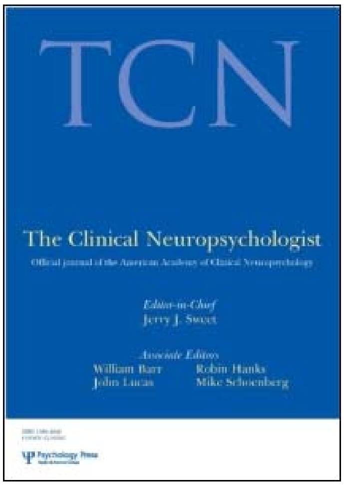


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# The Development of a Chinese Equivalence Version of Letter-Number Span Test

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# THE DEVELOPMENT OF A CHINESE EQUIVALENCE VERSION OF LETTER–NUMBER SPAN TEST

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***The present study aimed to develop a Chinese equivalence version of the Letter–Number (LN) Span Test and to explore the preliminary construct and discriminative validity of the developed version among a group of healthy Chinese volunteers and patients with stroke. A group of 165 (73 men and 92 women) healthy participants were recruited for the validation study, most of them were undergraduates or postgraduates. Moreover, a comparison was made between nine patients with stroke and the healthy controls. For the healthy sample, the Chinese version correlated significantly with the English version in total number of correct span ($r = .6$, $p < .00001$) and the longest span ($r = .5$, $p < .00005$). The Chinese version of LN Span Test was also found to be significantly associated with memory-loaded tests but not other tests. A series of ANCOVAs controlling for age, education, and IQ indicated that stroke patients performed significantly worse than the healthy controls in LN Span total number of correct responses ($p < .04$), immediate recall ($p < .0005$), and delayed recall ($p < .0005$) of WMS-R, SART total number of correct response ($p < .0005$), PASAT dyads correct response ($p < .01$). The preliminary findings suggest that the Chinese version of the LN Span Test shows impressive preliminary validity among a group of healthy volunteers and an impressive clinical discriminative validity among a group of stroke cases.***

***Keywords***: Chinese; Letter–number span; Multitasking; Working memory



## INTRODUCTION

Working memory constitutes the ability to simultaneously store and manipulate information in an immediately accessible memory store (Baddeley, 1998). There are existing instruments intended to measure the auditory working memory; however,

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most of them have been developed from Westerners and require the ability to read English. The LN Span Test is one of the working memory tests sensitive enough to discriminate patients with impairments in working memory, sequencing, switching, or part of the cognitive process of multitasking performance (Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997; Goldberg, Torrey, Gold, Ragland, Bigelow, & Weinberger, 1993; Park & Holzman, 1992). The LN Span Test requires the participants to sort out letters from numbers within a row of alternating letters and numbers that is read to them, and to separately recall the letters and numbers in successive order. For example, the answer for the "A1D62" should be "126AD." The number of correct recalls in the total trials with increasing difficulty (from two to seven items) is calculated. The test has also been incorporated into the Wechsler Adult Intelligence Test – III (WAIS-III) (Wechsler, 1997).

However, most of the studies have been done on Western-based samples. Data available for other non-English samples are scarce. Given the significant involvement of the language element in this test, it is likely that direct application of this test to other non-English speaking countries will not be feasible. Therefore, the development of new versions of the LN Span Test resembling the English version is highly recommended for non-English-speaking populations. The purposes of this brief report are to detail the preliminary findings on the Chinese version of the LN Span Test.

The main focus of this test adopts the concept of the "heavenly stems and earthy branches" from Taoism. In Daoism, there are 12 Terrestrial Branches (Zi, Chou, Yin, Mao, Chen, Si, Wu, Wei, Shen, ou, Xu, Hai ) and 10 Celestial Trunks (Jia, Yi, Bing, Ding, Wu, Ji, Geng, Xin, Ren, Gu) to account for the calculation of the Lunar Calendar. These "heavenly stems and earthy branches," particularly the first six of the 10 Celestial Trunks, i.e., Jia, Yi, Bing, Ding, Wu, Ji, were commonly used in the school system for grading students' performance, like the Western grading of A to F. Therefore, these are similar to the English alphabets but not at the same set size of 26. Here, we adopted the first six of the Celestial Trunks to replace the "Letter" of the LN Span Test. This means that the participant is required to rearrange the correct order of the spoken words on "Celestial Trunks and Number." For example, the correct order of "3 Bing Jia 2" should be given as "2 3 Jia Bing."

The goal of the first study was to provide preliminary data on the development of a Chinese version of the LN Span Test with healthy volunteers. It was anticipated that the Chinese version of the LN Span Test would be highly correlated with the English version. In addition, although assessment of healthy participants was the primary goal, it was anticipated that research should be done in clinical groups. The second study was aimed at establishing the discriminative validity of this Chinese version of LN Span Test among a group of patients with stroke and healthy controls.

## STUDY 1

### Method

**Research participants.** A total of 165 participants (73 men and 92 women) were recruited for the present study. They were all recruited from the sample pool for an assessment of neuropsychological performance; most of them were undergraduate or postgraduate students. All participants were naive to the nature of the tests and hypotheses of the study. The mean age was 26.28 years ($SD = 8.32$), and mean education level was 15.1 years ($SD = 2.42$). The mean IQ was 111.11 ($SD = 15.57$). No participants had a history of neurological and psychiatric disease.

**Measures.** Both English and Chinese versions of the LN Span Test (see Gold et al., 1997, for the English version) were implemented to participants. A set of memory-related tests and online updating tests were used to test for convergent validity. The Logical Memory Test and Visual Reproduction Test of the Wechsler Memory Scale –Revised (WMS-R) (Wechsler, 1987b) were used to assess verbal and nonverbal memory. The Paced Auditory Serial Addition Test (PASAT) (Gronwall & Sampson, 1974; Chinese version, Chan, 2002) was used to measure divided attention. Participants are required to add pairs of digits, such that each digit is added to the one that immediately preceded. A total of 60 digits are read and the participants are required to take the test in a rate of one digit per 2 seconds.

Another set of tests presumably capturing different constructs of neurocognitive performance were also implemented to all participants. These included the verbal fluency test, Modified Wisconsin Card Sorting Test (WCST) (Nelson, 1976), Stroop Test (Lee & Chan, 2000), Colour Trails Test (D'Elia, Satz, Uchiyama, & White, 1994), and the modified Six Elements Test (Wilson, Alderman, Burgess, Emslie, & Evans, 1996; Chinese version, Chan, 2002).

**Procedure.** Each participant was tested individually within a quiet cubicle. All participants gave informed consent according to the guidelines of the Department of Psychology at Sun Yat-Sen University. All participants were randomly assigned to either group by receiving the Chinese version first and then the English version of the LN Span test, or vice versa. Another comprehensive set of neuropsychological tests was also implemented to them.



### Results

Table 1 summarizes the demographics and neuropsychological function performance of the two sub-samples. No significant differences were found between the two sub-samples. Figure 1 shows the profile of the two versions of the LN Span Test between the two sub-samples. Again, no significant differences were found. They were then aggregated for subsequent correlation analysis.

Figure 2 shows that the Chinese version correlated significantly with the English version in total number of correct span ($r = .6$, $p < .00001$) and the longest span ($r = .5$, $p < .00005$).

**Effect of age, education, IQ, and gender.** Significant correlations were demonstrated between the LN Span Test, age, education, and IQ (Table 2). These were true for the total number of correct items and the longest item passed for both the English and Chinese versions. However, there was no gender effect demonstrated on both versions of the LN Span Test in terms of total number of correct items—English version, $t(164) = 1.654$, $p = .1$; Chinese version, $t(164) = 0.762$, $p = .447$—and the longest item passed—English version, $t(164) = 1.836$, $p = .08$; Chinese version, $t(164) = 0.635$, $p = .532$.

**Table 1** Comparison of demographics and neuropsychological performances between the two order of implementation

| | Sequence A ($n = 85$) | | Sequence B ($n = 80$) | | |
|---|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* | *p* value |
| Age | 26.82 | 8.80 | 25.73 | 7.79 | ns |
| Year of education | 15.02 | 2.52 | 15.18 | 2.32 | ns |
| IQ | 120.10 | 15.66 | 122.15 | 15.50 | ns |
| Visual reproduction (immediate) | 23.34 | 1.60 | 23.22 | 1.96 | ns |
| Visual reproduction (delayed) | 23.18 | 1.68 | 23.07 | 1.89 | ns |
| Logical memory (immediate) | 14.78 | 4.17 | 15.44 | 3.00 | ns |
| Logical memory (delayed) | 12.88 | 4.58 | 13.53 | 3.87 | ns |
| PASAT dyads correct response | 45.00 | 13.55 | 44.58 | 12.65 | ns |
| CTT1 reaction time (s) | 39.24 | 13.04 | 41.26 | 15.08 | ns |
| CTT2 reaction time (s) | 74.36 | 24.47 | 75.61 | 30.38 | ns |
| Stroop interference | 1.06 | 4.89 | 2.00 | 2.60 | ns |
| Verbal fluency (in 1 min) | 24.20 | 6.29 | 22.69 | 5.06 | ns |
| SART correct response | 197.17 | 5.37 | 197.15 | 5.32 | ns |
| SART commission error | 9.92 | 5.10 | 9.77 | 5.19 | ns |
| WCST perseverative error | 1.65 | 3.43 | 1.34 | 2.40 | ns |
| WCST categories | 5.59 | 1.02 | 5.66 | 0.91 | ns |
| SET total profile score | 3.61 | 0.69 | 3.55 | 0.74 | ns |

N-back: N-back response at 2-back pacing; PASAT: Paced Auditory Serial Addition Test at 2 second interval; CTTA, CTTB: Colour Trails Test Parts A and B; SART: Sustained Attention to Response Task; SDMT: Symbol Digits Modalities Test; SET, Six Elements Test; Non-parametric analyses showed the same results.

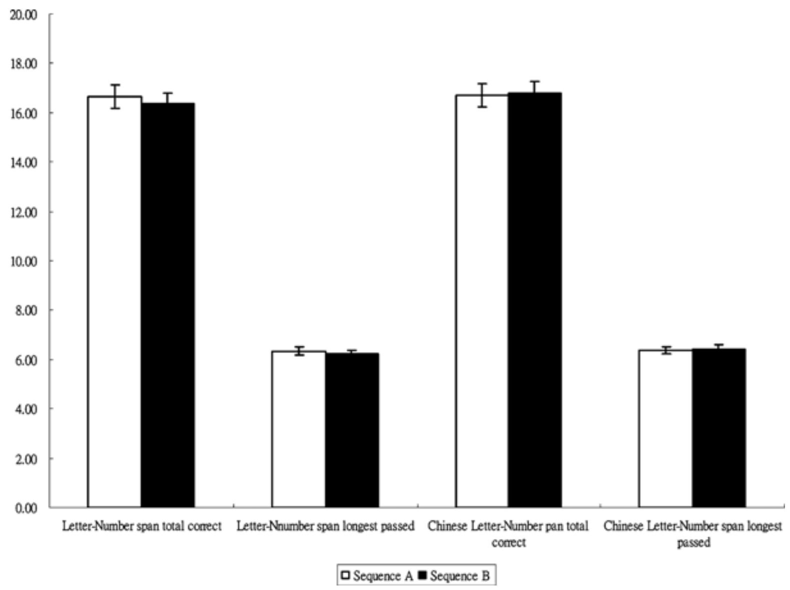


**Figure 1** Comparison of LN Span performance of the two sub-samples.

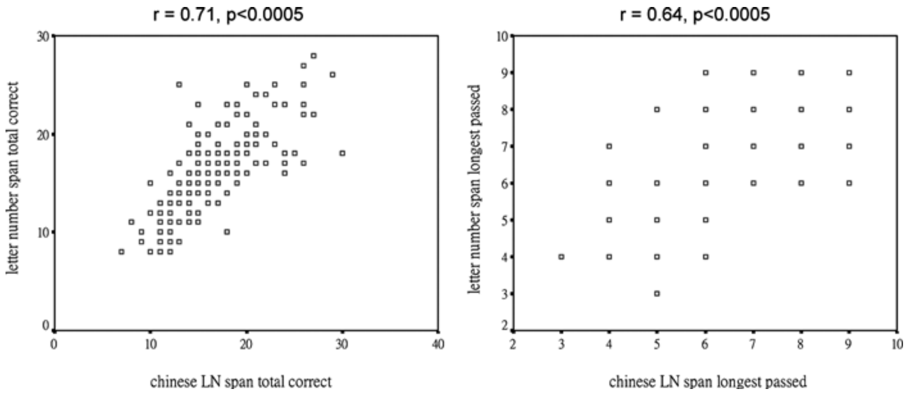


**Figure 2** Correlations between the Chinese and English versions of the LN Span Test.



**Convergent and divergent validity of the LN Span Test.** Table 2 summarizes the relationships between LN Span test and other neurocognitive tests. Significant correlations were found between the Chinese LN Span Test and other working memory and sequencing tasks. Partial correlation controlling for age, education, and IQ indicated that a significant relationship still remained between LN Span Test and Logical Memory delayed recall ($r = .21$, $p < .01$), PASAT ($r = .2$, $p < .05$), and SART correct response ($r = .2$, $p < .05$).

### Summary

The potential effects of age, education, IQ, and gender on the performance of the LN Span Test were explored. In general, the LN Span Test performance was correlated with age, education, and IQ. These are consistent with the general developmental pattern of working memory function along the lifespan (Haut, Chen, & Edwards, 1999; Haut, Kuwabara, Moran, Leach, Arias, & Knight, 2005). Recent research has shown that children develop different patterns and modalities of working memory at different stages (Luciana & Nelson, 1998). At the other extreme, it has been consistently demonstrated that there is a tendency to increasing lapses of action and attention in the elderly.

## STUDY 2

### Method

**Patients with stroke.** Nine patients with neurological disorders (eight men and one woman) were recruited from the neurological ward of the First Affiliated Medical School of Sun Yat-Sen University, Guangzhou. The mean age was 41.89 years ($SD = 14$), and mean education level was 12.67 years ($SD = 2.96$). The mean IQ and the mean duration of illness were 103.83 ($SD = 16.38$) and 5.2 years ($SD = 2.21$), respectively. All of them suffered from left-hemisphere lesions and had more than 1 time of stroke in the past years. Patients with language dysfunction such as expressive or comprehension problems were screened by an experienced

**Table 2** Correlations between LN-Span Test performance and various neurocognitive function performance

| | LN span total correct | LN span longest passed | Chinese LN span total correct | Chinese LN span longest passed |
|---|---|---|---|---|
| Age | −0.48**** | −0.46**** | −0.41**** | −0.33**** |
| Year of education | 0.5**** | 0.48**** | 0.37**** | 0.27**** |
| IQ | 0.64**** | 0.58**** | 0.58**** | 0.47**** |
| Visual reproduction (immediate) | 0.37**** | 0.3**** | 0.28**** | 0.18* |
| Visual reproduction (delayed) | 0.23*** | 0.16* | 0.18* | 0.11 |
| Logical memory (immediate) | 0.3**** | 0.19* | 0.28**** | 0.24*** |
| Logical memory (delayed) | 0.3**** | 0.21** | 0.32**** | 0.26**** |
| PASAT dyads correct response | 0.5**** | 0.48**** | 0.42**** | 0.36**** |
| CTT1 reaction time (s) | −0.35**** | −0.33**** | −0.22** | −0.20* |
| CTT2 reaction time (s) | −0.44**** | −0.39**** | −0.36**** | −0.32**** |
| Stroop interference | −0.14 | −0.11 | −0.06 | −0.04 |
| Verbal fluency (in 1 min) | 0.42**** | 0.37**** | 0.35**** | 0.31**** |
| SART correct response | 0.37**** | 0.34**** | 0.26**** | 0.14 |
| SART commission error | 0.09 | 0.00 | 0.04 | 0.04 |
| WCST perseverative error | −0.4**** | −0.37**** | −0.31**** | −0.26*** |
| WCST categories | 0.38**** | 0.33**** | 0.27**** | 0.23** |
| SET total profile score | 0.25*** | 0.21** | 0.29**** | 0.17* |

*$p < .05$; **$p < .01$; ***$p < .005$; ****$p < .001$.

speech therapist and were excluded from the present study. A total of 48 healthy controls (44 men and 4 women) were selected from Study 1 on the basis of matching age and education level as much as possible in order to provide a comparative group for the present study. The mean age was 38.83 years ($SD = 12.7$) and years of education 13.38 years ($SD = 3.23$). The mean IQ was 117.98 ($SD = 17.32$). Significant difference was found in IQ, $t(55) = 2.266$, $p = .027$. No significant differences were found between the two groups in terms of age and education.

**Measures.** Both English and Chinese versions of the LN Span Test were implemented to all participants. Moreover, all participants also received a set of tests presumably capturing working memory or online updating domains, including the Logical Memory Test and Visual Reproduction Test of the WMS-R (Wechsler, 1987b), PASAT (Gronwall & Sampson, 1974; Chinese version, Chan, 2002), N-Back Test (Callicott et al., 1998), Monotone Counting Test (Wilkins, Shallice, & McCarthy, 1987), and SART (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997).

**Procedure.** Each participant was tested individually within a quiet cubicle. All participants gave informed consent according to the guidelines of the Department of Psychology at Sun Yat-Sen University.



### Results

Table 3 shows summary statistics of the LN Span Test performance and other related test performances between patients and healthy controls. A series of univariate analyses of covariance controlling for age, education, and IQ indicated that the patient group performed significantly worse than the control group in LN Span total number of correct responses, $F(4, 52) = 4.25$, $p = .04$, immediate recall, $F(4, 52) = 39.73$, $p = .0005$, and delayed recall, $F(4, 52) = 46.09$, $p = .0005$, of WMS-R, SART total number of correct responses, $F(4, 52) = 25.54$, $p = .0005$, and PASAT dyads correct response, $F(4, 52) = 15.36$, $p = .014$.

**Table 3** Comparison of the LN Span Test performance and other memory-related test performance between patients and healthy controls (controlling for age, education, and IQ)

| | Patients | | Controls | | | | |
|---|---|---|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* | *F* statistics | *P* value | Effect size |
| Chinese LN Span correct response | 10.67 | 2.92 | 15.73 | 4.45 | 4.25 | 0.04 | −0.34 |
| Chinese LN Span longest item | 4.89 | 0.78 | 6.02 | 1.33 | 1.55 | 0.219 | −0.20 |
| Visual reproduction immediate recall | 15.56 | 6.58 | 23.21 | 1.37 | 39.73 | 0.0005 | −0.35 |
| Visual reproduction delayed recall | 13.11 | 7.32 | 22.54 | 2.13 | 46.09 | 0.0001 | −0.44 |
| Logical memory immediate recall | 14.78 | 4.32 | 14.44 | 4.15 | 2.37 | 0.13 | 0.03 |
| Logical memory delayed recall | 12.22 | 4.21 | 12.4 | 4.11 | 1.3 | 0.26 | −0.02 |
| SART correct items | 158.63 | 55.12 | 195.5 | 7.46 | 25.54 | 0.0005 | −0.20 |
| SART commission error | 7.75 | 5.68 | 9.5 | 5.71 | 0.45 | 0.504 | −0.19 |
| N-Back correct items | 5.86 | 2.61 | 9.79 | 4.1 | 1.72 | 0.196 | −0.43 |
| Monotone Counting correct response | 11.89 | 0.33 | 11.9 | 0.47 | 0.03 | 0.861 | 0 |
| PASAT dyads correct response | 18.75 | 13.57 | 37.23 | 15.36 | 6.39 | 0.014 | −0.53 |

### Summary

In parallel with most of the commonly used tests of working memory, performance on the Chinese LN Span Test significantly discriminated the patients with stroke from healthy controls in terms of the total number of correct responses. Owing to the exploratory nature of the present study, we wished to further investigate if there was any correlation found between the Chinese version of the LN Span Test and other "memory-related" measures. To do so, a post-hoc analysis was performed to check for the strength of correlation between performances on the LN Span Test and various memory-related measures in patients with stroke. As expected, the LN Span total number of correct responses was correlated with the N-Back correct responses ($r = .74$, $p = .05$) and the PASAT dyads responses ($r = .3$, $p = .05$). Similarly, the LN Span Test longest item passed was also correlated with N-Back correct responses ($r = .69$, $p = .05$) and PASAT dyads responses ($r = .37$, $p = .05$). However, the insignificant findings on the N-back performance between patients and controls may indicate that the "visuospatial working memory" function of the present sample might have been preserved as compared to the "semantic working memory" function.



## CONCLUSIONS

The results from Study 1 provide empirical evidence on the validity of the Chinese version of the LN Span Test in the healthy adult population. The impacts of age, education, and IQ were identified in confounding the corresponding performance on the LN Span Test. Study 2 further provides preliminary evidence suggesting the discriminative validity of the Chinese version of the LN Span Test in stroke cases and healthy controls. However, we should interpret these results with caution because of the small sample size and potential type I error after conducting so many correlational analyses. Moreover, there might be some limitations of our present Chinese version of the LN test. We only selected the first six of the Celestial Trunks to replace the letters of the Western LN test. It is understandable that it is difficult to find a set of stimuli in the Chinese language that parallels the 26 letters of the alphabet. However, using only six Celestial Trunks may create different difficulty levels of the LN test in the Chinese version and the Western version. For example, the former may be easier due to only limited letters appearing on each trial, and the last several trials may actually reflect the working memory load for the numbers mostly, not the numbers and the letters together. In addition, due to the same reason, the requirement for the participant to decide the sequence between letters will be reduced. Overall, the fact that the results in Figure 1 were not significant might be due to a biased sample (highly educated people) and there was a ceiling effect for some of the participants. There might also have been sample bias in the present two studies. For Study 1, the majority of the sample was relatively highly educated. Further study to recruit a wider range of participants with different levels of education should be required. For Study 2, we did not include any neuropsychological tests of language functioning that might introduce bias into its conclusion of poor LN test performances in stroke patients. The small sample of stroke cases might also limit the generalization of the present findings. Validation of the Chinese version of the LN Span

Test would require further study with a variety of clinical groups. Future research is recommended to investigate and develop the Chinese norms with this version from other Chinese-speaking countries and territories.

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