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Can the Trail Making Test be substituted by a 3D computerized visit to a supermarket? Clinical implications

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Abstract

In the present study, we assessed the convergent validity and clinical utility of the Supermarket Test (ST), which is a 3D computerized selective attention test that resembles the everyday life situation of visiting a supermarket (navigate and identify as quickly as possible certain 3D target-objects, e.g., plates, kettles, toothbrushes). The ST and the Trail Making Test (TMT) were administered to a sample of 50 healthy Greek participants (*N*=33 males, mean age=38.02, *SD*=11.56). To test the clinical utility of the ST, we administered the test to patients with diagnoses known to affect attentional performance, such as psychiatric (schizophrenia, bipolar disorder) and neurological diagnoses (multiple sclerosis). Pearson's *r* correlations between the performance indices on the ST and performance on the TMT revealed the existence of very high (r >.80) correlations. As regards the clinical utility of the ST, results from the case studies showed that patients presented a variety of difficulties (prolonged reaction times, errors and omissions) on the Supermarket subtest depending on their diagnosis. The very high correlations between the TMT and ST implies a similarity between the two tasks i.e., focusing on targets while simultaneously inhibiting other non-targets presented in the vicinity and alternating attention among the different stimuli. Thus, we conclude that the use of the ST could serve as a computerized analogue of the Trail Making Test resembling real-life situations. Also, the ST displayed excellent convergent validity with traditional attention tests and is, therefore, a valuable tool for the detection of attention disorders in patients.

Key-words: computerized assessment, selective attention, Trail Making Test, neuropsychology

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Conflict of Interest

The authors declare no conflict of interest.

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1. Introduction

Attention is a complex cognitive function which is crucial for everyday living, as it constitutes an integral part of the procedure of environmental information processing [1]. Selective attention is a main attentional subfunction responsible for guiding our awareness to a relevant environmental target while tuning out irrelevant, unnecessary or distracting details. By definition, selectivity helps us focusing on a particular target-stimulus (external or internal), while simultaneously inhibiting response to non-target stimuli [2].

Impairment in selective attention is a commonly observed consequence of neurological and psychiatric disorders. For example, in schizophrenia difficulty paying attention to irrelevant cues has been considered the underpinnings of positive symptoms [3]. Patients with bipolar disorder are prone to impulsivity errors especially during the manic phase, which can be interpreted as the inability of the inhibitory mechanism to filter out information that is distracting or irrelevant to the patient's concurrent undertaking [4]. Selective visual or auditory attention deficits have also been reported in a plethora of neurological diseases, such as Parkinson's disease [5], Huntington disease [6], stroke [7] and multiple sclerosis [8].

Diagnosis of attention disorders in neurological and psychiatric patients is essential for providing the appropriate medical treatment and planning a successful therapeutic intervention. This challenge is addressed with the help of neuropsychological assessment tools sensitive to attention disorders [i.e., 9]. Traditionally, attention assessment was based on paper-and-pencil administration performed by a trained neuropsychologist [10]. Examples of traditional clinical testing of visual selective attention include the Trail Making Test [11], the Stroop Color-Word Test [12] and for auditory attention the Paced Auditory Serial Addition Test [13]. The Trail Making Test (TMT) is a widely used selective attention test and examines a variety of underlying cognitive processes including selective and shifting of attention, visual screening, processing speed, sequencing, flexibility and action planning [14, 15] Due to its ease in administration and its usefulness in clinical settings, the TMT has gained international acceptance and has been used in many countries as an integral part of the neuropsychological evaluation. Additionally, research has demonstrated its sensitivity in detecting frontal lobe dysfunction [16] and is strongly related to driving performance [17] and functional outcome [18, 19]. Nevertheless, Part B of the TMT displays a considerable drawback, as it requires from patients to alternate between numbers and letters. The latter assumes that patients are literate and know the alphabet of their native language [20, 21]. Moreover, TMT has been claimed to work differently for some Asian [22] and European countries [23], exhibiting strong cultural effects. For example, difficulties in understanding the instructions on the TMT part B among a non-trivial percentage of cognitively healthy older Greek adults with low levels of education [24] detract from its utility in assessing this cohort for potential cognitive decline. Finally, the TMT testing material is experimental and resembles school-type tasks, thus resulting in little resemblance to patient's everyday reality.

Therefore, we constructed a 3D analogue of the test, by using the Unity3D game engine environment. The Supermarket Test was developed to simulate a visit to a supermarket, which includes navigation through the corridors and selection of the desired products. To our knowledge, it is the first time that 3D technology has been employed in neuropsychological attention testing. Thus, in the present study we sought to provide preliminary evidence for the validity of this newly developed diagnostic instrument and, to report the performance of three patient cases with psychiatric and neurological disorders that are known to affect attention.

2. Materials and Methods

2.1 Participants

The healthy sample consisted of 50 ($N = 33$ males) Greek-speaking participants aged from 24 to 72 (mean age = 38.02 years, $SD = 11.56$) with 16.84 mean years of education ($SD = 4.06$). Participants were interviewed individually about their medical history. Exclusion criteria from the study were the presence of any medical condition that affects the brain function (i.e., neurological or psychiatric illness).

The clinical cases that we examined were two male patients,

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a 34-year-old with schizophrenia (SCI) and a 31-year-old with moderate-to-severe relapsing remitting multiple sclerosis (MS) and a 40-year-old female patient with bipolar disorder (BPD). Patients were recruited from a private outpatient office and were known to have the respective medical diagnoses.

2.2 Instruments

Two selective attention tests were used in the present study, namely, the traditional paper-pencil Trail Making Test and the 3D Supermarket test. A short description of the tasks follows.

2.2.1 The Trail Making Test [11]

This well-known test consists of two parts (A and B). In each part 25 circles are presented dispersed on a A4 sheet of paper. In Part A the examinee is asked to connect consecutively and in ascending order numbered circles (from 1 to 25) on the worksheet. In Part B, the examinee must draw lines to connect numbers and letters in ascending order (for numbers from 1 to 13 and letters from A to N, in the Greek version) by alternating the two sequences. The examinee is advised to work as quickly as possible without lifting the pencil from the worksheet. In the event of an error, the examiner indicates that an error has been made, urging the examinee to correct it; thus a time penalty occurs for the participant's score. The TMT assesses speedy scanning, visuomotor tracking and flexibility [14]

2.2.2 The Supermarket Test

The Supermarket Test (ST) is one the four subtests included in the Computerized Battery for the Assessment of Attention Disorders [CBAAD, 25]. It is a selective attention subtest

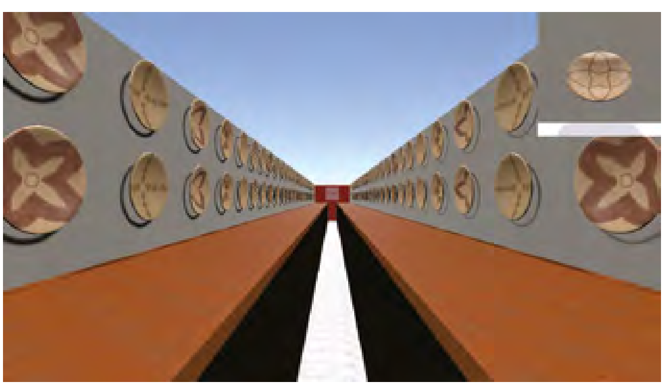

Figure 1. Scene of Levels 1 and 2 (plates)

Figure 2. Scene of Level 3 (toothbrushes)

Figure 3. Scene of Level 4 (handbags)

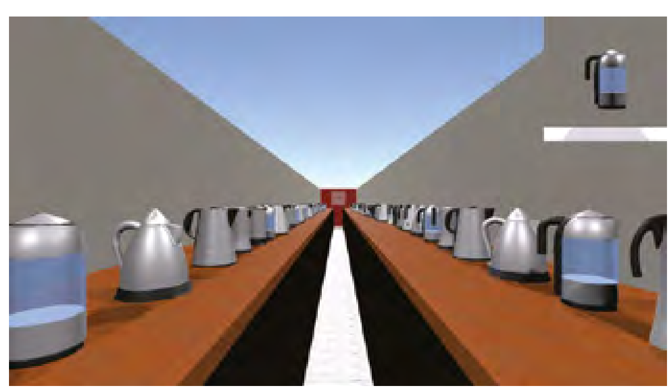

Figure 4. Scene of Level 5 (kettles)

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Figure 5. Scene of Level 6 (televisions)

that resembles a real visit to a 3D supermarket. Products (i.e., plates, toothbrushes, handbags, kettles and televisions, see Figures 1-5) in each level are placed at both sides of the visual field of the participant. The examinee must navigate through the aisles by scrolling with the computer-mouse, quickly scan the scene and identify the desired products among others resembling very much to the targets. He/she then uses the mouse to click on the target-items. Every correct product selection is registered as a correct response. The selection of a distracting product is recorded as an error. In order to reduce the memory demands of the task, the target product is displayed on the right upper side of the screen throughout the entire duration of the level. The test consists of 6 levels. Duration of each level depends on the examinee, as he/she is instructed to press a button and move on to the next level only when he/she thinks that all target products were identified. In the event that the examinee omits targets, those items are recorded as omission errors. All selectable products are 351 in number and 83 out of them are the targets. After the test has been completed, the scores are automatically saved in the CBAAD database and transformed into a .sav file further statistical analysis. Finally, output variables are the following, calculated separately for each level and for the total performance: hits, errors, omissions, level duration and time per hit (time score weighted by the number of correct responses). Moreover, means, medians and standard deviations are calculated for the total performance.

2.3 Procedure

All participants were informed of the purpose of the study and their rights as voluntary participants in research, and gave their written consent.

3. Results

3.1 Descriptive Statistics

Table 1 lists descriptive information (mean, standard deviation, minimum and maximum) for the Supermarket Test variables, indicating the sample's accuracy (hits, errors, omissions) and speed of performance indices (duration and time per hit) for each of the six levels of the test and for the total performance as well. With respect to accuracy indices, our healthy sample scored very highly with few or no errors and omissions that are characterized by low variance. In contrast, timed variables, as the duration of completing the task at each level, or weighted time scores presented a very high variance on all task levels. Mean time per hit performance on all levels varied between 3 to 4.2 seconds, with the exception of Level 6 (L6), on which the duration of completing the task reached 5.74 seconds. Despite there being fewer target objects (8 television sets) on this level, as compared to the number of target objects on the other levels (L1 = 16 plates, L2 = 12 plates, L3 = 16 items, L4 = 12 items, L5 = 19 items), the mean performance duration on L6 remained comparable to the other levels.

Table 1. Means, standard deviations, minimum and maximum performance of the healthy sample on the Supermarket Test

Supermarket Test Variables	Healthy Sample			
	Mean	Std	Minimum	Maximum
L1 hits	15.60	1.80	4	16
L1 errors	0.14	.54	0	3
L1 omissions	0.40	1.80	0	12
L1 duration	45.46	15.00	23.18	89.85
L1 TPH	3.09	1.83	1.45	13.83
L2 hits	11.43	0.89	8	12
L2 errors	0.08	0.34	0	2
L2 omissions	0.57	0.89	0	4

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L2 duration	44.06	15.90	18.58	81.43
L2 TPH	3.89	1.49	1.86	7.86
L3 hits	15.45	1.52	8	16
L3 errors	0.39	0.76	0	4
L3 omissions	0.55	1.52	0	8
L3 duration	44.27	18.39	25.04	92.34
L3 TPH	2.93	1.39	1.56	8.39
L4 hits	11.90	0.31	11	12
L4 errors	0	0	0	0
L4 omissions	0.10	0.31	0	1
L4 duration	38.58	16.46	21.40	86.48
L4 TPH	3.25	1.42	1.78	7.86
L5 hits	18.50	1.68	9	19
L5 errors	1.55	2.02	0	9
L5 omissions	0.51	1.70	0	10
L5 duration	53.39	21.45	29.51	126.97
L5 TPH	2.97	1.50	1.55	8.93
L6 hits	7.86	0.41	6	8
L6 errors	1.35	3.07	0	13
L6 omissions	0.14	0.41	0	2
L6 duration	43.80	19.32	19.59	98.08
L6 TPH	5.60	2.52	2.45	12.26
Total hits	80.71	3.9	66	83
Total errors	3.51	4.98	0	17
Total duration	269.55	90.73	142.87	492.26
Total TPH	3.36	1.21	1.90	6.17
Mean of TD	44.93	15.12	24	82
Median of TD	43.62	15.16	22	82
Std of TD	10.12	5.35	3	27

Note: L=level, hits = clicked on the correct items, errors = clicked on the false items, omission = not clicked on the correct items, duration = in seconds, TD = Total Duration, Std = standard deviation, TPH = time-per-hit

3.2 Convergent validity

In order to examine the convergent validity of the ST, Pearson's correlation coefficients were calculated with the participants' performance on each part of the TMT. More specifically, for the correlations we used speed of performance indices for both the ST (duration of each level, total duration and time per hit) and the TMT (completion time for Parts A and B). Correlations between accuracy scores was not calculated, as our healthy sample did not make a considerable amount of errors on either test. Total duration and mean duration in the ST correlated highly on both parts of the TMT, and, thus, mean duration was omitted from the analysis. Table 2 summarizes the correlations between the time scores of the two tests.

3.3 Contrasting patients' performance to that of the healthy group

Patients' performance on the ST is displayed in Table 3. It is evident that the patient with MS performed worse in comparison to the other two patients. More specifically, his performance pattern was characterized by increased time duration in all levels combined, with a higher rate of omission errors than the other two patients. With respect to the other two patients, although their performance in each level was comparable, the SCI patient displayed a slightly lower total time per hit score (4.17 sec) than the BPD patient (4.33 sec). In addition, the BPD patient made more errors (9 errors) than the other two patients, but achieved a median total time duration of the task (58.63 sec) that was comparable to that of the SCI patient (58.37 sec). When patients' performance was contrasted to the healthy sample's mean scores (see Table 2), we observed that patients needed more time

Table 2. Pearson's correlation coefficients between the time indices of the Supermarket Test and completion time on the Trail Making Test (Parts A & B).

Supermarket Test sec	L1 dur	L2 dur	L3 dur	L4 dur	L5 dur	L6 dur	Tot dur	Tot median dur	Tot std dur
TMT A sec	.804**	.812**	.764**	.694**	.806**	.632**	.821**	.837**	.743**
TMT B sec	.783**	.819**	.748**	.682**	.766**	.601**	.799**	.812**	.684**

Note: *p < .000, L = test level, dur = duration, sec =seconds, std =standard deviation

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to complete the test (1748.85 sec, 337.96 sec, 342.27 sec, respectively vs 269.55 sec in the healthy group) and the MS and BPD patients were less accurate (5 and 9 errors, respectively vs 3.51 mean errors of the healthy sample).

Table 3. Patients' performance scores on the Supermarket Test

Supermarket Test Variables	Patient with MS	Patient with BPD	Patient with SCI
L1 hits	14	15	16
L1 errors	0	0	0
L1 omissions	2	1	0
L1 duration	221.30	61.56	67.81
L1 TPH	15.81	4.10	4.23
L2 hits	7	10	11
L2 errors	0	0	0
L2 omissions	5	2	1
L2 duration	205.35	55.71	72.36
L2 TPH	29.34	5.57	6.58
L3 hits	15	15	16
L3 errors	1	4	0
L3 omissions	1	1	0
L3 duration	437.96	64.63	57.23
L3 TPH	29.20	4.31	3.57
L4 hits	10	12	12
L4 errors	2	0	0
L4 omissions	2	0	0
L4 duration	287.80	43.51	42.64
L4 TPH	28.78	3.63	3.55
L5 hits	10	18	19
L5 errors	2	5	1
L5 omissions	9	1	0
L5 duration	341.86	74.11	59.51
L5 TPH	34.19	4.12	3.13
L6 hits	6	8	8
L6 errors	0	0	0
L6 omissions	2	0	0
L6 duration	254.59	38.45	42.71
L6 TPH	42.43	4.81	5.32
Total hits	62	78	82
Total errors	5	9	1
Total omissions	21	5	1
Total duration	1748.85	337.96	342.27
Total TPH	28.21	4.33	4.17
Mean of TD	291.48	56.33	57.04
Median of TD	271.20	58.63	58.37
Std of TD	86.85	13.39	12.41

Note: MS=Multiple Sclerosis, BPD=Bipolar Disorder, SCI=Schizophrenia, hits = clicked on the correct items, errors = clicked on the false items, omission = not clicked on the correct items, duration = in seconds, TD = Total Duration, Std = standard deviation, TPH time = per hit

4. Discussion

In the present study, we provided evidence both for the convergent validity of the 3D Supermarket Test (ST) with another well-known and established traditional clinical tool, the Trail Making Test (TMT), and some preliminary evidence for its suitability with clinical cases with different neurological and psychiatric diagnoses.

To begin with, the ST is a subtest of the CBAAD, for which preliminary findings are reported from a healthy sample of Greek participants [25]. Therefore, trends observed in the present study with the ST, as for example, the high accuracy scores were expected and also reported previously. The pattern combination of high accuracy scores combined with much more varying level duration scores, is indicative of healthy participants not only for this test, but has also been reported in studies with other traditional attention tests, such as the TMT [24]. Moreover, because of its high variance, it has been argued that speed of performance scores are more representative and reliable metrics for assessing healthy participants' attention performance than accuracy scores [see in 9]. Another explanation for this trend, however, is that the CBAAD subtests were primarily designed to tap into the impairments of clinical populations with marked attention disorders (i.e., after traumatic brain injury or a severe stroke). In the present study, the ST was upgraded relative to

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our initial description of it [25]. and one more performance index was added, the time-per-hit score. The latter represents a weighted speed index, which enables comparison between the different levels of the test itself and among individuals' performances. It actually constitutes a pure attention score, free from other mediating variables, such as one's preferred strategy of speed vs accuracy, or the opposite [27, 28]. Time-per-hit was consistent across all task levels, except for L6. Thus, we conclude that L6 was more difficult due to the higher perceptual similarity of the objects than in other levels. This is in line with our previous findings, in which the ST was rated as the least easy subtest of the CBAAD battery on a utility questionnaire [25] Discussion with participants after completing the test in order to glean their reactions to the test, revealed that nearly all found L6 to be the most difficult.

As regards the correlation analysis, the very high correlations between the TMT conditions and the ST suggest good convergent validity of the latter. The TMT is a valid tool, widely used in clinical neuropsychological practice, that has been found to be sensitive to impairment in a variety of cognitive functions, such as selective and sustained attention, flexibility, shifting of attention, visual screening ability, executive functions, and processing speed [14, 29] Therefore, the high correlation of this well-established instrument with our new computerized tool could be attributed to the very similar underlying processes that are involved in both tasks, i.e., visual screening and focusing on targets (the supermarket products), while simultaneously inhibiting response to non-targets, and quickly switching attention among different stimuli. Although a digital version of the TMT [30] and an oral adaption of the test [31] also exist, they incorporate the limitations inherent in the original version. For example, a main drawback of all TMT versions is the strong influence of education on performance [20, 31, 32, 21]. That is, the test presupposes that the examinee must know the alphabet of his/her language well in order to connect letter and numbers correctly in Part B of the test. The latter makes TMT inappropriate for the examination of individuals who are illiterate, have a low level of education or are non-native speakers of the language in which they are examined, or persons with language processing disorders. Moreover, there have also been reported limitations in the use of the original TMT in cross-cultural settings. For example, a considerable number of studies in Asian countries are limited to the use of equivalent TMT forms [i.e., the Trail Making Test Black & White, 22], which in western cultures are used for people who are illiterate [i.e., the Color-Trails Test, 33, 34]. Moreover, recent studies comparing performance of Czech, English (North American) and Spanish speaking populations, report performance differences based on the sociocultural background [23]

In contrast to the TMT, the ST has a series of advantages that bypass some of the aforementioned drawbacks. Firstly, due to its non-verbal audio-visual material, it does not require literacy or language processing ability, and could therefore be suitable for the assessment of attention in patients with language and/or communication disorders, people from different cultures, and individuals who are illiterate or have limited education. Secondly, it resembles more closely the real demands with which a person may be confronted (i.e., visiting a supermarket) and, consequently, may be perceived as more relevant than typical lab-based tests [25] such as the TMT. Thirdly, it is a computerized test, which inherently includes all the positive attributes of form of assessment: millisecond accuracy in recording performance, elimination of human error in test administration and calculation of the results (standardized administration), and the ability to obtain complex and valuable performance indices (median and standard deviation of performance, which have been shown to be important indicators especially in the estimation of attention lapses [9]

With respect to the patients' performance, their pattern was unique to each diagnosis and in line with known cognitive impairments. Interestingly, the MS patient had marked difficulties in completing the task. Patients with multiple sclerosis are known in the literature to exhibit motor impairment, along with decreased processing speed [35]. Contrary to our expectations, that unlike the TMT, the ST does not involve fine motor movements related to writing and draw-

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ing lines, the response requirements of the task (navigation through the supermarket corridor and mouse clicking) appeared to cause considerable difficulty for the patient with MS. As a result, the patient needed significantly more time to complete the task, while simultaneously omitting some target objects. At first glance, one might conclude that the ST may not be suitable for assessing attention in neurological populations presenting motor symptoms, such as advanced stages of MS, Parkinson's or Huntington's disease, etc. A recent study, however, exploring upper limb motor skill performance in MS patients by using mouse cursor trajectory analysis and calculating kinematic metrics for point-and-click tasks suggested that is it possible, with an up to 70.9% accuracy, to identify the presence of early signs of MS [36]. We therefore suggest that instead of rejecting the use of the ST with MS patients, it would be valuable if administered to early stage MS patients in order to explore the possibility of predicting their prognosis. As concerns our psychiatric cases, despite their comparable times to complete the task, the BPD patient was prone to more errors than the patient with SCI. The latter may reflect the behavioral impulsivity that characterizes BPD [4, 37], but not schizophrenia. Finally, the fact that patients performed more poorly on both speed and accuracy on the ST as compared to the healthy sample, and yielded specific performance patterns, makes it a promising tool in research with clinical populations. Yet, the high accuracy indices observed in the BPD and SCI patients suggest the need to explore the performance of patients with severe neurological symptomatology, such as moderate traumatic brain injury or early-onset and mild frontal type dementia [38], as well.

Limitations of the present study include the small size of the healthy sample, the overrepresentation of males in the sample, the lack of data from illiterate individuals and different cultural environments, and people with language disorders. Studies with these populations may provide further support for the present conclusions.

5. Conclusion

The present findings suggest that the ST is a promising test and might serve as a computerized analogue of the Trail Making Test, with the benefit that it resembles real-life situations and does not require familiarity with the use of pencil-and-paper. Thus, it may be a valuable tool for the detection of attentional impairment in patients. Yet, the results of the present study are preliminary as regards the clinical validity of the ST. Only future research with clinical groups will enable us to draw robust conclusions.

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