The Shape Trail Test: Application of a New Variant of the Trail Making Test

Qianhua Zhao¹, Qihao Guo¹*, Fang Li²*, Yan Zhou¹, Bei Wang¹, Zhen Hong¹

¹ Department of Neurology, Huashan Hospital, Fudan University, Shanghai, China, ² Department of Gerontology, Fuxing Hospital, Capital Medical University, Beijing, China

Abstract

Objective: The Trail making test (TMT) is culture-loaded because of reliance on the Latin alphabet, limiting its application in Eastern populations. The Shape Trail Test (STT) has been developed as a new variant. This study is to examine the applicability of the STT in a senile Chinese population and to evaluate its potential advantages and disadvantages.

Method: A total of 2470 participants were recruited, including 1151 cognitively normal control (NC), 898 amnestic mild cognitive impairment (aMCI), and 421 mild Alzheimer disease (AD) patients. Besides the STT, the Mini mental state examination and a comprehensive neuropsychological battery involving memory, language, attention, executive function and visuospatial ability were administered to all the participants. In a subgroup of 100 NC and 50 AD patients, both the STT and the Color Trail Test (CTT) were performed.

Results: In NC, the time consumed for Part A and B (STT-A and STT-B) significantly correlated with age and negatively correlated with education (p<0.01). STT-A and B significantly differed among the AD, aMCI and NC. The number that successfully connected within one minute in Part B (STT-B-1 min) correlated well with STT-B (r=0.71, p<0.01) and distinguished well among NC, aMCI and AD. In the receiver operating characteristic curve analysis, the AUCs (area under the curve) for STT-A, STT-B, and STT-B-1min in identifying AD were 0.698, 0.694 and 0.709, respectively. The STT correlated with the CTT, but the time for completion was longer.

Conclusion: The TMT is a sensitive test of visual search and sequencing. The STT is a meaningful attempt to develop a “culture-fair” variant of the TMT in addition to the CTT.

Introduction

The Trail Making Test (TMT) was originally constructed in 1938 as “Partington’s Pathway” or the “Divided Attention Test” [1]. Scoring is expressed in terms of the time in seconds for Part A and Part B of the test. Some examiners also calculate a Trails B/Trails A ratio. The TMT is one of the most sensitive and popular tests for identifying mild cognitive impairment and mild dementia [2,3,4,5,6]. It measures the speed for attention, sequencing, mental flexibility and of visual search and motor function, mainly reflecting the ability of “set shifting” [7,8,9,10]. Set shifting is a main component of executive function, involving the control of endogenous attention, which refers to the cognitive strategy of individuals to shift the focus of their attention between various external stimuli in the face of two cognitive tasks competing for same mental resources [11].

The original TMT is a frequently administered neuropsychological test in English-speaking countries with limited utility in cross-cultural contexts because of the use of the English alphabet on Trail B12]. It requires the connection, by making pencil lines, between 25 enriched numbers randomly arranged on a page, in proper order (Part A) and of 25 enriched numbers and English letters in alternating order (Part B) (1-A-2-B-). Many Chinese elderly, especially the poorly-educated elderly, cannot read English letters, resulting in a very low accomplishment ratio with the classic TMT. In China, the Shape Trail Test (STT) [13] and the Color Trail Test (CTT) [14] are more widely used. The CTT and STT were developed with the intent to minimize cultural bias and provide a more accurate cognitive measure in diverse populations. The CTT requires the subjects to connect numbers alternating between two different colors (pink and yellow), while in the STT, Part B shows all numbers (from 1 to 25) twice, once in a circle and once in a square. The participants are asked to make lines alternating between circles and squares and disregarding the numbers of the alternate shapes.[See Figure 1] The reliability and validity of the CTT have been established [15,16,17,18], while for the STT, such data are still absent.

The aim of this study is to examine the applicability of STT in Chinese senile population, evaluate its potential advantages and disadvantages, and provide evidence for future research.

Citation: Zhao Q, Guo Q, Li F, Zhou Y, Wang B, et al. (2013) The Shape Trail Test: Application of a New Variant of the Trail Making Test. PLoS ONE 8(2): e57333. doi:10.1371/journal.pone.0057333

Copyright: © 2013 Zhao et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: dr.guoqihao@126.com (QG); lifangwa@sina.com (FL)
Participants

A total of 2470 participants were recruited, including 1151 cognitively normal controls (NC), 898 patients with amnestic mild cognitive impairment (aMCI), and 421 patients with mild Alzheimer disease (AD).

We recruited the controls using cluster sampling in Jingansi Community Shanghai, China. The inclusion criteria for NC were: age between 50 and 90; no memory complaints verified by an informant; cognitively normal, based on the absence of significant impairment in cognitive functions or activities of daily living (ADL); Clinical Dementia Rating (CDR) = 0; and Hamilton depression rating scale (HAMD) scored ≤ 12 on the 17-item scale in past 2 weeks. They had adequate visual and auditory acuity to allow cognitive testing. Participants with any significant neuropsychologic disease and psychiatric disorders/psychotic features were excluded.

All the patients with aMCI and AD were recruited from the Memory Clinic, Huashan Hospital, from Jun 2004 to Oct 2011. They finished the laboratory tests and cranial CT/MRI scan, and had no clinically significant abnormalities in vitamin B12, folic acid, thyroid function (free triiodothyronine-FT3, free tetraiodothyronine-FT4, thyroid stimulating hormone-TSH), rapid plasma regain (RPR), or treponema pallidum particle agglutination (TPPA).

The aMCI patients were diagnosed according to the following criteria: (1) cognitive complaints verified by an informant; (2) cognitive impairment lasting more than 3 months; (3) Mini-mental state examination-Chinese version (C-MMSE)[25] ≥ cut-off score for adjusted education; (4) Abnormal objective memory impairment documented by scoring below the age and education adjusted cutoff on an episodic memory test (Auditory Verbal Learning Test); (5) preserved basic ADL/minimal impairment in complex instrumental functions; (6) etiology unknown; (7) normal sense of hearing and sight; (8) has not met diagnostic criteria of dementia based on the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association (NINCDS-ADRDA).

The AD patients (n = 421) met the following criteria: (1) diagnosed as probable AD according to the NINCDS-ADRDA; (2) no obvious medical, neurological or psychiatric diseases or psychological dysfunction including anxiety and depression within the previous one month; (3) no visual or auditory deficit.

Materials and Methods

Participants with any significant neurologic disease and psychiatric disorders/psychotic features were excluded.

All the patients with aMCI and AD were recruited from the Memory Clinic, Huashan Hospital, from Jun 2004 to Oct 2011. They finished the laboratory tests and cranial CT/MRI scan, and had no clinically significant abnormalities in vitamin B12, folic acid, thyroid function (free triiodothyronine-FT3, free tetraiodothyronine-FT4, thyroid stimulating hormone-TSH), rapid plasma regain (RPR), or treponema pallidum particle agglutination (TPPA).

The aMCI patients were diagnosed according to the following criteria: (1) cognitive complaints verified by an informant; (2) cognitive impairment lasting more than 3 months; (3) Mini-mental state examination-Chinese version (C-MMSE)[25] ≥ cut-off score for adjusted education; (4) Abnormal objective memory impairment documented by scoring below the age and education adjusted cutoff on an episodic memory test (Auditory Verbal Learning Test); (5) preserved basic ADL/minimal impairment in complex instrumental functions; (6) etiology unknown; (7) normal sense of hearing and sight; (8) has not met diagnostic criteria of dementia based on the National Institute of Neurological and Communicative Disorders and Stroke and the Alzheimer’s Disease and Related Disorders Association (NINCDS-ADRDA).

The AD patients (n = 421) met the following criteria: (1) diagnosed as probable AD according to the NINCDS-ADRDA; (2) no obvious medical, neurological or psychiatric diseases or psychological dysfunction including anxiety and depression within the previous one month; (3) no visual or auditory deficit.

Ethical issues

The study was approved by the Independent Reviewing Board (IRB) of Huashan Hospital. Each subject or the proxy of the AD patient signed informed consent.

Measures

Participants were given neuropsychological tests by a trained rater who was blind to diagnosis. Besides MMSE, a comprehensive neuropsychological battery involving memory, language, attention, executive function and visuospatial ability was used. The tests were as follows: the Auditory Verbal Learning Test (AVLT), the Rey-Osterrieth Complex Figure Test (CFT), the Boston Naming Test (BNT; the 30-item version), the Animal verbal fluency test (AFT), the Symbol Digit Modalities Test(SDMT), the STT (including Part A and B), the Stroop Color-Word Test (SCWT), the Similarity test, the Clock-drawing test (CDT), the CDR and HAMD. All tests have been proven to have a good reliability and validity in Chinese.

Statistical analysis

Chi-square analysis was adopted for ordinal data. Overall differences among the groups were assessed with one-way analysis of variance (ANOVA). Post hoc pairwise comparisons between groups were assessed using the LSD test. The level of significance was set at α = 0.05. Pearson correlation was used to evaluate the relationship analysis. The receiver operating curve was used to assess the sensitivity, specificity and cut-off score. The area under the ROC curves (AUC) was used as an overall index of performance of the screening tests. The AUCs and their standard errors were calculated using the method of Hanley and McNeil.

Results

1. Basic characteristics of the STT

In the total of 2470 subjects, 188 (7.6%) could not complete the STT-Part B. Specifically, in the NC, aMCI and AD groups, 17 (1.5%), 43 (4.8%), and 128 (30.4%) failed in Part B. As such, a “floor effect” of the STT-Part B was observed in AD patients.

We analyzed the correlation between the STT and demographic variables in NC subjects. The time consumed for Part A and B (STT-A, STT-B) correlated with age (r = 0.204, 0.300) (p < 0.01) and negatively correlated with education (r = −0.208, −0.161) (p < 0.01). We then analyzed the gender difference in four subgroups (Group 1: age < 65yrs, formal education year < 12yrs; Group 2: age < 65yrs, education > 12yrs; Group 3: age > 65yrs, education < 12yrs; Group 4: age > 65yrs, education > 12yrs). In younger participants with lower education (Group 1), men perform better than women statistically in both STT-A and STT-B (STT-A, M: 49.76 ± 14.40, F: 60.21 ± 23.23, p = 0.000; STT-B, M: 131.86 ± 38.30, F: 162.32 ± 51.59, p = 0.000). In older NC participants with higher education (Group 4), women need more time to complete STT Part B than men (STT-B, M: 150.01 ± 45.88, F: 167.29 ± 52.88, p = 0.003). In other subgroups, we didn’t find any statistically significant gender difference.

In the NC group, the STT correlated well with other neuropsychological tests (p < 0.01). The STT-A correlated more closely than the STT-B with the BNT, AFT, and DSST, which reflected language and attention. Meanwhile, the STT-B correlated more closely than the STT-A with the AVLT and SCWT, which reflected memory and executive function. The STT-A correlated well with the STT-B (r = 0.543, p < 0.01). Both indexes correlated with the MMSE (r = 0.521, 0.426) (p < 0.01).
Table 1. Comparison among NC, aMCI and mild AD stratified by age and education.

| Group 1 | Group 2 | Group 3 | Group 4 |
|---------|---------|---------|---------|
| NC      | aMCI    | AD      | F(P)    | NC      | aMCI    | AD      | F(P)    | NC      | aMCI    | AD      | F(P)    |
| N       | 336     | 206     | 86      | 313     | 192     | 72      | 201     | 236     | 138     | 301     | 264     | 125     |
| Age     | 58.0    | (4.4)   | 56.8    | (5.1)   | 60.7    | (5.0)   | 59.3    | (4.7)   | 74.3    | (4.1)   | 74.8    | (4.1)   | 75.2    | (4.5)   | 2.75    | (0.06)  |
| Education | 8.7    | (1.9)   | 8.7     | (1.8)   | 13.7    | (1.6)   | 13.2    | (1.4)   | 9.5     | (2.0)   | 9.6     | (2.4)   | 9.1     | (2.6)   | 2.23    | (0.10)  |
| Sex     | 173:163 | 89:117  | 41:45   | 1.76    | (0.17)  | 167:146 | 108:84  | 33:39   | 1.14    | (0.32)  | 99:102  | 129:107 | 72:66   | 0.63    | (0.53)  |        |
| MMSE    | 28.1    | (1.7)   | 27.0    | (1.9)   | 21.0    | (3.1)   | 21.2    | (3.2)   | 27.5    | (1.7)   | 26.4    | (2.0)   | 20.8    | (2.6)   | 44.50   | (0.00)  |
| STT-A   | 54.8    | (19.8)  | 70.0    | (32.3)  | 132.4   | (75.1)  | 117.7   | (33.6)  | 65.2    | (24.5)  | 88.3    | (40.9)  | 119.3   | (59.0)  | 69.04   | (0.00)  |
| STT-B   | 146.8   | (47.8)  | 198.6   | (103.3) | 289.1   | (118.6) | 84.72   | (0.00)  | 136.3   | (50.2)  | 195.3   | (84.3)  | 292.0   | (133.1) | 112.22  | (0.00)  |

Group 1: age ≤65yrs, formal education years ≤12yrs; Group 2: age ≤65yrs, education >12yrs; Group 3: age >65yrs, education ≤12yrs; Group 4: age >65yrs, education >12yrs.

The data are presented as mean (Standard Deviation).

Comparison between NC group and aMCI group was marked behind “aMCI group”, **P<0.01.

Comparison between aMCI group and AD group was marked behind “AD group”, *P<0.01.

Comparison between NC group and AD group was marked behind “NC group”, ***P<0.001.

doi:10.1371/journal.pone.0057333.t001
2. Comparison among NC, aMCI and mild AD stratified by age and education

The performances of the STT Parts A and B were influenced by age and education. Thus, in the following analysis, participants were stratified as following: Group 1: age < 65yrs, formal education year < 12yrs; Group 2: age < 65yrs, education year > 12yrs; Group 3: age > 65yrs, education year < 12yrs; Group 4: age > 65yrs, education year > 12yrs. The STT-A and B were significantly different among the three diagnostic groups (AD > aMCI > NC). (Results see Table 1).

3. ROC analysis for the STT in identifying AD among NC

We established the cut-off score according to age and education. As we can see from Table 2, in Group 1 and Group 4, which were the younger subjects with lower education or the older population with higher education, the cut-off score for the STT-A was 80 seconds. For those younger subjects with higher education, the cut-off score decreased to 70 seconds whereas for the older participants with lower education, the cut-off score increased to 90 seconds. Similarly, with regard to the STT-B, the cut-off score for Group 1 and 4 was 220 seconds; for group 2 it was 200 seconds while for Group 3 it was 240 seconds. (see Table 2).

4. One minute index analysis

The numbers that the participants connected in the STT-Part B within the first one minute (STT-B-1 min) were also analyzed in a sub-sample of this study. A total of 474 (NC: 172; aMCI: 241; AD: 61) subjects finished this part of analysis. The STT-B-1 min correlated well with the STT-B (r = 0.71, p<0.01) and distinguished well among NC, aMCI and AD subjects (Table 3). In the ROC analysis, the AUCs for the STT-A, STT-B, STT-B-1min were 0.698, 0.694 and 0.709, respectively, for identifying AD. There was no significant difference between each of the two indexes (e.g., the STT-B vs STT-B-1min, z = 0.89, p = 0.37). In 196 participants who could not complete the STT-Part B, the STT-B scores were missing, but 5 of these participants still got an STT-B-1min score.

5. Comparison between the STT and the CTT

One hundred elderly NC (n = 100) and fifty mild AD (n = 50) patients completed both the STT and CTT. There were no significant differences in age, education and gender between the two groups (age: 65.9±8.6 vs 68.1±7.6; edu: 12.1±3.1 vs 11.8±2.9; gender M/F: 45/55 vs 24/26, p>0.05). The MMSE scores for them were 28.0±1.5 and 24.7±2.8, respectively (t = 7.72, P<0.01). The STT and CTT correlated well with each other.(See Table 4) But the time consumed for the STT Part A was shorter than the CTT Part A, while those for the STT Part B were longer than those for the CTT Part B, indicating that the interference burden in the STT Part B (which is shape) was

Table 2. Receiver Operating Characteristic Curve Analysis for STT for Identifying AD.

| Group | STT-A | STT-B | STT-A | STT-B |
|-------|-------|-------|-------|-------|
| 1     | 0.830 | 0.913 | >80   | 91.7  |
|       |       |       |       | 72.1  |
| 2     | 0.906 | 0.880 | >70   | 87.2  |
|       |       |       |       | 77.8  |
| 3     | 0.835 | 0.816 | >90   | 84.6  |
|       |       |       |       | 66.7  |
| 4     | 0.877 | 0.874 | >80   | 88.4  |
|       |       |       |       | 66.4  |

AUC*: area under the curve; ** CTT-A: time consumed for STT-Part A; ** CTT-B: time consumed for STT-Part B; ** cut-off score in seconds.

Table 3. STT-B-1 min in Three Different Diagnostic Groups.

|       | NC | aMCI | AD | F(P) |
|-------|----|------|----|------|
| N     | 172| 241  | 61 |      |
| MMSE  | 28.8(3.5) | 27.2(1.8) | 22.1(2.5) | 145.7(0.00) |
| STT-A | 52.1(17.4) | 68.7(27.6) | 49.0(43.0) | 47.46(0.00) |
| STT-B | 151.9(62.0) | 201.5(84.5) | 266.8(112.1) | 46.60(0.00) |
| STT-B-1min | 11.2(4.0) | 8.2(3.8) | 6.49(3.2) | 47.24(0.00) |

Correlation between NC group and aMCI group was marked behind “aMCI group”, **P<0.01.
Correlation between aMCI group and AD group was marked behind “AD group”, **P<0.01.
Correlation between NC group and AD group was marked behind “NC group”, **P<0.01.

Table 4. Correlation between Shape Trail Test and Color Trail Test.

|       | STT-A | STT-B | CTT-A | CTT-B |
|-------|-------|-------|-------|-------|
| STT-A | 1     | 0.522 | 0.502 | 0.526 |
| STT-B | 1     | 0.512 | 0.565 |       |
| CTT-A | 1     | 0.546 |       |       |
| CTT-B | 1     |       |       |       |

STT-A: time consumed for the Shape Trail Test (STT)-Part A; STT-B: time consumed for the STT-Part B; CTT-A: time consumed for the Color Trail Test (CTT)-Part A; CTT-B: time consumed for the CTT-Part B. **P<0.01.

doi:10.1371/journal.pone.0057333.t003

doi:10.1371/journal.pone.0057333.t004

Table 5. Comparison between NC, aMCI and mild AD stratified by age and education.

|       | NC | aMCI | AD | F(P) |
|-------|----|------|----|------|
| N     | 172| 241  | 61 |      |
| MMSE  | 28.8(3.5) | 27.2(1.8) | 22.1(2.5) | 145.7(0.00) |
| STT-A | 52.1(17.4) | 68.7(27.6) | 49.0(43.0) | 47.46(0.00) |
| STT-B | 151.9(62.0) | 201.5(84.5) | 266.8(112.1) | 46.60(0.00) |
| STT-B-1min | 11.2(4.0) | 8.2(3.8) | 6.49(3.2) | 47.24(0.00) |

Correlation between NC group and aMCI group was marked behind “aMCI group”, **P<0.01.
Correlation between aMCI group and AD group was marked behind “AD group”, **P<0.01.
Correlation between NC group and AD group was marked behind “NC group”, **P<0.01.

doi:10.1371/journal.pone.0057333.t005

doi:10.1371/journal.pone.0057333.t006
Table 5. Performance of Shape Trail Test and Color Trail Test between NC and mild AD.

|                | NC (n = 100) | Mild AD (n = 50) | t     | P   |
|----------------|--------------|------------------|-------|-----|
| STT-A          | 63.2 ± 24.0  | 76.2 ± 34.9      | 2.37  | 0.020 |
| STT-B          | 182.6 ± 71.0 | 230.5 ± 83.5     | 3.44  | 0.001 |
| CTT-A          | 78.0 ± 47.8  | 95.5 ± 47.4      | 2.12  | 0.036 |
| CTT-B          | 138.4 ± 44.2 | 190.3 ± 65.2     | 5.03  | 0.000 |

STT-A: time consumed for the Shape Trail Test (STT)-Part A; STT-B: time consumed for the STT-Part B; CTT-A: time consumed for the Color Trail Test (CTT)-Part A; CTT-B: time consumed for the CTT-Part B.

Discussion

Although the TMT is one of the most widely used measures in neuropsychological practice, it is culture-loaded because of reliance on the Latin alphabet, which has limited its application in Eastern populations. The recent variant form of the TMT is the CTT, which is designed to minimize the influence of language and covers the full children-to-adult age range. It has allowed broader application for cross-cultural studies, while at the same time being similar to the original TMT in terms of neuropsychological sensitivity. However, studies have also suggested that there might be a large variability in performance on the CTT because of culture-bound factors. Familiarity with testing procedures and relevance of the applied techniques to real-life experience could affect task performance. Besides, the possibility of a Stroop effect on CTT-B performance, as suggested by Spreen and Strauss, may influence test performance in a way that makes the CTT-Part B a qualitatively different task in comparison to the classic TMT-Part B. Additionally, the CTT requires four color-printed record sheets which increases the cost accordingly.

The STT is another variant form of the original TMT. It was developed by Agnes Chan from the Chinese University of Hong Kong in 2013. In the current study, we analyzed the correlation between the STT with demographic variables in cognitively normal individuals, which showed a similar trend to the TMT 3,21,22,23,24,25. The test loaded on both “rapid visual search” and “visuospatial sequencing” factors, as well as “cognitive set-shifting”. Factor analysis revealed that the STT-A and B correlated only moderately (r = 0.522) with each other, suggesting that they measure somewhat different functions, which is similar to the original TMT. In addition to switching between squares and circles, Part B also includes more visual interferences and a longer path length. Hence, Part B requires more visual perceptual processing ability than Part A. Our factor analysis revealed that the STT-A reflected language and attention while the STT-B relied more on executive function and memory.

The trail test has been reported to be sensitive to neuropsychological disorders such as closed-head injury, alcoholism and substance abuse. Studies have also found significant differences among AD, MCI and controls in the TMT26. Similarly, in the current study, the STT-A and B distinguished well among AD, aMCI and controls. When age and education-stratified cut-off scores were adopted, the AUC of the ROC curves of the STT-A and B ranged from 0.816–0.913, and the sensitivity and specificity were also acceptable. We did not find any significant difference between the STT-A and B in differential validity.
References

1. Spreen S (1998) A Compendium of Neuropsychological Tests. Administration, Norms, and Commentary. New York: Oxford University Press. 447p.

2. Lu L, Bigler ED (2002) Normative data on trail making test for neurologically normal, Chinese-speaking adults. Appl Neuropsychol 9: 219–225.

3. Hashimoto R, Meguro K, Lee E, Kasai M, Ishii H, et al. (2006) Effect of age and education on the Trail Making Test and determination of normative data for Japanese elderly people: the Tajiri Project. Psychiatry Clin Neurosci 60: 422–429.

4. Seo EJ, Lee DY, Kim KW, Lee JH, Hoon JH, et al. (2006) A normative study of the Trail Making Test in Korean elders. Int J Geriatr Psychiatry 21: 844–852.

5. Pena-Casanova J, Quinones-Ubeda S, Quintana-Aparicio M, Aguilar M, Badenes D, et al. (2009) Spanish Multicenter Normative Studies (NEUROMORA Project): norms for verbal span, visuospatial span, letter and number sequencing, trail making test, and symbol digit modalities test. Arch Clin Neuropsychol 24: 321–341.

6. Fernandez AL, Marconcis BA (2008) A comparison of normative data for the Trail Making Test from several countries: equivalence of norms and considerations for interpretation. Scand J Psychol 49: 239–246.

7. Moll J, de-Oliveira-Souza R, Moll FT, Bramati IE, Andreiauolo PA (2002) The cerebral correlates of set-shifting: an fMRI study of the trail making test. Arq Neuropsiquiatr 60: 900–905.

8. Koerte KB, Hornier MD, Windham WK (2002) The trail making test, part B: cognitive flexibility or ability to maintain set? Appl Neuropsychol 9: 106–109.

9. Oosterman JM, Vogels RL, van Harten B, Groen AA, Poggesi A, et al. (2010) Assessing mental flexibility: neuropsychological and neuroanatomical correlates of the Trail Making Test in elderly people. Clin Neuropsychol 24: 203–219.

10. Sanchez-Cabillo I, Perianez JA, Adrover-Roig D, Rodriguez-Sanchez JM, Ries-Lago M, et al. (2009) Construct validity of the Trail Making Test: role of task-switching, working memory, inhibition/interference control, and visuomotor abilities. J Int Neuropsychol Soc 15: 438–450.

11. Arbuthnot K, Frank J (2000) Trail making test, part B as a measure of executive control: validation using a set-switching paradigm. J Clin Exp Neuropsychol 22: 518–528.

12. Barn cord SW, Wanlass RL (2001) The symbol trail making test: test development and utility as a measure of cognitive impairment. Appl Neuropsychol 8: 99–107.

13. J.C. Lu QHG, Z Hong (2006) Trail making test used by Chinese elderly patients with mild cognitive impairment and mild Alzheimer dementia. Chinese Journal of Clinical Psychology 14: 118–121.

14. Hartman-Maeir A, Erez AB, Ratzon N, Mattatia T, Weiss P (2008) The validity of the Color Trail Test in the pre-driver assessment of individuals with acquired brain injury. Brain Inj 22: 994–998.

15. Elin-Frankston S, Lebowitz BK, Kapust LR, Hollis AM, O’Connor MG (2007) The use of the Color Trails Test in the assessment of driver competence: preliminary report of a culture-fair instrument. Arch Clin Neuropsychol 22: 631–635.

16. Lee TM, Cheung CC, Chan JK, Chan CC (2000) Trail making across languages. J Clin Exp Neuropsychol 22: 772–778.

17. Lee TM, Chan CC (2000) Are trail making and color trails tests of equivalent constructs? J Clin Exp Neuropsychol 22: 529–534.

18. Dugbartey AT, Townes BD, Maharin RK (2000) Equivalence of the Color Trails Test and Trail Making Test in nonnative English-speakers. Arch Clin Neuropsychol 15: 425–431.

19. Petersen RC SG, Waring SC, Ivnik RJ, Tangalos EG, Kokmen E (1999) Mild cognitive impairment. Arch Neurol 56: 6.

20. Lu L, Bigler ED (2000) Performance on original and a Chinese version of Trail Making Test Part B: a normative bilingual sample. Appl Neuropsychol 7: 243–246.

21. Heeter RL, Kinsella GJ, Ong B, McGregor J (2005) Demographic influences on baseline and derived scores from the trail making test in healthy older Australian adults. Clin Neuropsychol 19: 45–54.

22. Alexander NB, Ashton-Miller JA, Giordani B, Guire K, Schultz AB (2003) Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test. J Gerontol A Biol Sci Med Sci 60: 1558–1562.

23. Toubough TN (2004) Trail Making Test A and B: normative data stratified by age and education. Arch Clin Neuropsychol 19: 203–214.

24. Kennedy KJ (1981) Age effects on Trail Making Test performance. Percept Mot Skills 52: 671–675.

25. Davies AD (1968) The influence of age on trail making test performance. J Clin Psychol 24: 96–98.

26. Ashendorf L, Jefferson AL, O’Connor MK, Chaisson C, Green RC, et al. (2008) Trail Making Test errors in normal aging, mild cognitive impairment, and dementia. Arch Clin Neuropsychol 23: 129–137.

27. Drane DL, Yaspel RL, Huthwaite JS, Klingsler JK (2002) Demographic characteristics and normative observations for derived-trail making test indices. Neuropsychiatry Neuropsychol Behav Neurol 15: 39–43.

28. Martin TA, Hoffman NM, Donders J (2003) Clinical utility of the trail making test ratio score. Appl Neuropsychol 10: 163–169.

29. Ruffolo LF, Guilmette TJ, Willis GW (2000) Comparison of time and error rates on the trail making test among patients with head injuries, experimental malingerers, patients with suspect effort on testing, and normal controls. Clin Neuropsychol 14: 225–230.