The paced auditory serial addition test for working memory assessment: Psychometric properties

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Abstract

Background: The paced auditory serial addition test (PASAT) was primarily developed to assess the effects of traumatic brain injury on cognitive functioning. Working memory (WM) is one of the most important aspects of cognitive function, and WM impairment is one of the clinically remarkable signs of aphasia. To develop the Persian version of PASAT, an initial version was used in individuals with aphasia (IWA).

Methods: In this study, 25 individuals with aphasia (29-60 years) and 85 controls (18-60 years) were included. PASAT was presented in the form of recorded 61 single-digit numbers (1 to 9). The participants repeatedly added the 2 recent digits. The psychometric properties of PASAT including convergent validity (using the digit memory span tasks), divergent validity (using results in the control group and IWA group), and face validity were investigated. Test-retest reliability was considered as well.

Results: The relationship between the PASAT and digit memory span tests was moderate to strong in the control group (forward digit memory span test: r = 0.52, p< 0.0001; backward digit memory span test: r = 0.48, p< 0.0001). A strong relationship was found in IWA (forward digit memory span test: r = 0.72, p< 0.0001; backward digit memory span test: r = 0.53, p= 0.006). Also, strong test-retest reliability (intraclass correlation= 0.95, p< 0.0001) was observed.

Conclusion: According to our results, the PASAT is a valid and reliable test to assess working memory, particularly in IWA. It could be used as a feasible tool for clinical and research applications.

Keywords: Paced Auditory Serial Addition Test, Aphasia, Working Memory, Validity, Reliability

Introduction

Working memory (WM) is a brain function that obtains necessary representations of high-level cognitive tasks and daily living activities. This cognitive system is used for manipulation and temporary information storage (1-3). The WM system stays active and relevant for a short period of time (4, 5) and keeps stimuli available in the absence of external cues (6). The Baddeley and Hitch (3) WM model proposed a speech- or articulation-based format for WM and a format for representing and maintaining visual/spatial information for temporary storage and manipulation using these 2 subsystems. Subsequently, a multidimensional cache was added to this model; and using this new part, phonological and visuospatial information was connected (1).

WM can be adversely affected in various situations including neurological and psychological disorders as well as aging (7). Aphasia is one of the neurological disorders that impair WM capacity and function (8). Two WM components, namely, the phonological loop and central executive system are impaired in aphasia (9-11). The phonological loop, which is of particular interest in aphasiology, is responsible for rehearsing verbal information and recycling it to refresh its memory traces (12). Cognitive science suspects that the phonological loop is important, and even necessary, for the development of language (13). The central executive system controls the WM system and is responsible for focusing, dividing, and switching attention. Also, this system activates information for long-term storage when required (14).

What is “already known” in this topic:
The paced auditory serial addition test (PASAT) is a well-known tool to examine cognitive processing, in particular attention and working memory (WM), in different neurological dysfunctions.

What this article adds:
The Persian version of PASAT is a valid and reliable tool to assess WM, particularly in individuals with aphasia.
memory (2). WM limitations have negative effects on the ability to make decisions on aspects of rehabilitation in individuals with aphasia (IWA) (14).

In the last 4 decades, numerous neuropsychological assessments have been designed to evaluate WM (15-17). The paced auditory serial-addition test (PASAT) was developed in 1974 to evaluate the speed of information processing in patients with traumatic brain injury (TBI) (18). Thereafter, PASAT has been used to investigate cognitive processing including attention and WM in different neurological dysfunctions (19-21). PASAT imposes an extensive load on WM capacity. It has been known as a useful tool for WM assessment (20, 22). When an examinee performs the PASAT, s/he attempts to provide a response after every stimulus; the cognitive demands involved in working memory include active maintenance and control of task-relevant cognitive operations (23).

During PASAT administration, a series of single-digit numbers (1 to 9) are presented randomly, and the participant repeatedly sums the 2 recent digits. For example, if the digits are 3 and 5, the participant would sum them and respond with 8. When the next digit is presented, for example, 2, the participant would respond with the correct sum of the 2 most recent digits, ie, 7. Several versions of PASAT have been developed including versions that apply different interstimulus intervals (ISI) (24, 25). Also, some versions utilize visual modality, while the others employ auditory modality (26). PASAT’s psychometric properties have been investigated in previous studies. Gronwall’s study (18), which is one of the first studies to evaluate PASAT normative test data, was conducted on adults. Afterward, normative data were presented for the different versions of the PASAT (23, 27-32) by study of task-relevant cognitive operations (23).

Psychometric properties

The psychometric properties of the PASAT including face validity, construct validity, and reliability were investigated. Convergent validity and divergent validity were used to assess the construct validity of the measurement procedure. To determine convergent validity, the correlations between PASAT and both forward and backward digit memory span test (DMST) (50) were determined. DMSTs have previously been validated in the Persian language. The DMSTs are subtests of the revised version of the Wechsler adult intelligence scale (WAIS-R) (51).
that have been used in many aphasia studies (52-54). Comparison between the results of PASAT in IWA and the control group was used to obtain divergent validity. The same rater performed the PASAT for 20 control participants on 2 separate occasions to determine reliability. There were 3-week intervals between the test and retest (55). To assess test-retest reliability, the intraclass correlation coefficient (ICC) was applied as a reliability coefficient from zero to 1 based on the analysis of the variance (56). The ICC expresses the proportion of variance in an observation due to between-subject variability in the true scores (57). Values above 0.80 are considered the evidence of excellent reliability (58).

Tests
To assess WM, forward and backward DMST (50) as well as PASAT were examined. Participants were instructed to practice on a short-form of PASAT to be familiarized with the test. Participants received instruction on the PASAT until they understood the task and completed the practice items successfully (33).

Procedure
PASAT: Recorded high-quality auditory stimuli were presented via an external speaker at the most comfortable level (MCL) for the listener in PASAT administration. During the presentation, participants summed the 2 last digits recited and provided their response. To prevent the effect of any possible naming disorders or speech intelligibility problems on the results among IWA, digits (2 to 18) were printed on a piece of paper in a random order. Participants were instructed to respond to the PASAT by pointing to the printed digits instead of responding verbally (59). The scoring method was based on the total number of correct responses during test administration. Participant received a score of 1 for every correct response, and a score of 0 for every incorrect response. The final score was the total number of the correct responses. If the participants could not respond to 5 stimuli continuously, the test was terminated.

Forward digit memory span test (50): The examiner provided each participant with instruction explaining that the numbers would be spoken 1 second apart by the examiner and that the participants should repeat them in the same order in which they were presented. Increasing the test stimuli during each series elevated test complexity. The forward DMST began with 3 numbers and progressed to 8. The participant had 2 opportunities to recall the numbers at each test level. If the correct answer was not obtained in either of the 2 opportunities, the test was stopped at that level.

Backward digit memory span test (50): The test was administered under the same conditions and instructions as the forward DMST. The only difference was that the participant had to repeat each series of numbers in reverse from the last number to the first one. Corresponding to the forward DMST, the backward DMST complexity was enhanced by increasing the number of test digits. Initially, 2 numbers were presented and increased to a maximum of 7 numbers. The same administration and scoring methods were followed in DMSTs. The participants were scored based on the numbers of correct responses (maximum score was 12).

IWA were asked to respond by pointing to printed digits on paper. So, verbal errors due to naming or fluency problems were avoided in DMSTs.

At the end of the performance, to assess the face validity of the PASAT, we asked the participants to respond to some questions.

Statistical analysis
The normality assumption of the variables was investigated using the Kolmogorov–Smirnov test. To compare the results of the 2 control groups (aged 18 to 30 and 18 to 60 years), independent t test was used. A power analysis was also performed. All statistical analyses were conducted using SPSS Version 22.0; and p<0.05 was considered as statistically significant.

Results
Normality assumption was held for the control (p= 0.74) and IWA (p = 0.061) groups. The descriptive statistics for the PASAT, forward DMST, and backward DMST are presented in Table 1.

Validity
Convergent evidence: The correlation between the PASAT and DMST scores were determined. For clinical significance with the elucidation of correlational investigations, a cut-off of 0.30 or larger were considered evidence for a relationship between variables (22). The correlation effect size was characterized by Cohen’s criteria (60), where r = 0.10, r = 0.30 and r = 0.50 are considered to be small, medium, and large correlations, respectively. The correlations between the PASAT and both the forward and

<table>
<thead>
<tr>
<th>Measure</th>
<th>Groups</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>PASAT</td>
<td>Control, 18-30 years</td>
<td>70</td>
<td>53.76</td>
<td>4.94</td>
<td>41</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Control, 18-60 years</td>
<td>15</td>
<td>54.27</td>
<td>4.81</td>
<td>45</td>
<td>60</td>
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<tr>
<td></td>
<td>Aphasia, 18-60 years</td>
<td>25</td>
<td>10.64</td>
<td>13.14</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>Forward DMST</td>
<td>Control, 18-30 years</td>
<td>70</td>
<td>8.01</td>
<td>1.74</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Control, 18-60 years</td>
<td>15</td>
<td>8.13</td>
<td>1.6</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Aphasia, 18-60 years</td>
<td>25</td>
<td>3.92</td>
<td>1.41</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Backward DMST</td>
<td>Control, 18-30 years</td>
<td>70</td>
<td>7.41</td>
<td>1.58</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Control, 18-60 years</td>
<td>15</td>
<td>7.60</td>
<td>1.63</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Aphasia, 18-60 years</td>
<td>25</td>
<td>2.95</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

DMST: digit memory span test, PASAT: Paced Auditory Serial-Addition Test, SD: standard deviation

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| Table 3: Comparison between IWA and Matched Controls in PASAT and Forward and Backward DMSTs |
| Test | p | Partial η² | Power |
| PASAT | p < 0.001 | 0.84 | 1.000 |
| Forward DMST | p < 0.001 | 0.85 | 1.000 |
| Backward DMST | p < 0.001 | 0.91 | 1.000 |

Table 4: Reliability of PASAT, Forward and Backward DMST in Control Group

<table>
<thead>
<tr>
<th>Measure</th>
<th>Test (mean)</th>
<th>Retest (mean)</th>
<th>ICC (lower bound-upper bound)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PASAT</td>
<td>53.35</td>
<td>54.50</td>
<td>0.95 (0.84 - 0.98)</td>
</tr>
<tr>
<td>Forward DMST</td>
<td>8.25</td>
<td>8.70</td>
<td>0.81 (0.52 - 0.93)</td>
</tr>
<tr>
<td>Backward DMST</td>
<td>7.85</td>
<td>8.35</td>
<td>0.91 (0.78 - 0.97)</td>
</tr>
</tbody>
</table>

Divergent evidence: Comparisons between the control and IWA groups revealed significant differences in all the test results (Table 3).

Reliability: The test-retest means and ICC results for the PASAT, forward DMST, and backward DMST are summarized in Table 4.

Discussion

Psychometric properties of the PASAT in Persian were established based on the data from 85 controls without aphasia and 25 IWA. The PASAT has been determined to measure attention (61, 62), and WM (63). Importance of cognitive functions, especially WM, in successful completion of the PASAT was suggested by previous studies (64). In previous studies, DMSTs were used as WM assessment, so the relationship between PASAT and DMSTs would show the validity of the PASAT as a WM assessment tool. In the present study, a strong relationship between PASAT and DMSTs was established based on the data from 85 controls without aphasia and 25 IWA. PASAT showed good face validity of the Persian version of the PASAT in WM assessment was shown in the present study. The moderate relationship between PASAT and backward DMST in controls was due to the possibility of different processes required in PASAT and DMST. Difficult tasks elicit different brain resources. The PASAT is a difficult task, thus, the participants might use other brain processes to respond correctly. Also, it is claimed that during the PASAT administration, other resources such as attention, general intellectual ability, and arithmetic ability might be involved (22). Therefore, these resources might lead to better results in the PASAT compared to the backward DMST. However, further studies are required to elucidate the potential sources involved in the PASAT administration.

In case of divergent validity, significantly lower score of IWA than the control group reflected that the PASAT presumably has a high capability to distinguish IWA from a matched control group. This was the first study to use PASAT to evaluate WM in aphasia. Future studies could provide more evidence concerning PASAT advantages and limitations for WM assessment in aphasia and other language disorders.

With respect to reliability, ICC is the most commonly reported reliability measure in the literature. Also, ICC provides information about the measure’s ability to differentiate among individuals. This technique is most appropriate for investigating differences between groups of patients (57). In the present study, ICC was higher than 0.80 in the PASAT and both forward and backward DMSTs. This strong reliability indicates that PASAT could provide the same reliable results as forward and backward DMSTs. Our findings confirmed previous reports of PASAT’s reliability; ie, an ICC range of 0.76 and 0.95 was shown in previous studies (22, 68). In addition, the test-retest coefficients generally fell in the 0.90 to 0.97 range (69, 70). In our study, PASAT showed good face validity as a WM test based on the participants’ opinions. No information regarding PASAT face validity has been collected in the past studies.

To examine different types of validity, the use of a vari-
ation of WM tests is suggested for future studies. We used same ISI for presenting PASAT stimuli in all groups. Investigating the effect of ISI on the response of IWA could be an interesting subject for future studies. Aphasia group was not separated based on the type and severity due to small sample size. Such effects could be addressed in the next studies as well. In the present study, total correct (TC) scoring was applied to compare the effect of different scoring methods (ie, based on errors and no responses). Moreover, measurement of reaction time might provide further information in the future studies.

**Conclusion**

Overall, the Persian version of PASAT can evaluate WM with high reliability and moderate validity. It could also be a suitable clinical application for WM assessment in aphasia and can be used in both clinical and research settings. Examining other aspects of PASAT in aphasia is suggested in future studies.

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**Conflict of Interests**

The authors declare that they have no competing interests.

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