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Latent structure of the Test of Everyday Attention: Convergent evidence from patients with traumatic brain injury

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Abstract

Aim: The present study aimed to examine the nature of attention distinctions among sub-tests of the Test of Everyday Attention (TEA) underlying the performance of patients with traumatic brain injury (TBI).

Method: Confirmatory factor analysis was performed among a group of 92 patients with TBI experiencing chronic post-concussive symptoms. Comparisons were made of the fit of the previously identified models based on exploratory factor analysis, comprising three-to-four factors.

Main outcome: The results indicated that the 3-factor model with a visual selection component, a sustained attention component and a switching component provided an appropriate account of attentional performance than the other two 4-factor models.

Conclusion: These findings are consistent with those of healthy sample. This study, therefore, provides convergent evidence on the latent structure of the TEA. It is consistent and stable across healthy and clinical populations.

Keywords: *Attention, confirmatory factor analysis, traumatic brain injury*

Introduction

Robertson et al. [1, 2] developed the Test of Everyday Attention (TEA) for the evaluation of attentional performance among healthy and clinical samples. This test has several advantages for clinical and research purposes over similar tests of attention. First, it was mainly developed from theoretical frameworks of attention. For example, the selective attention system and vigilance system of Posner and Petersen's [3] neuro-anatomical model and the concept of attention switching mental sets were incorporated in its sub-test development. Hence, it provides a strong theoretical framework for clinicians and researchers to investigate attentional performance in various clinical populations.

Secondly, the test incorporates items that are not purely 'laboratory-based' but simulate daily activities. The test is based on the imaginary scenario of a vacation to Philadelphia in the US and includes tasks such as telephone number searches in a directory. These types of items may be more meaningful for clinical cases to complete than conventional laboratory-based test items, though they are not purely everyday life activities.

Thirdly, there is a children's equivalent of this test, the Test of Everyday Attention for Children (TEAch) [4, 5]. Given the diversity of the sub-tests that are embedded in the TEA, this test and its version for children may have a wide range of application, from healthy populations to various

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clinical populations along the developmental life-span continuum.

Fourthly, the TEA has three parallel versions, each with eight sub-tests. It is one of the very few clinical tests that provide parallel forms for continuous repeated evaluation. It is crucial for clinical practice because the provision of parallel forms may remove the learning or practice effect of repeated testing over several periods for clinical cases. This is especially important for prospective longitudinal clinical studies.

Finally, satisfactory psychometric properties, in terms of test–re-test reliability and preliminary construct validity, have been reported [1, 2, 6–9]. It has been demonstrated that the test discriminates between patients with traumatic brain injury (TBI) and participants with normal attention performance [6]. To make the test more applicable to a clinical setting for the screening of potential cases of attentional impairment for intervention, Crawford et al. [10] and Chan et al. [8] provide a method of examining the client's pattern of relative strengths and weaknesses with respect to attention. Clinicians are able to compare an individual's sub-test scores with norms for their age group. For example, if the individual only completes some of the sub-tests, clinicians can still determine the size of the difference between a particular TEA sub-test and the individual's mean sub-test score by referring to calculated critical values.

However, few studies have specifically examined the factor structure that is embedded within this test. Of the limited studies, most have only adopted principal component analysis to explore the factor structure of the TEA [2, 7, 11], which suggests a 3- or 4-factor model is embedded in the test. For example, Robertson et al. [2] demonstrated a 4-factor model of attention among a group of healthy participants ($n = 155$) by using the principal component analysis. These factors are identified as visual selective attention or speed (map search, telephone search), attentional switching (visual elevator), sustained attention (lottery test, elevator counting, dual task decrement) and auditory-verbal working memory (auditory elevator with reversal, auditory elevator with distraction). Chan et al. [7] found a similar 4-factor structure in the Cantonese version of the TEA among a group of 49 healthy Hong Kong Chinese. The main difference in the findings of Chan et al. [7] was the fourth factor, namely divided attention, as compared to the auditory-working memory factor of Robertson et al. [2] Bate et al. [11] applied the original version of the TEA on a mixed group of healthy participants and severe TBI patients and found a similar 4-factor model, as compared with Chan et al. [7] and Bate et al. loaded the elevator counting and elevator counting with reversal onto both the divided attention factor and the divided attentional switching factor.

Most recently, Chan et al. [9] used confirmatory factor analysis to test the models of attention structure that were identified by previous studies in a group of healthy Hong Kong Chinese. It was found that the 3-factor model that was proposed by Robertson et al. [2]—visual selection, sustained attention and switching—provide a better account of attentional performance than the 4-factor model for the healthy sample. However, this 3-factor model has not been validated in another clinical TBI sample. The study that is reported herein was among the first to cross-validate the 3-factor model of attention in a clinical sample in the Chinese context. In particular, it was hypothesized that visual selection, sustained attention and attentional switching were embedded in the Cantonese version of the TEA in a group of patients with TBI.

Methods

Participants

The sample comprised 92 TBI patients (26 women and 66 men) with TBI. They were recruited from the out-patient specialty clinics of two main regional hospitals in Hong Kong. All the patients had persistent complaints of post-concussive symptoms. Potential participants were excluded if they (1) had other neurological diseases, psychiatric illness or other medical complications, (2) had communication problems, such as receptive or expressive dysphasia and (3) were chronic smokers, drinkers or drug addicts. Qualified medical officers had made diagnoses within 24 hours of the injuries. The reported mean age of the patient group was 37.63 years ($SD = 9.62$). The mean number of years of education was 9.39 years ($SD = 3.38$). The patients reported a median of 0 day (with a range of 0–7 days) of PTA and was at a median of 12 months (with a range of 3–78 months) post-injury. The median score of the GCS was 15 (with a range of 6–15) and a median LOC was 0 (with a range of 0–7 days). This data indicates that the majority of the CHI patients suffered from a mild-to-moderate grade of injury. Table I summarizes the other clinical data of the patient group.

Table I. Clinical data for patients with TBI.

Causes of injury	
Slip and fell	13 (14.1%)
Hit by heavy/falling objects	29 (31.5%)
Traffic accidents	27 (29.3%)
Fall	23 (25%)
CT Scan	
No abnormality detected	51 (55.4%)
Frontal region	22 (23%)
Temporal region	3 (3.3%)
Parietal region	3 (3.3%)
Occipital region	1 (1.1%)
Multiple regions	8 (10.8%)
Ventricle dilation	2 (2.2%)
Employment Status	
Full-time	40 (43.5%)
Part-time	9 (9.8%)
Unemployed	43 (46.7%)
Litigation	
Yes	16 (17.4%)
No	76 (82.6%)

Procedures

Each participant was given the full battery of the TEA according to the instruction manual [1]. All participants were given version A of the Cantonese translated test. The participants were asked to perform eight sub-tests of everyday tasks in different scenarios that had been described in detail elsewhere [2, 7, 8].

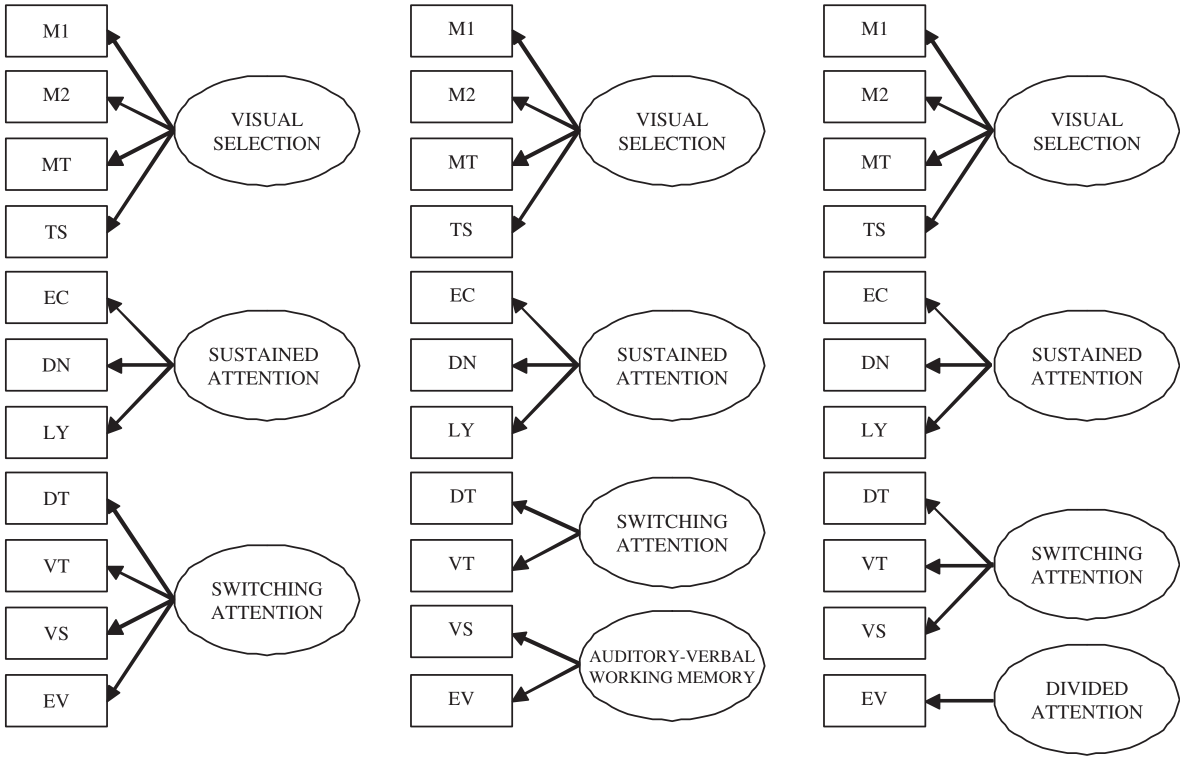
In the LISREL models, the differences between the sample covariance matrix and the covariance matrix that had been generated by the hypothesized model were minimized through maximum likelihood estimation. The degree of a lack of good fit in a model was assessed through the application of a chi-square test on the degree of discrepancy between the two covariance matrices. As the chi-square test is very sensitive to sample size and the probability of rejection of any model increases as the sample size increases even when the model is minimally false [12], other fit indices were recommended parallel to the chi-square test to assess the goodness of fit of the CFA models [13, 14]. The goodness of fit index (GFI) and the comparative fit index (CFI) were used to assess the three competing models and the GFI and CFI scores of 0.90 or higher [14] (or close to 0.9513) were considered evidence of a good fit. The standardized root mean square residual (SRMR) was also used to indicate the average size of the absolute standardized differences between the sample and the estimated matrices, with a score of less than 0.08 that was considered evidence of a good fit in the present study [15].

The models that were compared (see Figure 1) included one 3-factor model (visual selection, sustained attention and switching) and two 4-factor models from Robertson et al. [2] (sustained attention, selective attention, attention switching and auditory-verbal working memory) and from Chan et al. [7] (visual selection, sustained attention, switching and divided attention). The 4-factor model of Bate et al. [11] was not included in the present study because of the heterogeneous nature of their sample.

Results

Table II summarizes the mean scores of the eight sub-tests of the TEA. Table III presents the results of the inter-correlations of the TEA sub-tests. The correlation matrix was a non-positive definite and the variable Map Search in 2 Minutes (*M*2), which was identified as the cause of the problem, was excluded from the modelling. This study assumed, as have other researchers, that correlations between variables should be explained by the latent factors in the models and tested the models with uncorrelated observed variables [16].

Table IV displays the results of the confirmatory factor analysis for each of the competing models in the present sample. Although the factor loadings in the three competing models are all significant, none of the tested models provide a satisfactory fit for the patient sample. The problem of a non-positive definite occurs in both 4-factor models where the latent factor of switched attention is split into two factors. An exploratory model is constructed based on the original 3-factor model of Robertson et al. Adjustments to the model are applied one-at-a-time to the factor loadings that have modification indices (MI) greater than 10. The Telephone Search (TS) and the Visual Elevator Time (VT) score are suggested to be indicators of sustained attention, with the MI greater than 40. The original loadings for the TS and the VT become non-significant after adjustment and, therefore, fixed at zero. No further change is suggested and the exploratory model produces significant ($p < 0.05$) factor loadings for all of the indicators with a better fit than the three proposed models (χ^2 (33) = 68.94, $p = 0.002$, GFI = 0.88, CFI = 0.94 and SRMR = 0.07). The GFI of 0.88 is close to satisfactory and this model is the least mis-specified model among the other tested models. The factor loadings for the exploratory model are of a magnitude above 0.60 and the correlations between latent factors are ~0.60.



A: Robertson et al.'s (1996) original 3-factor model

B: Robertson et al.'s (1996) 4-factor model

C: Chan et al.'s (1999) 4-factor model

M1: Map search in 1 minute; M2: Map search in 2 minutes; MT: Map search total; TS: Telephone search; EC: Elevator counting; DN: Dual task decrement – Telephone Search While Counting; LY: Lottery task – Lottery in digits raw score; DT: Elevator counting with distraction; VT: Visual elevator raw score – Reaction time; VS: Visual elevator time score – Switch; EV: Elevator counting with reversal

Figure 1. Testing models of attentional components of the TEA.

Table II. Performance on TEA in patients with TBI.

Subtest performance ($N = 92$)	Mean/*n*	SD/%
Map Search 1	33.67	(15.41)
Map Search in the 2 min	23.66	(7.64)
Map Search Total	57.34	(16.93)
Telephone Search	4.15	(2.50)
Elevator Counting	6.43	(0.88)
Telephone Search While Counting	6.23	(14.87)
Lottery in Digits Raw Score	8.52	(1.85)
Elevator Counting with Distraction	6.43	(2.56)
Visual Elevator Raw Score	7.28	(2.35)
Visual Elevator Time Score	5.86	(4.32)
Elevator Counting with Reversal	4.66	(2.56)

Taken together, there should be three types of attention based on the 10 tasks of the TEA (Figure 2). Whether the variables TS and VT are indicators for sustained attention is yet to be investigated as the theory does not suggest it and it has not been *a priori* tested. The M2 should be excluded because of possible redundancy and the problem of the non-positive definite correlation matrix.

Discussion

The results indicate the 3-factor model of the TEA, which was originally proposed by Robertson et al. [1, 2], is the best conceptualization of the inter-relationships that underlie the sub-tests of the TEA among a group of patients with TBI. The results are consistent with those of previous studies that collected both behavioural and experimental data by using neuro-imaging techniques [17–20].

However, the original Robertson et al. 3-factor model is slightly modified as compared to the healthy sample [9]. Unlike the healthy sample, the TS and the VT are suggested as indicators of sustained attention. The variation of factor structure that is observed in the present findings are consistent with previous studies on evidence for qualitatively different attentional systems that are linked to different brain structures and attentional performance in patients with TBI [3, 21–24]. The incident of brain injury may affect the attentional structure, as is found in participants without brain impairment. Spikeman et al. [24] suggested there may be two main reasons to account for such a variation.

Table III. Correlation of TEA items in TBI sample.

Subtest	M1	M2	MT	TT	ET	DN	LY	DT	VT	VS	EV
M11	1	–	–	–	–	–	–	–	–	–	–
M2	−0.04	1	–	–	–	–	–	–	–	–	–
MT	0.89**	0.42**	1	–	–	–	–	–	–	–	–
TT	−0.51**	−0.26*	−0.58**	1	–	–	–	–	–	–	–
ET	0.37**	0.18	0.42**	−0.48**	1	–	–	–	–	–	–
DN	−0.31**	−0.18	−0.37**	0.74**	−0.55**	1	–	–	–	–	–
LY	0.47**	0.19	0.51**	−0.61**	0.32**	−0.46**	1	–	–	–	–
DT	0.54**	0.12	0.55**	−0.42**	0.46**	−0.40**	0.39**	1	–	–	–
VT	0.27**	0.22*	0.35**	−0.48**	0.33**	−0.52**	0.46**	0.51**	1	–	–
VS	−0.46**	−0.20	−0.51**	0.76**	−0.57**	0.69**	−0.49**	−0.43*	−0.44**	1	–
EV	0.52**	0.04	0.49**	−0.37**	0.29**	−0.35**	0.30**	0.72**	0.62**	−0.39**	1

*$p < 0.05$; **$p < 0.01$

M1: Map search in 1 minute; M2: Map search in 2 minutes; MT: Map search total; TS: Telephone search; EC: Elevator counting; DN: Dual task decrement–Telephone Search While Counting; LY: Lottery task–Lottery in digits raw score; DT: Elevator counting with distraction; VT: Visual elevator raw score–Reaction time; VS: Visual elevator time score–Switch; EV: Elevator counting with reversal.

Table IV. Factor loadings and goodness of fit indices of competing CFA models in TBI patients.

Subtest	Single factor model	Robertson et al.'s 3-factor model	Robertson et al.'s 4-factor model	Chan et al.'s 4-factor model	Exploratory 3-factor model
Map Search 1	0.68	0.92[a]	0.92[a]	0.92[a]	0.91[a]
Map Search Total	0.73	0.97[a]	0.97[a]	0.97[a]	0.98[a]
Telephone Search	−0.84	−0.60[a]	−0.61[a]	−0.60[a]	0.90[b]
Elevator Counting	0.61	0.66[b]	0.66[b]	0.65[b]	−0.61[b]
Telephone Search While Counting	−0.74	−0.74[b]	−0.75[b]	−0.74[b]	0.80[b]
Lottery in Digits Raw Score	0.65	0.62[b]	0.62[b]	0.63[b]	−0.63[b]
Elevator Counting with Distraction	0.65	0.79[c]	0.74[c]	0.71[c]	0.83[c]
Visual Elevator Raw Score	0.61	0.70[c]	0.68[c]	0.66[c]	0.68[c]
Visual Elevator Time Score	−0.80	−0.66[c]	0.58[d]	−0.66[c]	0.85[b]
Elevator Counting with Reversal	0.59	0.77[c]	−0.67[d]	1.00[e]	0.86[c]
Chi-square	232.06	182.40	169.78	147.98	68.94
df	35	32	29	30	32
p for Chi-square	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
SRMR	0.11	0.14	0.14	0.13	0.07
GFI	0.67	0.72	0.74	0.77	0.88
CFI	0.67	0.75	0.76	0.8	0.94

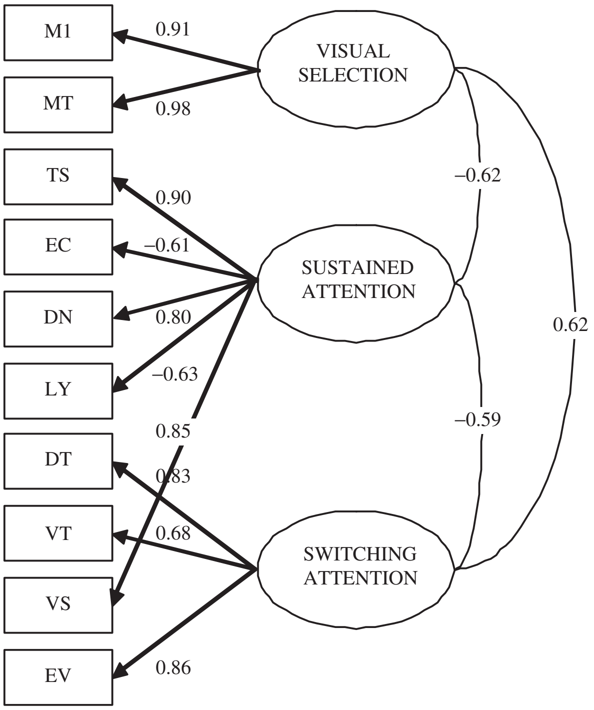
[a] visual selection; [b] sustained attention; [c] switching attention; [d] auditory-visual working memory; [e] divided attention.

Notes: All factor loadings were significant at 0.05 level. Items of Map Search in 2 minute and Elevator Counting were not included in the model computations.

The first reason is a between-groups difference. As the presence and location of focal lesions varies between patients with TBI, it can be expected that there is more variability in attention test results within the patient group due to selective disruption of different attentional brain systems. The second reason is the slowing of information processing following a brain injury. This mental slowness results in a decrease of processing capacity that may require patients to process information in a qualitatively different way.

This study has a number of methodological limitations. First, this stidy only recruited $\sim$100 cases for the confirmatory factor analysis. Typically, a sample of more than 200 participants is required for a rigorous confirmatory factor analysis. Secondly, the present sample mainly comprised patients with mild TBI who experienced chronic post-concussive symptoms. Moreover, the mean years of education and range suggest that there could be significant variability and that attention deficit disorder could certainly have been a pre-morbid issue.

The use of the TEA with a normal population and patients with TBI is common, but satisfactory measurement properties are usually obtained from studies of the general population. The present study provides support for the use of the TEA in the study of attention in patients with TBI. Although a 3-factor model that is similar to the healthy sample is supported, the indicators for the factors have differences and clinicians should pay attention to



Exploratory 3-factor model based on
Robertson et al.'s (1996) original 3-factor model
$\chi^2(32)=69.94$, $p<0.01$; GFI=0.88; CFI=0.94; SRMR=0.07

M1: Map search in 1 minute; M2: Map search in 2 minutes;
MT: Map search total; TS: Telephone search;
EC: Elevator counting; DN: Dual task decrement –Telephone Search While Counting;
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EV: Elevator counting with reversal

Figure 2. Final exploratory models of attentional components of the TEA.

these differences when they use the TEA on patients with TBI. Further research is needed into how the latent structure of attention in patients with TBI is manifested through the indicators of the TEA.

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