to judge the clinical utility of the CTIP. Percentile scores for RTs on the CTIP were calculated from the scores of a normative sample of 301 individuals (Tombaugh & Rees, 2006). The normative sample was divided into three, 20-year age groups (20–39, 40–59, and 60–79). The number of MS patients falling at the 50th, 10th, and 5th percentiles of the normative sample was determined. The 10th and 5th percentiles represent cut-offs commonly utilized in clinical settings to determine whether an individual has performed at an impaired level on a given test. The number of individuals and percentages of each group scoring at or below each of these cut-offs are presented in Table 2 for each CTIP test. Chi-square tests were used to determine if any relationships existed between group membership and whether performance fell above the designated cut-offs or not. A significantly greater number of MS patients fell at each cut-off for all CTIP tests. It is noteworthy that greater than 50% of the MS patients fell below the 10th percentile for each CTIP test.

Table 2
Percentage (number) of individuals falling at or below cut-offs for the CTIP

<table>
<thead>
<tr>
<th>Cut-off percentiles</th>
<th>Control</th>
<th>MS</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th</td>
<td>47(28)</td>
<td>75(45)**</td>
</tr>
<tr>
<td>10th</td>
<td>15(9)</td>
<td>52(31)**</td>
</tr>
<tr>
<td>5th</td>
<td>8(5)</td>
<td>33(20)**</td>
</tr>
<tr>
<td>CRT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th</td>
<td>63(38)</td>
<td>83(50)*</td>
</tr>
<tr>
<td>10th</td>
<td>27(16)</td>
<td>50(30)**</td>
</tr>
<tr>
<td>5th</td>
<td>10(6)</td>
<td>40(24)**</td>
</tr>
<tr>
<td>SemRT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th</td>
<td>58(35)</td>
<td>90(54)**</td>
</tr>
<tr>
<td>10th</td>
<td>17(10)</td>
<td>53(32)**</td>
</tr>
<tr>
<td>5th</td>
<td>8(5)</td>
<td>47(28)**</td>
</tr>
</tbody>
</table>

* $p < .05$.
** $p < .01$. 

Fig. 3. Reaction times (ms) on same/different judgements for MS and Control groups on the SemRT test.
3. Discussion

The major finding of the present study was that patients with MS obtained longer RTs than controls on each CTIP test with the shortest RTs occurring for the simple task and the longest RTs for the semantic search task. These results cannot be explained by differences in age or sex since similar results were obtained when these variables were statistically controlled. Depression was also discounted as a major variable. When the scores of the 43 MS patients classified as minimally depressed were compared to the healthy participants the results were very similar to those obtained for the analysis including the entire MS sample. Thus, even when the cognitive effects of depression are absent, MS patients perform more poorly on the CTIP than controls.

Impaired motor ability, one of the primary symptoms of MS, often makes it challenging to assess cognitive deficits in MS patients. In order to control for potential motor effects, the RT scores from the Simple RT task were used as a baseline measure and percent change scores were calculated for the other two tasks. Although the motor response in the SRT task is not precisely identical to that in the CRT and SemRT tasks (SRT: press the space bar; CRT/SemRT: press either the “?” or “Z” key) it is similar enough that it was judged to serve as a useful baseline measure. A repeated measures analysis of these percent change scores revealed that significant differences between the groups remained across the CRT and SemRT tests. Even though motor dysfunction may account for some of the variance in responding, it appears that differences in cognitive processing are also present and influence the performance of MS patients.

Since performance did not systematically increase across the three, 10-trial blocks, it may be concluded that no within session practice effects were present. This is consistent with previous findings indicating that repeated administrations occurring either within or between sessions do not produce gains in performances (Baird, 2004; Reicker, 2007; Tombaugh et al., in press; Willison & Tombaugh, 2006). The lack of practice effects associated with the CTIP has important implications for use in both research and clinical practice and represents an advantage over the PASAT which is considered to be the “gold standard” measure for assessing cognition in MS clinical trials and has pronounced practice effects.

It was speculated that the demands of the choice task would be greater than that of the simple task due to the introduction of a decisional component. This additional processing demand was expected to produce a significant increase in RTs over and above those observed for the simple task. Percent change analyses did not confirm this expectation but rather supported previous suggestions that a minimal amount of internal search and processing was involved in performing a simple two-item discrimination problem and, as such, the Choice RT represents a relatively light cognitive load (Tombaugh et al., in press). However, the SemRT, which employed a second type of choice procedure that involved a higher cognitive load, did produce the anticipated results. Even within the semantic task different levels of cognitive demands exist as evidenced by the finding that responses for the “different” category were longer than those for the “same” category.

The present findings are supported by the results of an fMRI study investigating the performance of MS patients on the CTIP. Walker, Smith, Freedman, and DeMeulemeester (2006) reported that 12 MS patients, in comparison to age/education matched controls, were not able to substantially activate areas in the left hemisphere to perform the Semantic RT task but were able to do so more efficiently for the simpler Choice RT task. This suggests that as information processing requirements increased, the MS patients were not able to recruit appropriate brain regions to perform the tasks accurately. Thus, it appears that not all of the CTIP tests are equally capable of detecting cognitive deficits in MS patients and clearly illustrate that the cognitive demands of the RT task must be sufficiently challenging for the tests to be sensitive to the cognitive deficits produced by MS. Moreover, the sensitivity of the RT tests appears to be roughly proportional to the cognitive demands of the test. One implication of the current results is that in future research applications, administration of only the SRT and SemRT tests is justified, at least within the MS and TBI populations. However, since the normative data collected for the CTIP included the administration of the CRT test, it is recommended that clinicians or researchers wishing to apply those normative percentiles should continue to administer all three tests.

The results discussed thus far have focused on the comparison of the performances of the groups but have neglected to provide direct evidence that the CTIP can serve as a useful clinical tool. One way to provide such information is to determine how many participants in the MS group would have been classified as impaired in respect to a normative sample. In order to make such a determination, the number of individuals that fell below different percentile values (i.e. 50th, 10th, 5th percentiles) was calculated. Significant differences in the percentages of the groups that fell at or below these levels were observed at each cut-off for each CTIP test. This further supports the sensitivity of the
CTIP to cognitive deficits associated with MS and provides evidence that the CTIP can function as a clinical tool. The percentage of controls scoring at or below the 5th percentile remained relatively consistent across the three tests; however, the percentages of MS patients performing at this level tended to increase as the cognitive demands became greater across the tests.

Overall, the findings of the present study are readily interpreted within the Relative Consequence Model (DeLuca et al., 2004). According to this model, the primary difficulty with information processing for patients with MS is reduced IPS. These IPS deficits result in the dysfunction of other higher level cognitive processes. This is hypothesized to occur because fewer cognitive operations are able to be completed in a given amount of time and because products of earlier operations may not be available by the time later, more complex operations are completed. Therefore, as the number of complex operations increases from the simple to the semantic task, it would be expected that the RTs of the MS patients would become increasingly longer. This trend was observed for the MS patients included in this study. However, other possible explanations for these results could apply as well. For instance, the differences in RT between the tests could be due to deficits specific to the cognitive processes involved. For example, the SemRT test is assumed to require a search of semantic memory in order to determine whether a word represents a member of a specific category or not. Subsequently, the longer RTs observed for this test could be a result of deficient memory or language abilities, which are not necessary for completion of the other two tasks, instead of an underlying, generalized cognitive slowing. One limitation of the CTIP is that it does not permit differentiation of the specific cognitive processes that contribute to performance. Therefore, it cannot be directly determined whether longer SemRT scores are due to difficulties with IPS, memory, language, etc., or an interaction of various dysfunctions. However, a large body of research confirming that reductions in processing speed are a consistent and significant effect of MS is emerging, and it is likely that such IPS deficits would influence the performance of MS patients on the CTIP.

In conclusion, these results suggest the newly developed reaction time measure, the CTIP, is sensitive to the decline in information processing speed that represents a primary cognitive deficit for patients with MS. It appears that the CTIP could offer certain advantages over the measures currently in use to assess processing speed. However, one weakness of the current design is that the CTIP was not directly compared to traditional measures. Therefore, future research must evaluate the effectiveness of the CTIP to detect processing speed deficits in comparison to other measures, such as the PASAT, before any one test could be recommended over another.

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