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The Tens Test©

A measure of sustained and selective auditory attention and information processing

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INTRODUCTION

Measures of sustained concentration, commonly referred to as continuous performance tests (CPTs), have a longstanding history in the field of psychology (Rosvold et al., 1956). These assessments are highly sensitive indicators of cerebral impairment and disorders such as Attention Deficit Hyperactivity Disorder (Barkley, 1990) and traumatic brain injury (Cicerone, 1997).

Many clinical groups show early signs of cognitive impairment on measures of attention and processing.

- Dementia is typically characterized by memory loss. However, memory loss may not be the sole or predominant clinical presentation. Deficits in processing speed can be a pre-clinical sign of dementia and are associated with the presence of Apolipoprotein E-e4 and white matter volume changes in otherwise healthy mid-life individuals (Ready et al, 2011).
- In a cohort of Parkinson's disease patients in the early stages of the disease, devoid of clinical suspicion of cognitive impairment, 34% exhibited signs of cognitive deficits (Pfeiffer et al., 2014). Furthermore, a subsequent study elucidated that attentional abilities were a domain of impairment in Parkinson's disease, serving as a predictor of cognitive decline (Lawson et al., 2021).
- Cognitive deficits affect approximately 40-65% of individuals with multiple sclerosis (Jongen et al, 2012). In early-stage MS, patients with minimal physical problems can nonetheless experience impaired information processing (Olivares, 2005). Information processing inefficiency is related to lesion volume (Archibald et al, 2004), quality of life, and emotional aspects of the disease (Shawaryn, 2002). Given its sensitivity to the information processing challenges associated with Multiple Sclerosis (MS), the Paced Auditory Serial Addition Test (PASAT) was integrated into the Multiple Sclerosis Functional Composite (MSFC), a clinical outcome measure for MS (Rudick, 1997; Cutter, 1999; Fischer, 1999).
- In the diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), sustained concentration tests are frequently employed. Notably, individuals exhibiting the Sluggish Cognitive Tempo variant of ADHD exhibit particularly pronounced slowed cognitive processing, as evidenced by research conducted by Mitchell et al. (2020).
- In concussions, deficits in attention and processing speed are significantly associated with overall cognitive impairment (Guty and Arnett, 2018).
- Psychiatric disorders are also associated with attentional impairments (Grant and Chamberlin, 2022). These impairments have been observed in individuals with schizophrenia (Hahn et al., 2012), manic and euthymic bipolar disorder patients (Bora, Vahip, and Akdenia, 2006), and Major Depressive Disorder (Wang, Zhou, and Zhu, 2020).

Inadequately functioning attentional capacity compromises numerous cognitive processes. It serves as a fundamental ability that underpins language, literacy, and mathematical skills (Stevens and Bavelier, 2012) and memory (Chun and Turk-Browne, 2007).

DESCRIPTION OF THE TENS TEST

The Tens Test was designed to assess sustained and selective auditory attention. Additionally, cognitive processes involving working memory and response speed, as well as the ability to inhibit responding, are crucial. The test involves listening to a series of spoken digits and indicating, via an oral or motor response, when consecutive number pairs add up to 10. The test presents the same set of stimuli at three progressively faster rates to challenge the attentional system. The total time required to administer the test is approximately 8 minutes.

Stimuli

The test stimuli are recorded in an MP3 file. The test must be played from the audio file because the stimulus presentation interval is specific, and the norms are based on those recorded intervals. The MP3 file can be played on any media player. The test is structured so that each possible correct number pair is presented nine times, with the series of pair combinations occurring in the same sequence over the three trials. There are 270 stimuli and 45 possible correct targets.

Inter-stimulus interval

A software program generated spoken digits at three different rates, progressively increasing the cognitive load over time.

1.8 secs. 1.4 secs. 1.0 secs.

Each of the three inter-stimulus intervals contains 90 digits, resulting in a total of 45 target pairs. All target pairs are identical within each interval.

Pairs	Occurrences
1/9 or 9/1	9
2/8 or 8/2	9
3/7 or 7/3	9
4/6 or 64	9
5/5	9

Age Range

The Tens Test is suitable for individuals from adolescence to the elderly. While some older preteen children may also be able to complete the test adequately, this has not been systematically evaluated. Adequate hearing is necessary. The volume should be appropriate for the subject, and a quiet environment should be provided.

Cognitive Processes Involved with the Tens Test

Sustained Attention

The Tens Test is administered over an eight-minute duration, necessitating the individual's sustained attention, harness, and concentration for an extended period. The test's stimulus presentation rate varies, commencing at 1.8 seconds and progressively increasing to 1.4 and then 1.0 seconds. Consequently, not only must the individual maintain focus but also demonstrate the ability to adapt to escalating demands on working memory and response speed.

Selective and Flexible Attention

A successful Tens Test performance necessitates the individual's ability to recall the response principle that when two consecutive numbers add up to 10, they must promptly signal that event. The challenge lies in the fact that five numeric combinations add up to 10 (i.e., 1-9, 2-8, 3-7, 4-6, and 5-5), and these number pairs can occur in reverse order (e.g., 8 and 2, as well as 2 and 8). Consequently, they must attentively listen and respond to the presentation of nine potential numeric pairs. The arithmetic component of the Tens Test is relatively straightforward for teenagers and adults, thereby minimizing the demands on calculation abilities.

Working Memory, Processing Speed, and Response Inhibition

An additional cognitive demand of the Tens Test involves working memory, that is, the individual must remember the immediately preceding number and perform a rapid calculation. Given that the individual must respond quickly, efficient processing and response speed are important. As the test progresses, the individual must be able to make decisions and respond more quickly. Response inhibition is also a factor. The individual must not respond when non-adjacent numbers are added to 10 (e.g., 2-1-8). This is the most common type of commission error. Other types of commission errors are more significant and indicate a misunderstanding of the directions or significant cognitive impairment.

Applications for the Tens Test

- For clinical populations in which auditory attention and information processing can become impaired (e.g., head trauma, ADHD, neurologic disease, dementia, psychiatric disorders)
- Altered cognitive processes due to acute or chronic 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
- Pharmaceutical drug trials to assess neurocognitive side effects or cognitive enhancement
- Changes in alertness (e.g., due to sleep deprivation)
- Any other situation or disorder that could affect the cognitive skills assessed by the test

ADMINISTRATION and SCORING

The Tens 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 talk*) **immediately after hearing two consecutive 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. Remember, say 10 immediately when you hear two numbers that come one right after the other that add to 10."**

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 if necessary). Any questions? Let's begin."**

The individual responds verbally to the Tens Test (i.e., saying "ten") or indicates in a nonverbal manner that a target pair has been identified (e.g., tap on the table, raise a hand or finger).

The volume should be loud enough for the individual to hear, usually at normal conversational volume. Often the volume has to be increased for elderly individuals. Ambient noise should be minimized.

To be considered correct, a response must come before the second digit after 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 2. That response would be circled and would represent an omission error. Inattention or slow processing can result in these types of omission errors.

A commission error occurs when a response is made to a non-target pair (i.e., one 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.") Rarely did this occur in the healthy sample, and somewhat more frequently, albeit still infrequently, in clinical populations. A commission error is believed to transpire when the inhibitory mechanism is weakened, concentration is variable, or the instructions are forgotten, resulting in an erroneous ten-response despite the examinee's initial comprehension of the directions. Other commission errors that lack any "10" target pairs should be interpreted as indications of severe impairment or confusion regarding the directions.

Both correct identifications (hits) and false positive errors (commissions) are recorded on the response form.

If the examinee demonstrates substantial difficulty with the test, administer only the initial (1.8-second) trial. The Accuracy Index can be prorated if you believe an approximate representation of the entire test can be provided. However, in such circumstances, the prorated score may potentially overrepresent the examinee's actual ability at the time.

Scoring and recording issues:

- Ask the individual to speak loudly and clearly.
- Do not hesitate to repeat the directions before the start of the test and offer as many examples as needed to ensure the examinee's comprehension of the instructions. Occasionally, it may be beneficial to provide a written example of the test utilizing numerical examples to ensure a clear understanding of the instructions.
- Some examinees may indicate that they comprehend the instructions but subsequently fail to respond once the test commences. In such instances, it is advisable to promptly pause the test and inquire if they are certain of their understanding of the diresctions.
- Some individuals will verbalize the correct target pair (e.g., stating "1 and 9") instead of saying "Ten," but this takes time and can result in missing the next pair, so a verbal response should be discouraged when it first occurs.
- Scoring accuracy also depends on the examiner's attentiveness. It is important for the examiner to closely listen to the examinee's answers.

A sample scoring form is presented on the next page.

Sample Tens Test Scoring Form

Available from www.PRTpublishing.com

TENS TEST©

Name		Date	Administration #
Age	☐ Male ☐ Female	Education (years or degree)	Diagnosis

DIRECTIONS

"Listen carefully to the numbers that will be spoken. Say ten (*or identify a nonverbal signal if the individual cannot talk*) immediately after hearing two consecutive numbers that add to 10. That is, listen for the number pairs 1 and 9, 2 and 8, 3 and 7, 4 and 6, or 5 and 5 because those number pairs all add to 10. Remember, listen for two numbers that come one after another that add to 10, and then say 10 right away.

"Let's try one 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 if necessary*). "Any questions? Let's begin." (Make sure the audio is sufficiently loud).

SCORING

Place a slash **/** on each correct response (enlarged and in **bold**). A correct response occurs no more than one digit after a correct target. Circle omissions of a correct target. Indicate errors with **X** over an incorrect response. A commission error is a response to a target that does not add to 10 with the prior number, or a late response.

TEST

1.8 Second 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

Number Correct ☐ Commission Errors ☐

1.4 Second 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

Number Correct ☐ Commission Errors ☐

1.0 Second 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

Number Correct ☐ Commission Errors ☐

RESULTS

AWARENESS of PERFORMANCE

Ask: **Rate the difficulty of this test using this scale:**

- ☐ Easy
- ☐ Little difficult
- ☐ Moderately difficult
- ☐ Extremely difficult

Ask: **About what percent of the total ten combinations do you think you got right?**

Estimate _______%

Actual _______%

☐ Difference

PLOT of PERFORMANCE

Correct **/** vs. Commissions **X**

1.8 seconds	1.4 seconds	1.0 seconds
15	15	15
14	14	14
13	13	13
12	12	12
11	11	11
10	10	10
9	9	9
8	8	8
7	7	7
6	6	6
5	5	5
4	4	4
3	3	3
2	2	2
1	1	1
0	0	0

SCORE SUMMARY Use the Excel© program for calculations

Totals: ☐ Correct ☐ Commissions

___________% Accuracy Index (AI)

___________ A.I. vs Healthy Gp. ☐ z ☐ T ☐ SS Metric used

Performance Rating

- ☐ Normal
- ☐ Borderline
- ☐ Mild impairment
- ☐ Mild to Moderate impairment
- ☐ Moderate impairment
- ☐ Extreme impairment

Telehealth administration

The Tens Test can be administered over the Internet with the following important caveats:

- A high-speed connection is available on both ends with minimal lag and no audio drop-out. Many factors can affect audio quality and latency (e.g., the internet speed on both ends, computer hardware specifications, microphone quality). The best way to assess this is to have a conversation with the examinee and determine if any potentially problematic issues are present. Even so, audio quality can vary during a session.
- While environmental factors (i.e., ambient distractions) can be managed on the clinical or experimental end, this is not possible if the examinee is at home or in some other locale.

Even under ideal conditions, the norms for the test were developed in a controlled person-to-person setting, so caution is recommended when making decisions about the examinee's performance under telehealth conditions.

INTERPRETATION and ANALYSIS

The Tens Test is easy for most healthy people. Few people commit more than one or two errors. Individuals with neurologic disease, dementia, brain trauma, ADHD, and many people with mental health disorders perform less adequately. Two types of errors can occur on the test and these are recorded on the response form.

Omission Errors

An omission error occurs when a target pair (i.e., adjacent numbers adding to 10) is not noticed or reported. 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 that add to 10 are nonadjacent. The most common error is when the examinee responds "ten" to non-adjacent numbers (e.g., **3**…4…**7**). This may represent fluctuating attention or selective attention to digit combinations that fulfill the 10 criteria regardless of the task directions to respond only to adjacent digits that sum to 10. This type of error may reflect deficiencies in attention, disinhibition, or intermittent confusion. Any other type of commission error likely reflects more serious cognitive difficulty.

Commission errors are uncommon and occur rarely in the normative group. If they occur early and frequently in a testing, the examiner should pause the testing and 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 indicate that they comprehend the instructions but do not truly understand the task.

Examinee's Perception of Performance

After administration, the examinee can be asked to rate their perception of the difficulty level of the test and 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 perform are not aware of their inability to appropriately process the information. People who **underestimate** their performance may be depressed or self-doubting and avoid situations requiring concentration. Some very self-aware individuals can subsequently become upset when confronted with deficiencies in the skills tapped by the Tens Test (e.g., people with multiple sclerosis). Differences of over 10% are flagged in the scoring software but the larger the difference in perception the more meaningful is the discrepancy.

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 clinical condition. 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 represents 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 an average correct 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 from that group.

Other metrics used to evaluate a score are the T score (mean of 50 and SD of 10) and standard score (mean of 100, sd of 15). The Excel spreadsheet will perform these calculations.

Accuracy Index

The recommended approach to evaluate an individual's performance is to consider both the number of correctly identified targets and the number of commission errors. That is, an individual who has 43 correct responses and no commission errors is 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:

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

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

$$\frac{36}{46} \times 100 = 78.3\%$$

To facilitate scoring and analysis of a Tens Test performance a free Excel spreadsheet is available from PRT with purchase of the Tens Test.

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
Average WAIS-III FSIQ for the clinical sample = 96.85 (14.35)

Group characteristics

These are norms from an outpatient neuropsychology practice. Other groups and clinical situations may yield different norms.

Healthy Sample (Average age = 44.96 (sd = 19.43), Education = 15.54 (sd = 3.27), age range = 13 to 84

This is an adult group comprised of community-dwelling individuals consisting of waiting room family members or friends of patients, students, and a convenience sample of individuals in a healthcare institution who reported no neurological, major psychiatric illness, learning disabilities, or acute diseases at the time of testing.

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

Dementia (Average age = 74.18 (sd = 8.15), Education = 13.45 (sd = 3.27), age range = 57 to 91

This is a group of community-dwelling individuals referred by their physicians 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 a review of medical history. This group is a generally mildly to moderately impaired group. More advanced cases of dementia will perform more poorly on the Tens Test.

Closed Head Injury (Average age = 40.21 (sd = 16.70), Education = 13.24 (sd = 2.29), age range = 10 to 74

These patients represent a mix of individuals with mild CHI or 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 acutely injured or inpatient TBI population.

Attention Deficit Hyperactivity Disorder (ADHD) (Average age = 27.65 (sd = 13.65), Education = 12.63 (sd = 3.27), age range = 12 to 72

These were generally younger individuals than the above groups who were referred for assessment of possible ADHD. They were diagnosed with ADHD using a comprehensive test battery, questionnaires, and supporting historical information.

Neurologic Disease (Average age = 54.44 (sd = 15.78), Education = 14.20 (sd = 2.85), age range = 19 to 85

This is a heterogeneous group of individuals referred for outpatient neuropsychological assessment by neurologists or primary care practitioners and was generally comprised of individuals with chronic disorders, such as multiple sclerosis and post-acute cases of CVA.

Psychiatric (Average age = 44.19 (sd = 13.09), Education = 14.40 (sd = 2.30), age range = 14 to 60

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

RELIABILITY and VALIDITY

Reliability

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

Interrater reliability among trained examiners is very high at r = .99.

Validity

A basic index of validity is whether different clinical groups display 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. These are generally non-acute patient groups. (See Figure 1).

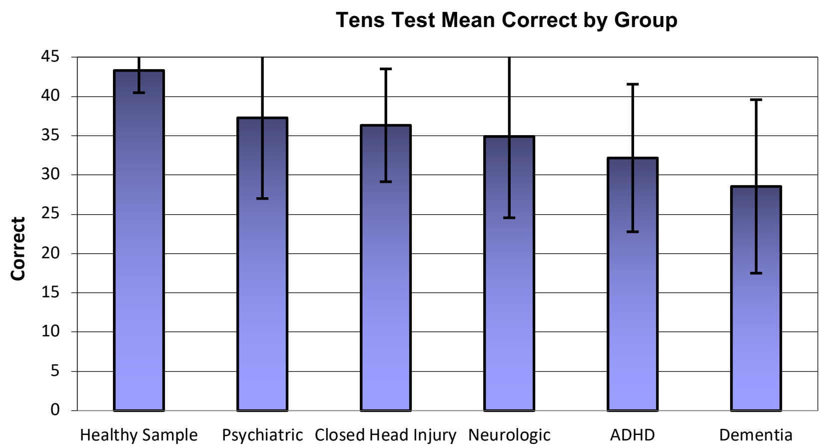


Figure 1. The mean number correct for five clinical groups and healthy Ss.

ANOVA indicated that the pooled clinical sample performed significantly worse than the Healthy group. Group comparisons indicated that the ADHD, Dementia, and Neurological 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 the most impaired.

Correlations

The following table presents correlations with the Accuracy Index from a 2022 analysis of a mixed outpatient clinical group (N = 69) with diagnoses of dementia and neurological disease.

				WAIS IV											
	Age	Ed	Accuracy Index	Verbal	PR	WM	PS	FSIQ	Arith	RAVLT Learned	Trails B	Letter Fluency	Animal Fluency	MOCA	Written Math
Correlation	0.00	0.36		0.48	0.60	0.64	0.68	0.70	0.46	-0.70	0.62	0.53	0.46	0.56	0.69
Mean	63.1	14.6	79.4	103.6	97.1	97.4	92.0	97.6	39.2	40.8	33.8	17.3	22.8	9.3	97.7
SD	15.7	2.7	18.2	18.1	15.6	16.3	14.8	16.4	13.7	17.0	13.7	7.6	4.4	3.4	16.0

All of the correlations are significant at p >.05. The Tens Test has moderately strong correlations with a variety of measures of cognitive ability reflecting the central role that sustained attentional and processing operations have with cognitive functioning. Of note is the absence of a correlation with age in this group, and minimally with level of education. The high correlation with FSIQ indicates the test is moderately related to *g,* and is not simply a measure of attention, but attests to the important role of information processing in general mental ability. A similar high correlation has been found between FSIQ and the PASAT (Crawford, Obonsawin & Allan, 1998, Tombaugh, 2006). The Tens Test did not correlate with age and minimally with education in this sample, which is similar to what has been found with the PASAT, but at lower levels with the Tens Test.

An analysis of the Tens Test using separate analyses of the number of Tens Test correct responses and number of commission errors with a different mixed group of outpatients presenting to a neuropsychological outpatient practice revealed the following correlations with the WAIS-III and MMSE. Bold text indicates a significant correlation.

			WAIS-III			**MMSE (Dementia Sample)**
	Age	**Ed**	**FSIQ**	**VIQ**	**PIQ**	
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

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

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 is less correlated to math ability than the PASAT (MS version).

Correlations with Verbal Measures

	Animal Naming	**FAS**	**WAIS-III Similarities**	**WAIS-III Vocab**	**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

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.

CONCURRENT VALIDITY   Tens Test and Paced Serial Addition Test (PASAT)

The Tens Test offers an alternative to the Paced Auditory Serial Addition Test (PASAT (Gronwall, 1977). The PASAT consists of auditorily-presented strings of single digits and the individual must add each new spoken digit to the preceding one, with the stimuli increasing in rate of presentation throughout the test. While the PASAT demonstrates sensitivity in measuring information processing, it faces several limitations. The PASAT is susceptible to practice effects (Barker-Cello, 2005) and manipulation (Rosti et al., 2006). Individuals can reduce the difficulty of the PASAT by skipping a number and then adding the next two numbers, skipping 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 highly correlated with mathematical ability, with the correlation coefficient ranging as high as r = .68 in some studies. Another limitation of the PASAT is the requirement for a verbal response, precluding its use with individuals with aphasia.

The PASAT is also psychologically aversive, eliciting negative emotional responses (Holdwick & Wingenfield, 1999). In a study, 17% of patients declined to participate in the PASAT, and 6% discontinued during the mid-administration phase (Aupperle, 2002). Furthermore, the PASAT has been utilized as a stress-inducing tool (Lejuez et al., 2003). Test refusal or premature abandonment can pose significant research challenges, particularly in cases involving relatively small sample sizes. In clinical settings, early termination by the examinee results in wasted time.

The Tens Test provides a less demanding assessment of information processing capabilities that also accommodates nonverbal responses. These attributes render it potentially applicable to a diverse range of clinical populations for whom the PASAT imposes excessive cognitive, physical, and emotional demands.

The Tens Test was compared to the version of the PASAT used with MS patients. The Tens Test is less demanding than the PASAT as shown by the higher number of correct responses from normative samples. Whereas healthy, middle-aged subjects obtained 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 less aversive for impaired individuals. Conversely, the reduced difficulty level of the Tens Test may render it a less appropriate measure for mildly impaired or high-functioning 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.

In a study by Silversteen et al. (2012) with 24 MS patients, the Tens Test (TT) was compared to the PASAT. They found both measures were significantly and moderately correlated (r = .59), yet the TT provides unique variance as well. Significant correlations were found between the number of T2 lesions and PASAT Total score (r = -0.51, p = .02), T2 lesions and TT Accuracy Index (r = -0.43, p < .05), and the PASAT Total score and EDSS (r = -0.54, p = .007) but just missed significance with the TT Total correct score and the EDSS (r = - 0.37, p = 0.08). Patients rated the PASAT to be much more difficult than the TT and the PASAT much more stressful. Correlations of the measures with demographic variables revealed no correlations with Age but the TT was significantly correlated with years of education. Using an average retest interval of 99 days (sd = 28.8) both the PASAT and TT were reliable measures in this clinical group.

Pearson-product Moment Correlations between neurological measures, the PASAT (MS version), and Tens Test AI in MS patients

	T2 lesions	3rd Vent. Width*	EDSS	25 ft walk x 2	9 Hole Peg Dom Hand	9 Hole Peg Non-Dom Hand
PASAT Total	**-0.511 p = .018**	-0.129 p = .660	**-0.539 p = .007**	-0.297 p = .159	-0.362 p = .082	-0.004 p = .984
TT Accuracy Index	**-0.434 p = .049**	-0.040 p = .893	-0.297 p = .159	-0.348 p = .095	-0.330 p = .116	.795 p = -.297

Significant correlations in bold
* 3rd Ventricle Width is a partial correlation with the correlation between Age and 3rd Ventricle Width controlled
Both measures are correlated with the number of gadolinium-enhanced T2 lesions while the PASAT also correlated with the EDSS.

Despite the comparability in the correlations between the two measures and neurological variables, the PASAT was judged to be significantly more difficult and stressful than the Tens Test.

Patient Rated Degree of Difficulty and Stressfulness of PASAT and Tens Test

	DIFFICULTY RATING		STRESSFULNESS RATING	
	Administered 1st Mean (SD)	Administered 2nd Mean (SD)	Administered 1st Mean (SD)	Administered 2nd Mean (SD)
PASAT	6.83 (2.12)	7.6 (2.5)	6.67 (2.39)	8.3 (2.06)
Tens Test	4.15 (2.21)	4.41 (2.02)	5.00 (3.09)	5.25 (2.73)

The tests were administered in a counterbalanced order to control for the order effect. The difference between the ratings was significant (difficulty t = 5.1, df = 23, p < .0001; stressfulness t = 3.5, df = 23, p = .002). 10-point scale from 0 (none) to 10 (severe).

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

CONCURRENT VALIDITY Correlations with a Continuous Performance Test (CPT)

The Tens Test Accuracy Index was evaluated against the Integrated Visual and Auditory (IVA) Continuous Performance Test (CPT) which quantifies visual and auditory attention and response control (Sandford, J. A., & Turner, A., 1995). A total of 19 patients referred for ADHD assessment were evaluated (average age 29.0, sd = 11.3, age range 18-47) and took both measures. Many of the correlations were in the moderate range, with the Tens Test perhaps slightly harder given its speeded pacing and greater working memory demands than the IVA.

N = 19	Quotient		RCQ		Sustained		Auditory			Visual			Auditory			Visual			Fine Motor	
IVA Scale	Auditory	Visual	Auditory	Visual	Aud Att Q	Vis Att Q	Vigilance	Focus	Speed	Vigilance	Focus	Speed	Prudence	Consist	Stamina	Prudence	Consist	Stamina	Hyper Event	Hyper
A.I. corr	0.43	0.46	0.37	0.07	0.47	0.33	0.46	0.28	0.49	0.44	0.28	0.54	0.50	0.38	-0.31	0.22	0.15	-0.31	-0.31	0.34

<u>IVA Scales</u>

Attention Scales

- **Vigilance** – measures general ability. Deficits in vigilance result from errors of omission that occur under both high and low-demand situations.
- **Focus** – a measure of attention “drifting off” or staying on-task.
- **Speed** – processing speed; ability to perceive and respond to visual stimuli.

Response Control Scales

- **Prudence** – a measure of impulsivity as defined by errors of commission; ability to inhibit responses to non-target stimuli.
- **Consistency** – a measure of ability to respond reliably based on reaction time.
- **Stamina** – a measure of the ability to sustain the speed of response time during the test.

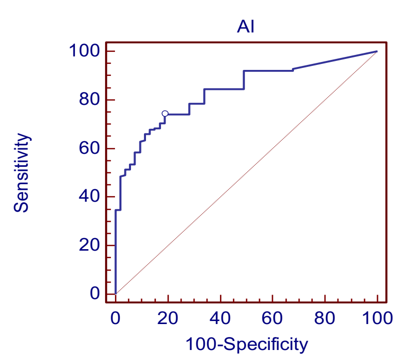
Fine Motor Hyperactivity – measures off-task, spurious, impulsive, and inappropriate fine motor activity. Quotient scores above the average range are reflective of better-controlled and more self-regulated responses.

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). 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) consisting of a group of patients with mild traumatic brain injuries, neurologic disease, dementia, psychiatric illness, and ADHD. This group was compared to a sample of healthy individuals 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

Graphical illustration of the representation of sensitivity and specificity for the Tens Test Accuracy Index (AI).



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	

CASE EXAMPLES

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

The clinical significance of the Tens Test was evaluated in a 75-year-old woman diagnosed with Normal Pressure Hydrocephalus (NPH). Neurosurgical intervention is frequently associated with substantial physical improvements in this condition, although cognitive improvement tends to exhibit variability.

Consistent with the other cognitive measures administered, the Tens Test demonstrated the post-surgical improvement in this individual. In some respects, it captured the clinical improvement more effectively than certain 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 several other individuals with NPH, however, have revealed a 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 type of patient response.

2) Adult with Attention Deficit Hyperactivity Disorder

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

As an adult, Jane reports experiencing persistent forgetfulness, difficulty managing tasks, and challenges with organizational skills. Even routine tasks like laundry prove to be arduous. She frequently encounters difficulties locating important paperwork within her home. Additionally, she struggles to complete tasks, such as washing the dishes, despite initiating them. Jane describes herself as starting numerous projects but failing to finish any of them. Her husband has labeled her as scatterbrained. In general, Jane expresses a sense of being overwhelmed and unable to accomplish anything meaningful.

WAIS-IV 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

While mild relative weaknesses were present, the scores were all within the average range. Additional cognitive test scores are presented next.

Measure	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	98^{th} percentile (impaired)
Conners CPT Commission errors	99^{th} percentile (impaired)
Stroop (Victoria version) Interference	- 1.44
Tens Test Accuracy Index	69% (- 4.65 SD)

WAIS-IV results indicate average ability with 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 was also a strong family history of ADHD (the 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 (MS)

JC, a 62-year-old woman, was diagnosed with relapsing-remitting multiple sclerosis (MS) at the age of 55. However, she had experienced symptoms of MS nine years prior, specifically right eye optic neuritis. She had a high school education and worked as a banking benefits specialist for 20 years with duties involving processing payments, computer data entry, and computational tasks. JC was experiencing significant challenges at work. Her primary concerns included difficulty adhering to intricate instructions, misusing terminology, failing to articulate her thoughts fully, making decisions, and often not recognizing her errors until receiving feedback. She had forgotten procedures she was once familiar with and committed clerical errors, such as transposing numbers. Consequently, tasks took her considerably longer to complete. Additionally, she was experiencing persistent right-side weakness as a physical ailment.

Upon neuropsychological assessment, she had just completed prednisone treatment for a flare-up. Testing revealed low average to average ability with WAIS-IV Verbal Comprehension (89), Perceptual Reasoning (90), Working Memory (97), Processing Speed (92) and FSIQ (89). Reading, reading comprehension, and calculation skills were average. She performed well on the Woodcock-Johnson III Achievement Test reading and math fluency subtests – basic 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 forgetfulness was evident in delayed recall, and intrusion errors were present. In terms of immediate and delayed recall, she performed better on the Wechsler Memory Scale III Logical Memory stories. However, confabulatory responses were observed. Executive function measures indicated difficulties with the Wisconsin Card Sorting Test (3 of 6 categories completed), with 23% perseverative errors, phonemic fluency, and rapid mental set shifting (Trail Making B, 8th percentile). Visuoconstruction errors were also present in the Rey Complex Figure. Additionally, her right side exhibited impairments in grip strength and fine motor speed.

In terms of information processing, which is often a significant area of difficulty for individuals with multiple sclerosis (MS), JC performed within the average range on the 3-second portion of the MS version of the PASAT (50 correct responses). However, her performance was impaired on the 2-second trial, where she achieved only 31 correct responses. Her Tens Test performance was severely affected, as she was only able to identify 24 of the 45 targets, resulting in an Accuracy Index of 53%, which falls below the 1st percentile for healthy individuals. When rating the perceived difficulty and stress associated with both measures, JC assigned a 10 out of 10 rating to the PASAT (indicating the highest level of stress) and a 5 out of 10 rating to the Tens Test (indicating the lowest level of perceived difficulty). JC demonstrated a high level of self-awareness regarding her performance, estimating that she correctly identified 50% of the Tens Test targets. In this case, the Tens Test proved to be sensitive to the processing challenges experienced by the patient, while simultaneously being less aversive to the individual.

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