MANUAL

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The Tens Test©

A measure of sustained and selective auditory information processing

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INTRODUCTION

Continuous performance tests are sensitive measures of cerebral impairment and neurocognitive disorders such as Attention Deficit Hyperactivity Disorder (Barkley, 1990), traumatic brain injury (Cicerone, 1997) and multiple sclerosis (Snyder, Cappelleri, Archibald, & Fisk, 2001). Perhaps the best known such measure is the Paced Auditory Serial Addition Test (PASAT (Gronwall, 1977). The PASAT consists of auditorially-presented strings of single digits and the individual must add each new spoken digit to the preceding one, with the stimuli increasing in speed of presentation over the course of the test.

The value of assessing sustained information processing can be seen in studies of patents with multiple sclerosis (MS). In early-stage multiple sclerosis, patients who have minimal physical problems can nonetheless experience impaired information processing (Olivares, 2005). Information processing efficiency is related to lesion volume (Archibald et al, 2004) and to quality of life and emotional aspects of the disease (Shawaryn, 2002). Due to its sensitivity to the information processing problems associated with MS, the Paced Auditory Serial Addition Test has been incorporated into the Multiple Sclerosis Functional Composite (MSFC), a clinical outcome measure for MS (Rudick, 1997, Cutter, 1999, Fischer, 1999).

While a sensitive measure of information processing, the PASAT is problematic as a gold standard of auditory information processing. It is prone to practice effects (Barker-Cello, 2005). Furthermore, the PASAT appears to be susceptible to manipulation (Rosti et al. 2006). That is, individuals can reduce the difficulty of the PASAT by skipping a number and then adding the next two numbers, skip a number, adding the next two numbers and so forth, which provides an opportunity to mentally pause and systematically (and easily) add groups of intermittent number pairs. For some individuals this strategy can increase the number of correct responses. In his review of the PASAT, Tombaugh (2005) concluded that the PASAT is also negatively affected by increasing age and decreasing IQ (Tombaugh, 2006).

Success on the PASAT is also related to mathematical ability, with the correlation with math skills ranging as high as r = .68 in some studies. The PASAT also correlates highly with general intelligence (Egan, 1988, Crawford et al., 1988), Deary et al, 1991, MacLeod & Prior 1996, and Sherman et al., 1997) but this may simply reflect the importance of information processing ability for higher cognitive functioning.

The PASAT is also a psychologically aversive cognitive task causes negative emotional reactions (Holdwick & Wingenfield, 1999). In one study, 17% of the patients refused the PASAT and 6% quit in mid-administration (Aupperle, 2002). It has even been used as a measure to induce stress (Lejuez et al., 2003). Test refusal or premature abandonment can become a significant research issue when data collection involves relatively small sample sizes. In individual clinical cases, early termination by the examinee means wasted time.

Another limitation of the PASAT is that very impaired individuals may not be able to complete the test, reducing its usefulness with individuals with, for example, advanced neurologic conditions or severe traumatic brain injury. Therefore, there is a need for a measure that assesses information processing in individuals who have limited capacity to manage the considerable difficulty and stress level of the PASAT, but whose information processing capacity needs to be assessed. Another limitation of the PASAT is the need for a verbal response, precluding its use with persons with aphasia.

Among the groups that would be served well by an easier information processing measure are the elderly, those with moderately severe brain trauma or disease, and, for individuals who have an expressive aphasia, a task that does not require a verbal response.

The Tens Test was constructed to provide a less-demanding measure of information processing that permits nonverbal responding. These features make it potentially applicable to a variety of clinical groups for whom the PASAT poses excessive cognitive, physical, and/or emotional demands.

DESCRIPTION OF THE TENS TEST

The principle behind the Tens Test is simple. The individual listens to a series of spoken digits and indicates, via any available response modality, when adjacent numeric pairs are heard that add to 10.

Using the PASAT and Gordon Diagnostic System (Gordon & Mettelman, 1988) as models, the Tens Test was designed to assess two important aspects of attention:

- Sustained Attention
- Selective Attention

Sustained Attention: The Tens Test lasts about eight minutes; therefore, the individual must harness and sustain concentration for a reasonably long period. The test varies in speed of stimulus presentation, beginning at a relatively slow rate (1.8 sec.) and then accelerating. The three inter-digit intervals are 1.8, 1.4 and 1.0 seconds. Therefore, not only must the person sustain attention but also be able to handle the increasing demands on rapid processing.

Selective Attention: A successful Tens Test performance requires that the individual recall the principle that when two consecutive numbers occur that add to 10 they must respond. The challenge is that there are five numeric combinations that add to 10 (i.e., combinations of 1-9, 2-8, 3-7, 4-6 and 5-5) so the individual must exercise vigilance for multiple correct numeric combinations. As the reverse of the pairs also adds to the same target 10 number (i.e., 2 and 8 as well as 8 and 2) the range of potential targets to be monitored increases to nine. The arithmetic aspect of the Tens Test is relatively easy for an adult, so the test is largely a measure of concentration and selective attention, with minimal demands on calculation ability.

Additional cognitive demands of the Tens Test tap working memory (the individual must remember the immediately preceding number and perform a rapid calculation), and response inhibition, when non-adjacent numbers add to 10. The individual must also respond quickly, thus, processing and response speed are important.

The test stimuli are recorded on a CD (Mp3 file), but can be transferred to a computer for playback. The test must be played from pre-recorded media because the stimulus presentation interval is specific and the changes in the inter-stimulus interval that occur within the test would be impossible for someone to replicate by reading the numbers aloud. The mp3 file can be played on any computer media player (e.g., Windows Media Player, QuickTime, RealPlayer) or CD music player. Either Windows or Macintosh operating systems will play the Tens Test audio file.

APPLICATIONS FOR THE TENS TEST

The Tens Test is intended to offer a relatively brief measure that is sensitive to impairments in sustained and selective attention. The Tens Test can be used to assess:

- Auditory information processing in clinical populations (e.g., head trauma, ADHD, neurologic disease, dementia, psychiatric) in whom these skills may be affected
- Altered mentation due to substance use (alcohol or drug)
- Alterations in processing due to environmental changes that can alter cognitive functioning (e.g., hypoxia due to high altitude exposure).
- The cognitive effects of medications
- Changes in alertness (e.g., due to sleep deprivation)
- Any other situation that could affect information processing efficiency

ADMINISTRATION and SCORING

The test instructions are read from the scoring form:

> **"Listen carefully to the numbers that will be spoken. Say "ten" (*or make a nonverbal signal if unable to speak*) immediately after hearing two numbers spoken one right after the other that adds to 10. That is, you should be listening for the number pairs: 1 and 9, 2 and 8, 3 and 7, 4 and 6 or 5 and 5 because they are the only whole number pairs that add to 10. The numbers must come together in pairs with no numbers in between."**

Present a practice example, again using the instructions on the scoring form:

> **"Let's try some for practice (*say at about 1.5 seconds between digits*): 5…7…3 (*pause*). At this point you would say ten because the last two numbers, 7 and 3, add to 10." (*Provide more examples for practice if the individual is confused*).**
>
> **"Do you have any questions?" (*Elaborate and paraphrase as needed to ensure comprehension*). Let's begin.**

The individual can respond verbally to the Tens Test (i.e., saying "ten") or indicate in a nonverbal manner that a target pair has been identified (e.g., tap on the table, raise a hand). Some individuals will state the number pairs that they are responding to, but this takes time and as it can result in missing the next pair, should be discouraged.

The volume should be loud enough for the individual to hear, usually at normal conversational volume. Often the volume has to be increased for the elderly. High fidelity is not required, as long as the respondent can hear the digits clearly. Ambient noise should be minimized.

To be considered correct, a response must come before the second digit past a target pair. For example, if the presented numbers are: 4…6…7…2 a response of "ten" would be correct after the 6 or the 7, but not if the response occurs after the 2.

A commission error occurs when a response is made to a non-target pair (i.e., that does not add to 10). Most errors of this type occur when the numbers are close but non-adjacent (e.g., 2…7…8 "ten.") This occurred rarely in the healthy sample, and somewhat more often, albeit still infrequently, in clinical populations. A commission error is thought to occur when the inhibitory mechanism is weakened or concentration is variable and a positive response is made despite the instruction that there be no intervening number. More egregious errors to digit sequences that do not contain any "10" targets should be considered as indications that the individual is very impaired or confused about the test rule. In that case, stop the test and review the response principle, but do this only once. Both correct identifications (hits) and false positive errors (commissions) are recorded on the response form.

A sample scoring form is presented on the next page.

Sample Score Sheet

Tens Test ©

Name		Date	Administration #
Age	Gender	Education (years or degree)	
Diagnosis	GROUP Neurologic TBI Dementia ADHD Psych Healthy Med		

Directions

"Listen carefully to the numbers that will be spoken. Say "ten" (*or make a nonverbal signal if unable to speak*) immediately after hearing two numbers that add to 10. That is, you should be listening for the number pairs: 1 and 9, 2 and 8, 3 and 7, 4 and 6 or 5 and 5. The numbers must come together, in pairs, with no numbers in between."

"Let's try some for practice (*say at about 1.5 seconds between digits*): 5…7…3 (*pause*). At this point you would say ten because the last two numbers, 7 and 3, add to 10." (*Provide more examples for practice if the individual is confused*).

"Do you have any questions?" (*Elaborate and paraphrase as needed to ensure comprehension*). Let us begin.

Scoring

Place a slash / on each correct response (enlarged and in bold). Circle omissions. Indicate errors with **X**.
A correct response is one that occurs no more than one digit after a correct target.

		Number Correct	Errors of Commission
1.8 seconds interval	3 4 **6** 2 5 4 5 **5** 9 3 2 7 **3** 8 8 9 4 7 8 **2** 9 3 8 3 **7** 9 9 5 1 8 5 6 **4** 2 **8** 7 2 6 **4** 8 5 2 1 7 2 3 1 **9** 4 3 2 5 8 7 6 5 **5** 3 2 2 4 5 **5** 9 4 7 **3** 2 9 8 9 3 2 5 4 9 **1** 7 8 **2** 5 7 9 **1** 8 5 9 3 2 1	☐	☐
1.4 seconds interval	3 4 **6** 2 5 4 5 **5** 9 3 2 7 **3** 8 8 9 4 7 8 **2** 9 3 8 3 **7** 9 9 5 1 8 5 6 **4** 2 **8** 7 2 6 **4** 8 5 2 1 7 2 3 1 **9** 4 3 2 5 8 7 6 5 **5** 3 2 2 4 5 **5** 9 4 7 **3** 2 9 8 9 3 2 5 4 9 **1** 7 8 **2** 5 7 9 **1** 8 5 9 3 2 1	☐	☐
1.0 seconds interval	3 4 **6** 2 5 4 5 **5** 9 3 2 7 **3** 8 8 9 4 7 8 **2** 9 3 8 3 **7** 9 9 5 1 8 5 6 **4** 2 **8** 7 2 6 **4** 8 5 2 1 7 2 3 1 **9** 4 3 2 5 8 7 6 5 **5** 3 2 2 4 5 **5** 9 4 7 **3** 2 9 8 9 3 2 5 4 9 **1** 7 8 **2** 5 7 9 **1** 8 5 9 3 2 1	☐	☐

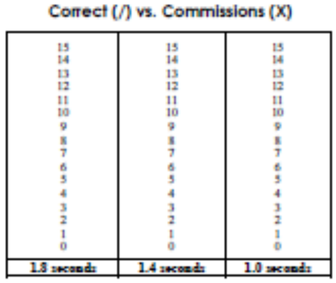
How difficult did you find this test?

- ☐ Easy
- ☐ A little difficult
- ☐ Moderately difficult
- ☐ Extremely difficult

About what percentage of the total ten combinations do you think you got right?

Estimate _______ % Actual _______ %

PLOT
Correct (/) vs. Commissions (X)



Summary of Results

Correct ______ Comm. ______

Accuracy Index = ______ %

Normative Comparisons z score

vs. Healthy Group = ______

vs. Diagnostic Group = ______

Comments:

After administration, the patient can be asked to rate their perception of the level of difficulty of the test, and then to estimate the percentage of total correct targets they believe were identified. This can provide useful clinical information in regards to the individuals' ability to judge their performance. People who greatly overestimate how well they performed are not aware of their inability to track salient auditory information. People who underestimate their performance may be depressed or self-doubting and avoid situations requiring concentration that they may do well in.

Research is not presently available to guide the interpretation of discrepancies between self-report and actual level of performance, but differences of a very large magnitude should be considered as indications that an individuals' capacity to evaluate their information processing ability is impaired. Some clinical groups, on the other hand, are often very self-aware and subsequently can become distressed when confronted with deficiencies in these skills (e.g., people with multiple sclerosis).

TEST STRUCTURE

The test is structured so that each possible correct number pair is presented nine times, in a semi-random order. There are 270 stimuli and 45 possible correct targets.

Task Length

The total time to administer the test is about 8 minutes.

Counts

Pair	Occurrences
1/9	9
2/8	9
3/7	9
4/6	9
5/5	9

Pace

The test presents the stimuli at three different rates:

1.8 secs.

1.4 secs.

1.0 secs.

There are 90 stimuli within each section with 15 possible targets pairs. The digits are the same within each interval.

INTERPRETATION

The Tens Test is relatively easy for most healthy people; few commit more than one or two errors. Individuals with neurologic disease, dementia, and closed head injuries perform more poorly on the test, as do people with ADHD. Two types of errors can occur on the test; these are to be recorded on the response form.

Omission Errors

The most common error is an omission error. This occurs when the individual fails to notice or report a target pair of numbers. The possible reasons for omissions include:

- Inattentiveness
- Slowed information processing
- Distractions (from internal factors such as pain or intruding ideation, or external from ambient noise)
- Confusion
- Mental fatigue
- Sleepiness
- Poor compliance

Commission Errors

Commission errors occur when the individual reports "ten" for a number pair that does not add to 10 or when the numbers being responded to are nonadjacent. The most common error observed is when non-adjacent numbers are added correctly to 10 (e.g., **3**…4…**7**). This may represent fluctuating attention or a selective attention to digit combinations that fulfill the 10 criterion regardless of the task directions to respond only to adjacent digits that sum to 10. This type of error tends to occur intermittently in a protocol and may reflect deficiencies in attention, inhibition or intermittent confusion. Any other type of commission error is more egregious, and probably reflects more severe confusion with the task demands or more serious cognitive impairment.

Commission errors are uncommon, occurring rarely in the normative group. If they occur frequently in a protocol, the examiner should query the individual about their comprehension of the test instructions. Sometimes, an impaired individual will initially understand and then forget the task principle. Other people will acquiesce and never truly understand the task, even though they may say that they do. If the examiner believes this to be the case then the protocol should be judged invalid.

Standard Score Conversions

A raw score in and of itself provides little meaningful information. To assess the level of performance the raw score needs to be judged relative to a comparison group of interest, such as healthy persons or people with a specific condition, for example, dementia. To accomplish this, the results from a protocol should be converted to a standard score such as a *z* score or T score to evaluate the degree of deviation from a comparison group.

A z score is marked in standard deviation units with a mean of 0.00. Thus, a *z* score of 1.00 represents a performance that is one standard deviation above average, while a *z* score of –1.00 represents a performance one standard deviation below average. The formula used to derive a z score is:

$$z = \frac{X_t - M_t}{S_t}$$

where X_t = the raw score from the Tens Test,
M_t = the mean for the group you are comparing the individual to,
and S = standard deviation for the Tens Test.

For example, if an individual obtains a raw score of 38 on the Tens Test, and the normative group has a mean correct number of 43 and standard deviation of 3.5, the *z* score would be:

$$z = \frac{38 - 43}{3.5} = \frac{-5}{3.5} = -1.4$$

Thus, this individual scored 1.4 standard deviations lower than the average person.

Another common metric used to evaluate a score is the T score. A T score is derived by changing the mean of the standard score scale from zero to some other value and/or by changing the unit of measurement to a specific multiple or fraction of one standard deviation. A T score has a mean of 50 and standard deviation of 10.

Accuracy Index

Another way to evaluate an individuals' performance is to consider both number of correctly identified targets and commission errors. That is, an individual who has 43 correct responses and no commission errors is clearly performing differently than another individual with 43 correct responses and five commission errors. The individual with multiple commission errors is having more difficulty with the test and responding errantly at times. The Accuracy Index (AI) statistic takes this into account. Given the high number of correct responses by healthy people (43.32) and low commission errors (.36), the accuracy index for cognitively intact people is high (95.3%).

The AI is calculated in the following manner:

$$\frac{\text{No. correct}}{45 + \text{no. errors}} \quad \text{X } 100$$

For example, if the respondent has 36 correct and one commission error the AI would be 78.3%:

$$\frac{36}{46} \quad \text{X } 100 \qquad \mathbf{= 78.3\%}$$

The AI is the best metric for assessing an individual's level of performance.

STATISTICAL PROPERTIES

Norms

Group	n	Mean Correct (SD)	Mean Commissions (SD)	Accuracy Index (SD)
Healthy Sample	53	43.23 (2.19)	.45 (.87)	95.16 (5.65)
Psychiatric	43	40.21 (5.99)	.27 (.65)	88.63 (13.47)
Closed Head Injury	43	35.52 (8.05)	.78 (1.11)	77.73 (18.06)
Neurologic Disease	89	36.28 (9.51)	1.16 (2.74)	79.10 (21.74)
ADHD	51	35.65 (9.39)	0.67 (1.58)	78.22 (19.14)
Dementia (outpatient)	73	30.36 (10.58)	1.73 (2.50)	65.20 (23.31)
All Clinical Ss	299	34.98 (9.52)	1.26 (2.45)	75.97 (21.46)

Note: *Maximum correct Tens Test score = 45*
Mean age of Healthy Sample = 44.96 (19.43)
Mean education of Healthy Sample = 15.54 (3.27)
Mean WAIS-III FSIQ for the total clinical sample = 96.85 (14.35)

Group characteristics

Dementia

This is a group of community dwelling individuals referred by their physicians to a private practice for neuropsychological assessment for suspected dementia. These individuals were diagnosed with dementia, either Alzheimer's, vascular or mixed type, using a neuropsychological test battery, medical tests and review of medical history. This group is a mildly to moderately demented group. Institutionalized individuals will perform worse on the Tens Test.

Closed Head Injury

These patients represent a mix of individuals with mild CHI or post-concussion symptoms. As they were seen in an outpatient practice and were assessed from a few weeks to several months post-injury, their level of cognitive impairment is much less than what should be expected in an acute inpatient TBI population.

Attention Deficit Hyperactivity Disorder (ADHD)

These are somewhat younger individuals than the above groups who were referred for assessment of possible ADHD and diagnosed with the disorder using a test battery and other supporting historical information.

Neurologic Disease

This is a heterogeneous group of individuals referred for neuropsychological assessment by neurologists and was generally comprised of individuals with chronic disorders, such as multiple sclerosis, tumors and CVA.

Psychiatric

This is a group of individuals with diagnoses of depression or anxiety.

The test scores in the healthy sample are asymmetric, as is expected with a relatively easy measure, with a negative skewness (-2.49). The clinical sample is less negatively skewed (-1.19).

Validity & Reliability

Reliability

For healthy subjects, internal consistency was assessed using coefficient alpha. The Tens Test has very good internal reliability (coefficient alpha = .91).

Interrater reliability is very high at r = .99.

Validity

A basic index of validity is whether different clinical groups display the expected below average information processing ability. The data show this to be the case on the Tens Test. When the total number correct is graphed there is a separation in the level of performance for the four clinical groups compared to the healthy Ss. (See Figure 1).

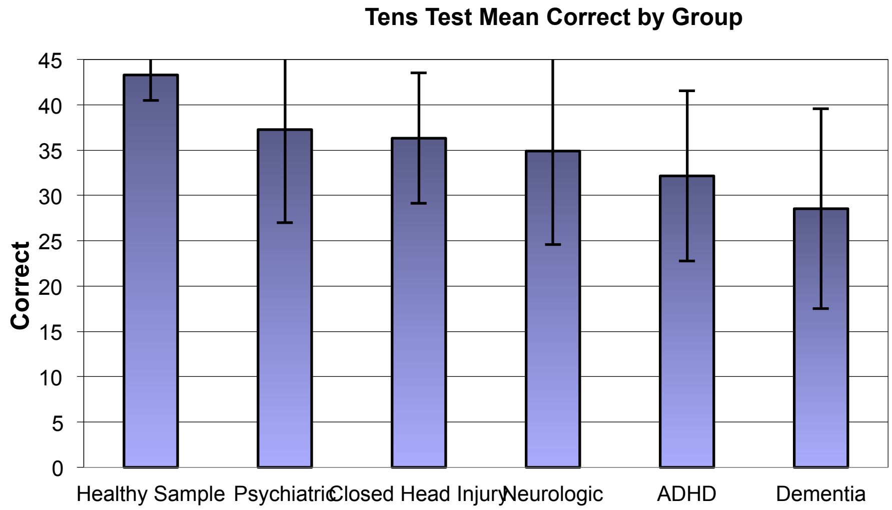


Figure 1. Mean number correct for five clinical groups and healthy Ss.

ANOVA indicated that the pooled clinical sample performed significantly worse than the Healthy group. Group comparisons indicated that the ADHD, Dementia and Neurologic groups all performed significantly worse than the healthy sample. Similarly, the mean number of errors per group also shows a separation in results, with the dementia group being most impaired (See Figure 2).

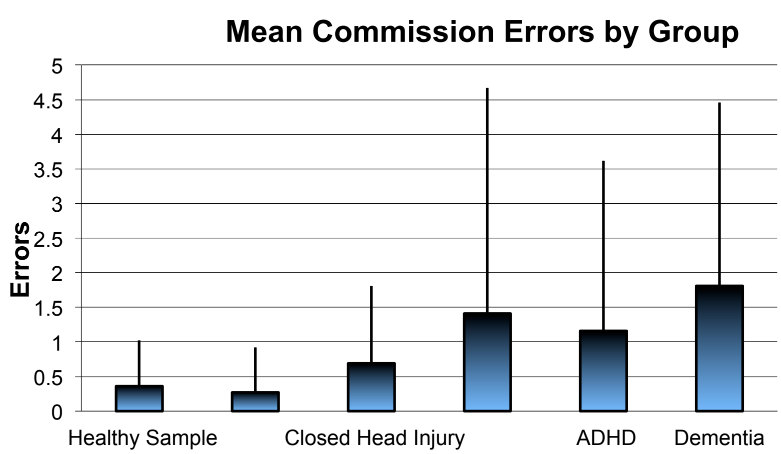


Figure 2. Mean errors for total test for five clinical groups and healthy Ss.

Correlations

The following charts contain correlations between the Tens Test and demographic variables and other cognitive measures. Blue (and bold) text indicates a significant correlation.

General Correlations

	Age	Ed	WAIS-III FSIQ	WAIS-III VIQ	WAIS-III PIQ	MMSE (Dementia Sample)
Tens Test Total	**-0.22**	**0.35**	**0.52**	**0.39**	**0.46**	**0.49**
Tens Test Errors	**0.25**	**-0.25**	-0.14	**-0.29**	0.13	-0.22

Total and Errors *r* = -.16

The test correlates modestly with age and education, which is similar to what has been found with the PASAT, but at lower levels, and shared variance is low.

Correlations with Processing Speed / Concentration Measures

	Dig Span F	Dig Span B	Num-Letter	Rhythm	Speech-Sounds	Trails A	Trails B	WAIS-III Arith	WRAT3 Arith
Tens Test Total	**0.33**	0.25	**0.46**	**0.34**	**-0.50**	**-0.43**	**-0.29**	**0.47**	**0.42**
Tens Test Errors	**-0.35**	-0.14	-0.15	0.17	-0.09	0.16	0.18	-0.22	-0.10

Correlations with Verbal Measures

	Animal Naming	FAS	WAIS-III Similarities	WAIS-III Vocabulary	WRAT3 Reading	RAVLT Total
Tens Test Total	**0.46**	**0.52**	**0.43**	**0.25**	**0.28**	**0.49**
Tens Test Errors	**-0.18**	-0.03	-0.12	-0.09	0.12	**-0.22**

Correlations with Depression and Anxiety Measures

	Beck Depression Inventory -II	Beck Anxiety Inventory
Tens Test Total	0.06	-0.02
Tens Test Errors	0.02	0.15

Correlational analysis revealed interesting results. The highest correlation was with the WAIS-III FSIQ. Thus, the test is highly related to *g,* and is not simply a measure of attention or processing, but taps into a more fundamental and general cognitive ability attesting to the important role of information processing in general mental ability. A similar high relation has been found between FSIQ and the PASAT (Crawford, Obonsawin & Allan, 1998, Tombaugh, 2006). The Tens Test has modest shared variance with measures of working memory and executive function tasks (e.g., verbal fluency) indicating that it will add unique information to a neuropsychological test battery.

Mathematical ability contributes 19% to 35% to the variance in PASAT scores (Chronicle & MacGregor, 1998) with *r* = .63 in one study (Crawford, Obonsawin & Allan, 1998). The Tens Test correlations are lower when assessed using a test of written math (WRAT3 Arithmetic *r* = .42) and mental math (WAIS-III Arithmetic *r* = .47). Thus, the Tens Test appears to be less related to math ability per se, but the correlations in this study with math skills are among the higher correlations, accounting for a modest 22% of Tens Test variance.

Correlations with measures of self-reported depression and anxiety were non-significant indicating the test is not related to self-report measures of these mental health conditions. This lack of confound by emotional distress is an important characteristic of the Tens Test and distinguishes it form many other measures of attention.

Tens Test Compared to PASAT

The Tens Test was compared to the version of the PASAT used with MS patients. The Tens Test is “easier” than the PASAT as shown by the higher number of correct responses from normative samples. Whereas healthy, middle aged subjects obtain a 72% accuracy rate on the slowest rate in the PASAT and 45% with the quickest presentation (Fisk & Archibald, 2001) the healthy Tens Test sample identified 96% of the targets. Thus, the Tens Test should prove less challenging and, perhaps, less aversive for very impaired individuals. Conversely, the reduced difficulty level of the Tens Test may render it a less appropriate measure for mildly impaired or more intelligent individuals than the PASAT. The Tens Test is significantly correlated with the MS version of the PASAT, as expected, with a higher correlation with the slower (3 sec) pace.

	Correlation	Shared variance
Tens & 3" PASAT	0.558	31%
Tens & 2" PASAT	0.423	18%
Tens & PASAT Total	0.511	26%

Receiver Operating Characteristic (ROC)

In signal detection theory, a receiver operating characteristic (ROC), or ROC curve, is a graphical plot of the sensitivity vs. (1 - specificity) for a binary classifier system as its discrimination threshold is varied. The ROC can also be represented equivalently by plotting the fraction of true positives (TPR = true positive rate) vs. the fraction of false positives (FPR = false positive rate). Also known as a Relative Operating Characteristic curve, because it is a comparison of two operating characteristics (TPR & FPR) as the criterion changes.

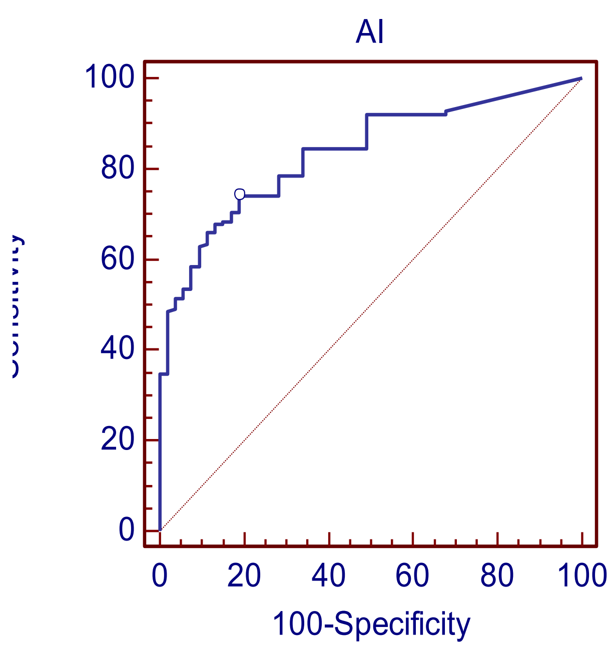
The ROC for the Tens Test was assessed using a pooled clinical sample (n = 224) that consisted of individuals with mild traumatic brain injuries, neurologic disease, dementia, psychiatric illness and ADHD. Thus, this is a very heterogeneous sample. This group was compared to a sample of healthy individuals who volunteered to be assessed for normative purposes as well as individuals who were referred for neurological assessment but had normal results on neuropsychological testing. The Accuracy Index (AI) was used in the analysis. The findings are presented below.

Area under the ROC curve (AUC)	0.835
Standard error	0.0357
95% Confidence interval	0.785 to 0.876
z statistic	9.362
Significance level P (Area = 0.5)	0.0001

Criterion values and coordinates of the ROC curve (+LR = Positive Likelihood ratio, - LR = Negative Likelihood ratio).

Criterion	Sensitivity	95% CI	Specificity	95% CI	+LR	-LR
< 4.4444	0.00	0.0 - 1.7	100.00	93.2 - 100.0		1.00
<=72.7273	34.82	28.6 - 41.5	100.00	93.2 - 100.0		0.65
<=73.33	34.82	28.6 - 41.5	98.11	89.9 - 99.7	18.46	0.66
<=80.8511	48.66	41.9 - 55.4	98.11	89.9 - 99.7	25.79	0.52
<=81.25	49.11	42.4 - 55.9	96.23	87.0 - 99.4	13.01	0.53
<=82.9787	51.34	44.6 - 58.1	96.23	87.0 - 99.4	13.60	0.51
<=83.33	51.34	44.6 - 58.1	94.34	84.3 - 98.8	9.07	0.52
<=84.4444	53.57	46.8 - 60.2	94.34	84.3 - 98.8	9.46	0.49
<=84.78	53.57	46.8 - 60.2	92.45	81.8 - 97.9	7.10	0.50
<=86.6667	58.48	51.7 - 65.0	92.45	81.8 - 97.9	7.75	0.45
<=86.67	58.48	51.7 - 65.0	90.57	79.3 - 96.8	6.20	0.46
<=87.234	62.95	56.3 - 69.3	90.57	79.3 - 96.8	6.67	0.41
<=87.5	63.39	56.7 - 69.7	88.68	77.0 - 95.7	5.60	0.41
<=88.8889	66.07	59.5 - 72.2	88.68	77.0 - 95.7	5.84	0.38
<=89.13	66.07	59.5 - 72.2	86.79	74.7 - 94.5	5.00	0.39
<=89.1304	67.86	61.3 - 73.9	86.79	74.7 - 94.5	5.14	0.37
<=89.36	67.86	61.3 - 73.9	84.91	72.4 - 93.2	4.50	0.38
<=89.5833	68.30	61.8 - 74.3	84.91	72.4 - 93.2	4.53	0.37
<=91.11	68.30	61.8 - 74.3	83.02	70.2 - 91.9	4.02	0.38
<=91.1111	70.54	64.1 - 76.4	83.02	70.2 - 91.9	4.15	0.35
<=91.3	70.54	64.1 - 76.4	81.13	68.0 - 90.5	3.74	0.36
<=91.4894 *	**74.11**	**67.9 - 79.7**	**81.13**	**68.0 - 90.5**	**3.93**	**0.32**
<=93.33	74.11	67.9 - 79.7	71.70	57.7 - 83.2	2.62	0.36
<=93.4783	78.57	72.6 - 83.8	71.70	57.7 - 83.2	2.78	0.30
<=93.62	78.57	72.6 - 83.8	66.04	51.7 - 78.5	2.31	0.32
<=95.5556	84.37	78.9 - 88.9	66.04	51.7 - 78.5	2.48	0.24
<=95.65	84.37	78.9 - 88.9	50.94	36.8 - 64.9	1.72	0.31
<=97.7778	91.96	87.6 - 95.2	50.94	36.8 - 64.9	1.87	0.16
<=97.78	91.96	87.6 - 95.2	32.08	19.9 - 46.3	1.35	0.25
<=97.8261	92.86	88.7 - 95.9	32.08	19.9 - 46.3	1.37	0.22
<=100	100.00	98.3 - 100.0	0.00	0.0 - 6.8	1.00	

A graphical representation of sensitivity and specificity for the Tens Test is illustrated below.



CASE EXAMPLES

1) Pre- and Post Assessment of a Woman with Normal Pressure Hydrocephalus

The sensitivity of the Tens Test to clinical change was examined in a 75-year-old woman with Normal Pressure Hydrocephalus (NPH), a potentially reversible dementia for which neurosurgical intervention often produces significant physical improvement, although, cognitive improvement is more variable.

Consistent with the other cognitive measures that were administered, the Tens Test reflected the post-surgical improvement in this individual, and in some respects seem to capture the marked clinical improvement better than some other measures (e.g., RAVLT total words recalled).

Measure	Pre-Surgery	Post-Surgery
Trail Making A	95 sec.	79 sec.
Trail Making B	unable	4’46”
RAVLT Total Recalled	24	29
RAVLT 30 min Recall	50%	86%
Controlled Oral Word Association Test	16	33
Animal Naming	7	10
Boston Naming Test	45	49
Tens Test Total	**18**	**38**

Assessments with a number of other individuals with NPH, however, have revealed a very diverse cognitive profile, ranging from minimal cognitive difficulties to more significant cognitive impairment. Similarly, the Tens Test scores vary considerably in this group and pre-post test scores do not always reflect the above patient response.

2) Adult with Attention Deficit Hyperactivity Disorder

Jane’s primary care physician referred her for assessment of ADHD. She reported lifelong signs of ADHD. In elementary school, she remembers getting into frequent trouble for excessive talking, being easily distracted and not doing her schoolwork. Jane struggled in 7^{th} and 8^{th} grade, passed 9^{th} grade but then quit school in 10^{th} grade stating, “I could not stay focused…I was always drawing on my notebook.” She began to work as a store manger at Wendy’s when she was 16, and enjoyed the constant activity in that position.

As an adult, she reports struggling with forgetfulness, problems keeping track of things, and problems with tasks that require organization, even basic tasks such as laundry. She has difficulty finding paperwork at home. She starts but then does not finish the dishes. She says she starts 20 things and accomplishes one. She says her husband describes her as scatterbrained. In general, Jane says she will “run circles around myself and finish nothing.”

Intelligence testing revealed the following results:

WAIS-IV	Composite Score	
Verbal Comprehension	VCI	100
Perceptual Reasoning	PRI	94
Working Memory	WMI	102
Processing Speed	PSI	94
Full Scale	FSIQ	97

Additional cognitive test scores are presented next.

	Results
Memory	
RAVLT five trials	7, 11, 13, 15 and 14 words
RAVLT Delayed	15
Academic	
Letter-Word Identification	SS = 108
Reading Fluency	SS = 98
Understanding Directions	SS = 95
Calculation	SS = 105
Math Fluency	SS = 95
Attention and Self-Regulation	
Conners CPT Ommission errors	98th percentile (impaired)
Conners CPT Commission errors	99th percentile (impaired)
Stroop (Victoria version) Interference	- 1.44
Tens Test Accuracy Index	69% (- 4.65 SD)

WAIS-IV results indicate average level ability. Note the average Working Memory and Processing Speed scores, measures that are often lower in individuals with ADHD. She also performed well on a measure of verbal memory and measures of basic academic skills, including fluency (i.e., speed of operations) and on a measure of receptive language. The measures of attention and self-regulation all indicated problems. Thus, the Tens Test was consistent with the other attention and self-regulation measures. Questionnaire assessment using the Conners Adult ADHD Rating Scale also had clinically significant scale elevations on measures of inattention for the patient and spouse reports. There is also a strong family history of ADHD (patient's mother and her two children). In sum, the Tens Test was a sensitive indicator of the cognitive signs of ADHD in this individual.

3) Adult with Multiple Sclerosis

JC was a 62-year-old woman diagnosed with relapsing-remitting multiple sclerosis at the age of 55, although signs of MS were apparent 9 years earlier when right eye optic neuritis occurred. She had a high school education and described herself as a fair student who struggled with English and math. JC worked as a banking benefits specialist for 20 years. Her job responsibilities include processing payments, computer data entry and computational tasks. JC was having difficulties at work. Her major complaints involved difficulty following complex directions, using the wrong words, and not completing her spoken thoughts. She has problems making decisions and said she often did not realize she made a mistake until she received feedback. She forgets things she used to remember. She makes clerical mistakes, such as transposing numbers. Tasks take her longer to complete. Persistent right side weakness is a chronic physical complaint.

When evaluated with a neuropsychological assessment she had recently completed prednisone treatment for a flare-up and was on Famciclovir, Baclofen, Provigil, Lisinopril and Rebif. The neuropsychological testing revealed a woman of low average to average ability with the following WAIS-IV composite scores: Verbal Comprehension = 89, Perceptual Reasoning = 90, Working Memory = 97, Processing Speed = 92, and FSIQ = 89. Basic skills in reading, reading comprehension, and written calculations were within average limits. She performed well on the Woodcock Johnson III Achievement Test subtests of reading and math fluency – simple reading and math tasks that she needed to perform as quickly as possible. Her memory was mildly weak in terms of learning efficiency on a list-learning task (RAVLT), a mild degree of forgetting was present at delayed recall, and intrusion errors were present. She performed better on the Wechsler Memory Scale III Logical Memory stories in terms of immediate and delayed recall, but confabulatory responses were present. Executive function measures revealed moderate difficulty with the Wisconsin Card Sorting Test (3 of 6 categories completed) and 23% perseverative errors, phonemic fluency, and rapid mental set shifting (Trail Making B, 8th percentile). Visuoconstruction errors were present on the Rey Complex Figure – a complicated design copying task, but not on less complex designs. The right side was impaired in terms of grip strength and fine motor speed.

In terms of information processing, often a significant area of difficulty for people with MS, JC performed in the average range on the 3 second portion of the MS version of the PASAT (50 correct) and in the low average range on the faster (2 second) portion (31 correct). However, her Tens Test performance was very impaired as she identified only 24 of the 45 targets. JC's 53% accuracy index on the Tens Test is below the 1st percentile for healthy individuals (healthy individuals perform at 95% accuracy). When asked to rate her reaction to both measures, JC rated the PASAT 10 out of 10 (10 being the worst score) in terms of difficulty and stress, but she rated the Tens Test only 5 out of 10 on both in terms of degree of difficulty and perceived stress. JC was able to accurately gauge her performance, estimating that she identified 50% of the targets.

In this case, the Tens Test was more sensitive to the processing problems the patient was experiencing but also less aversive to the patient. Her PASAT was unusually good for an individual with MS, perhaps due to practice with rapid calculations in her job.

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