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Normative Data and Construct Validation for a Novel Nonverbal Memory Test

Amir Poreh, Ph.D. and Max Teaford, M.A.

Abstract

The present study describes the normative data and convergent validity of the Poreh Spatial Memory Test (PSMT). 204 participants (96 males and 108 females) between the age of 18 to 85 years were administered the PSMT. A subsample was administered the Rey Osterith Complex Figure Test (ROCFT) as well as the Rey Auditory Verbal Learning Test (RAVLT) and another subsample was administered the Biber Figure Learning Test – Extended (BFLT-E). The present study demonstrated that the mean scores for the learning trials within each group exhibited robust inverse logarithmic learning curves. Accordingly, three indices were derived: learning, learning curve, and delayed retention. As one might expect from a "pure" visuospatial memory test, age, but not gender or education, correlated with the PSMT learning and delayed retention scores. Additional analysis revealed that the PSMT correlated significantly with the ROCFT and the BFLT-E, supporting the convergent validity of the new measure. Age based norms for this new measure were computed for the learning and delayed retention subscores, using a regression based procedure. Additional studies using various clinical samples including patients with lateralized brain injuries are underway to further establish the sensitivity and specificity of the PSMT.

Introduction

Since the early years of psychological testing there have been numerous attempts to develop tests for assessing visuospatial memory. The most widely used clinical tests include Wechsler's Visual Reproduction Test (Loring & Papanicolaou, 1987; Wechsler, 1997, 2009; Yerkes, 1948) and the Rey Osterrieth Complex Figure Test (ROCF, Rey, 1941). In both of these tests the subject is instructed to copy a design or draw the design from memory after a brief or extended delay. However, many clinicians and researchers have critiqued the use of these measures asserting that the use of a single learning trial classifies them as tests of retention rather than learning. Additionally, studies have repeatedly shown that these tests, while capable of detecting memory problems, have limited value in identifying material-specific memory deficits (Loring et el., 2008; Willment & Golby, 2013; Bouman, Elhorst, Hendriks, Kessels, & Aldenkamp, 2016). Furthermore, studies have found that the performance on many of the existing nonverbal memory tests correlates with visual constructional ability and executive functioning (Loring & Papanicolaou, 1987; Troyer, Moscovitch, & Winocur, 1997; Troyer & Wishart, 1997).

Other tests which include multiple learning trials, such as the Biber Figure Learning Test-Extended (BFLT-E; Glosser, Cole, Khatri, DellaPietra, & Kaplan, 2002), were developed to address this limitation. These tests have a number of drawbacks including the reliance on grapho-motor skills and the fact that they are not comparable to behavioral tasks used in animal research, thus casting doubt on the translational ability of animal models of different diseases and disorders commonly used for pharmaceutical research (Possin et al., 2016; Fajnerová et al., 2014; Pratt, Winchester, Dawson, & Morris, 2012).

To address the limitations of existing visuospatial memory measures many researchers have developed human analogous versions of measures such as the Morris Water Maze (MWM; Fajnerová et al., 2014; Higa, Young, & Geyer, 2016; Possin et al., 2016; Woolley et al., 2010) and the Radial Arm Maze (RAM; Astur, Germain, Baker, Calhoun, Pearlson, & Constable, 2005; Bertholet et al., 2015; Levy, Astur, & Frick, 2005). Using virtual reality these researchers have shown that the performance on these measures is selectively related to the volume of the medial temporal lobes (Burgess, Maguire, & O'Keefe, 2002; Daugherty et al., 2015; Moffat, Hampson, & Hatzipantelis, 1998). A number of studies have demonstrated that the performance of patients with Alzheimer's and Schizophrenia on these measures is comparable to the performance of animal models with the same disease (Possin et al., 2016; Fajnerová et al., 2014). However, due to the complexity and cost of virtual reality technology the above tests do not lend themselves to use in clinical practice or to neuroimaging research such as MRI and PET studies. Therefore, the first author developed a multi-trial variant of Morris Water Maze, which does not require the use of virtual reality.

The aim of the present study was to provide initial data regarding the convergent validity of the new test as well as obtain normative data for the measure. Several hypotheses were made regarding the new test: (1) it was hypothesized that performance would significantly differ by age but not gender or level of education. This was due to previous findings, which found that allocentric spatial relational learning did not differ between men and women (Lavenex & Lavenex, 2010). (2) Following the early studies of Tulving, Mandler, and Baumal (1964), Hodges (1996), and more recent studies conducted by Poreh and colleagues on the Rey Auditory Verbal Learning Test (2005, 2012, and 2016) it was predicted that the trial-by-trial memorization of locations in space will produce a logarithmic curve, and this curve will appear across all age groups. (3) It was predicted that the new measure will share some variance with exiting nonverbal memory tests including the ROCF immediate and delayed scores as well as the BFLT-E learning and delay scores but not the Rey Auditory Verbal Learning Test (RAVLT; Taylor, 1959).

Method

Participants. 204 participants (96 males and 108 females) were recruited in two separate studies from a Midwestern university and the general community. All the participants were physically healthy, and did not report any neurological or psychiatric symptoms. Subjects who were older than 65 were screened using Saint Louis Mental Status Exam (SLUMS; Tariq, Tumosa, Chibnall, Perry, & Morley, 2006) or the Montreal Cognitive Assessment Version 7.1 (MOCA; Nasreddine et al., 2005) to rule out mild cognitive impairment or dementia. Table 1 summarizes the demographic characteristics of the combined samples according to seven age groups. The first sample was comprised of 146 Participants (58 Male and 81 Female). The second sample was comprised of 58 participants (26 Male and 32 Female) from the same region.

Materials. *Poreh Spatial Memory Test.* The Poreh Spatial Memory Test (PSMT) is a computerized test comprised of 6 trials. Each trial consists of 9 stimuli. Each stimuli is comprised of 10 squares which together form an abstract geometric design that does not lend itself to a verbal description. Trials 1-5 are learning trials, thirty minutes after they are completed a delay recall trial is administered. Figure 1a provides a sample of one of four simple geometric designs. Figure 1b provides a sample of one of five complex geometric designs. The term simple geometric design refers to figures which are comprised of symmetrically organized squares. The term complex geometric design refers to geometric designs comprised of asymmetrically organized squares.

The goal of the individual taking the PSMT is to locate a target (square) which turns red when clicked, resulting in the computer saying “that is correct”. The individual is then given 3 seconds to commit the location of the square to memory. After the 3 seconds are up a new geometric design is presented. Each of the 9 geometric designs is presented once each trial in the exact same order. The goal of the test is to learn the location of the targets with as few clicks as possible. It is noteworthy that the scores on trial one reflect the initial random search for the targets embedded within the nine stimuli.

To administer the test one must place an individual directly in front of a computer. After entering the demographic information, the individual is told to listen to the instructions which are read to them by the computer. The individual who is being administered the test will then be presented with the first stimuli and begin clicking on squares which are presented on the screen. After completing trials 1 through 5 a box will pop up on the computer screen prompting the clinician to start the delay. After the 30-minute delay the person is asked to complete the sixth trial.

The PSMT performance data includes 4 indexes: (a) the absolute number of attempts for the five learning trials, reflecting the ability of the subject to lay down new spatial memories (a learning curve); (b) absolute number of attempts for learning the simple spatial cued cards; (c) an absolute number of attempts for learning the complex cards and, (d) the absolute number of attempts for the delay trial (PSMT-Delay).

Table 1

Demographic Characteristics of the Sample

Age Group (years)	Gender	N	Age Mean	(SD)	Education Mean	(SD)
18-20	M	29	18.79	.819	12.86	.915
	F	9	18.78	.972	12.78	1.093
	Combined	38	18.79	.843	12.84	.945
21-30	M	20	24.80	2.285	14.75	1.773
	F	15	24.33	2.944	15.20	2.484
	Combined	35	24.60	2.558	14.94	2.086
31-40	M	18	34.56	2.995	14.44	1.653
	F	16	37.56	2.555	15.25	2.266
	Combined	34	35.97	3.148	14.82	1.977
41-50	M	11	45.18	3.125	14.82	2.639
	F	17	45.06	3.614	15.29	2.418
	Combined	28	45.11	3.370	15.11	2.470
51-60	M	17	54.94	3.211	14.94	2.926
	F	8	53.38	1.996	13.38	2.446
	Combined	25	54.44	2.931	14.44	2.830
61-70	M	6	64.24	2.915	14.50	2.665
	F	9	63.55	2.571	15.56	2.744
	Combined	15	63.82	2.633	15.13	2.669
70-85	M	9	74.17	3.078	14.22	2.906
	F	17	76.67	5.347	12.18	.529
	Combined	26	75.81	4.776	12.88	1.966

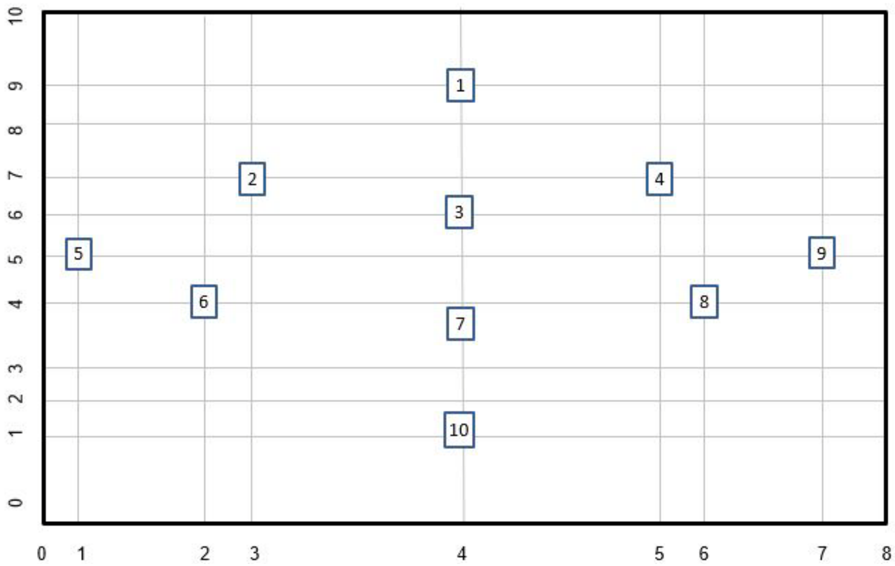

Figure 1a. Example PSMT simple geometric design distance calculation, done by using the rise and run between each square and the target (square # 6) on a simple card.
Note that the grid and numbers do not appear on the test.

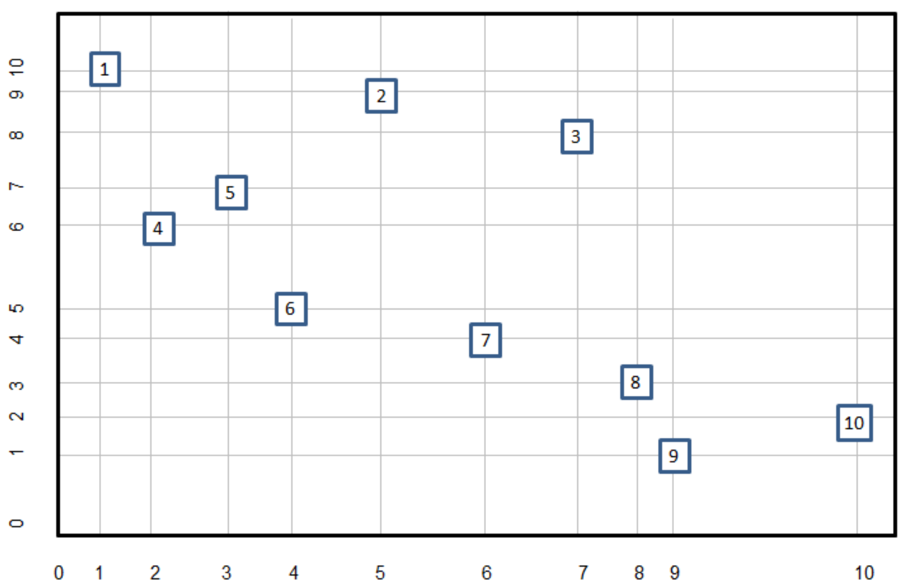

Figure 1b. Example PSMT complex geometric design distance calculation, done by using the rise and run between each square and the target square (square # 9) on a complex card.
Note that the grid and numbers do not appear on the test.

Rey Osterrieth Complex Figure Test. The ROCF (Rey, 1964) was administered using the directions described by Meyers and Meyers (1995). Three indexes were calculated: reproduction, immediate delay, and 20-minute extended delay reproduction scores. Each index was recorded and placed in the data set.

Biber Figure Learning Test – Extended. The BFLT-E was administered using the directions of Glosser, Cole, Khatri, DellaPietra, and Kaplan (2002).and three indexes were derived: learning (Trial 1-5), delay, and recognition. Each index was recorded and placed in the data set.

Rey Audiory Verbal Learning Test. Finally, the RAVLT was administered using the directions provided by Lezak, Howieson, & Loring (2004). Four indexes were derived including learning (trial 1-5), immediate delay, delay, and recognition. Each index was recorded and placed in the data set.

Procedure. After providing informed consent to participate in each of the studies, all participants were administered the PSMT as part of a more comprehensive evaluation. Subjects who had a history of psychiatric illness, head injury, and history of psychoactive drug use were excluded. Following the initial screening, older adults were also screened for dementia using the SLUMS or MOCA. The first sample (n=146) was also administered the PSMT, the ROCF and the RAVLT. Whereas the second sample (n=58), collected in separate study, was administered the PNMT and BFLT-E

Statistical analysis. Initial statistical analysis was performed using SPSS version 20 software. The best-fit linear logarithmic equation for the raw mean recall data in each age group was initially determined using the Trend function in Microsoft Excel without any preprocessing or preconditioning. This analysis was then repeated using the SPSS curve fitting module.

Following Mitrushina, Boone, Razani, and D'Elia (2005, p.51) participants were assigned into one of the following seven age groups; 18-20, 21-30, 31-40, 41-50, 51-60, 61-70, and 71-85. Following Guàrdia-Olmos, Peró-Cebollero, Rivera, and Arango-Lasprilla (2015), participants were also assigned to one of two education groups: 1 to 12 years, or more than 12 years (higher education).

Results

To examine the effect of age group, gender and education group on the total learning score (Sum of trials 1 to 5), a Factorial 2 × 7 × 2 (Gender × Age Group × Education Group) ANOVA was performed. Prior to conducting this analysis normality was assessed using a Kolmogorov-Smirnov Test and Homogeneity was assessed using a Levene Test. Both aforementioned tests were non-significant, suggesting that statistical assumptions were met and it was safe to proceed with the analysis. The 2 × 7 × 2 Factorial ANOVA revealed a significant main effect for age group $F(6, 201) = 5.51$, $p<0.001$, $\eta_p^2 = .162$, observed power = .996. Significant main effects were not found for gender or education group. A polynomial trend analysis showing that the performance across age groups linearly decreased F=5.5, $p<0.001$, $\eta_p^2 = .162$, observed power = .996. Given these findings the normative data is presented for each of the age groups, with separate tables for the learning and delay scores (see Table 2 and 3).

Table 2

Norms for the Total Learning Subscore of the PSMT

	Z Score	3	2.5	2	1.5	1	0	-1	-1.5	-2	-2.5	-3
	Percentile	>99	99	98	94	92	50	32	7	2	1	0.1
Age												
20		26.6	43.2	0.6	92.9	109.4	126.0	142.5	159.1	160.6	192.2	208.7
25		43.2	59.7	92.8	109.4	125.9	142.5	159.1	175.6	177.1	208.7	225.3
30		47.3	63.9	97.0	113.5	130.1	146.6	163.2	179.7	181.2	212.9	229.4
35		51.4	68.0	101.1	117.7	134.2	150.8	167.3	183.9	185.4	217.0	233.5
40		55.6	72.1	105.2	121.8	138.4	154.9	171.5	188.0	189.5	221.1	237.7
45		59.7	76.3	109.4	125.9	142.5	159.0	175.6	192.1	193.6	225.3	241.8
50		63.9	80.4	113.5	130.1	146.6	163.2	179.7	196.3	197.8	229.4	245.9
55		68.0	84.5	117.6	134.2	150.8	167.3	183.9	200.4	201.9	233.5	250.1
60		72.1	88.7	121.8	138.3	154.9	171.4	188.0	204.6	206.1	237.7	254.2
65		76.3	92.8	125.9	142.5	159.0	175.6	192.1	208.7	210.2	241.8	258.3
70		80.4	96.9	130.1	146.6	163.2	179.7	196.3	212.8	214.3	245.9	262.5
75		84.5	101.1	134.2	150.7	167.3	183.9	200.4	217.0	218.5	250.1	266.6
80		88.7	105.2	138.3	154.9	171.4	188.0	204.5	221.1	222.6	254.2	270.8
85		92.8	109.4	142.5	159.0	175.6	192.1	208.7	225.2	226.7	258.3	274.9
90		96.9	113.5	146.6	163.1	179.7	196.3	212.8	229.4	230.9	262.5	279.0

Table 3

Norms for the PSMT Delay Trial

	Z Score Percentile	3 >99	2.5 99	2 98	1.5 94	1 92	0 50	-1 32	-1.5 7	-2 2	-2.5 1	-3 0.1
Age												
20		9.6	10.1	0.9	11.7	12.2	12.7	13.2	13.8	15.3	14.8	15.3
25		14.4	14.9	15.9	16.4	17.0	17.5	18.0	18.5	20.0	19.5	20.1
30		15.6	16.1	17.1	17.6	18.1	18.7	19.2	19.7	21.2	20.7	21.3
35		16.7	17.3	18.3	18.8	19.3	19.9	20.4	20.9	22.4	21.9	22.4
40		17.9	18.5	19.5	20.0	20.5	21.0	21.6	22.1	23.6	23.1	23.6
45		19.1	19.6	20.7	21.2	21.7	22.2	22.8	23.3	24.8	24.3	24.8
50		20.3	20.8	21.9	22.4	22.9	23.4	23.9	24.5	26.0	25.5	26.0
55		21.5	22.0	23.1	23.6	24.1	24.6	25.1	25.7	27.2	26.7	27.2
60		22.7	23.2	24.3	24.8	25.3	25.8	26.3	26.8	28.3	27.9	28.4
65		23.9	24.4	25.4	26.0	26.5	27.0	27.5	28.0	29.5	29.1	29.6
70		25.1	25.6	26.6	27.2	27.7	28.2	28.7	29.2	30.7	30.3	30.8
75		26.3	26.8	27.8	28.3	28.9	29.4	29.9	30.4	31.9	31.4	32.0
80		27.5	28.0	29.0	29.5	30.0	30.6	31.1	31.6	33.1	32.6	33.2
85		28.6	29.2	30.2	30.7	31.2	31.8	32.3	32.8	34.3	33.8	34.3
90		29.8	30.4	31.4	31.9	32.4	32.9	33.5	34.0	35.5	35.0	35.5

To examine the effect of age and gender on the PSMT five trials, a 2 × 7 × 5 (Gender × Age Group× Trial Score) Repeated Measures MANOVA was performed. Statistical assumptions were assessed prior to conducting the analysis. Normality was assessed using Levene Tests for each learning trial. Neither the Box's M or Levene Tests were significant suggesting statistical assumptions had been met. An examination of Wilk's Lambda revealed that the main effect of age was significant $F(24, 643.11)=1.765$, $p<0.01$, $\eta_p^2=.055$, observed power = .969. No significant main effect was found for gender. None of the interaction effects were found to be significant either. Post hoc analyses using Tukey's procedure indicated that over the five trials the 70+ age group performed significantly worse than the 18–20 and 21–30 groups. The 61–70 age group also performed significantly worse than the 18–20 and 21–30 age groups.

A 2 x 7 x 1 (Gender x Age Group x Delay Score) Factorial ANOVA with the dependent factor being PSMT delayed trial and gender and age group being the independent variables was performed. Since the delay trail data was positively skewed, a data transformation was performed using a log10 function. After this transformation, the data exhibited both normality (using a Kolmogorov-Smirnov Test) and homogeneity as assessed using the Levene Test. The Tolerance was .957 and a Variance Inflation Factor was 1.045 suggesting a lack of multicollinearity. After assuring all assumptions were met the ANOVA was performed. The only statistically significant finding was for the main effect of age, $F(6, .253) = 10.482$, $p<.001$, $\eta_p^2=.254$, observed power = 1.00

Analysis of the simple design sub-score produced near identical results. A 2 x 7 x 2 (Gender x Age Group x Education) Factorial ANOVA with the dependent factor being PSMT simple designs learning subscore and gender, education and age group being the independent variables, was carried out. Since the Kolmogorov-Smirnov Test was significant a Log 10 transformation was used to normalize the data. The Variance Inflation Factor values ranged from 1.020 to 1.048 and Tolerance values ranged from .954 to .980 suggesting a lack of multicollinearity. Once more, the age but not gender or education emerged as statistically significant, $F(27, 187)=12.972$, $p<.0001$, $\eta_p^2=.329$, observed power = 1.00 and education $F(1, 187)=4.302$, $p<.05$, $\eta_p^2=.026$, observed power =.541 were found.

Analysis of the complex design sub-score produced similar results. A 2 x 7 x 2 (Gender x Age Group x Education), Factorial ANOVA with the dependent factor being PSMT complex design subscore and gender, education and age group being the independent variables. Neither the Levene Test for homogeneity or Kolmogorov-Smirnov Test for normalcy were significant. The Variance Inflation Factor values ranged from 1.020 to 1.048 and Tolerance values ranged from .954 to .980 suggesting a lack of multicolinearity. The only statistically significant finding was for the main effect of age $F(6, 187)=3.132$, $p<.01$, , $\eta_p^2=.096$, observed power =.913.

Previously, it was hypothesized that the PSMT and the RAVLT repeated mean learning trial-to-trial recall would both form a logarithmic learning curve. To test this hypothesis, we conducted a curve fitting analysis of the mean scores on both measures within all of the seven age groups on three curve-fitting methods: linear, quadratic, and logarithmic. Table 4 shows that the logarithmic solution produced the most robust results, across the seven age groups.

Table 4

PSMT and RAVLT Curve Fitting Analyses

	PSMT			RAVLT		
Age Group	Linear	Quadratic	Logarithmic	Linear	Quadratic	Logarithmic
18-20	R=.921	R=.971	R=.968	R=.901	R=.997	R=.991
	F=16.8	F=33.6	F= 92.0	F=27,3	F=361.3	F=316.9
	p=0.03	p=0.03	p= 0.002*	p=0.01	p=0.003*	p=0.0001*
21-30	R=.910	R=.989	R=.960	R=.859	R=.971	R=.986
	F=14.2	F= 43.8	F= 72.9	F=18.3	F=34.0	F=106.4
	p=0.03	p= 0.02	p= 0.003*	p=0.02	p=0.03	p=0.002*
31-40	R=.904	R=.958	R=.977	R=.823	R=.967	R=.953
	F=28.1	F= 22.8	F= 124.8	F=13.9	F=28.89	F=60.22
	p=0.01	p= 0.04	p= 0.002*	p=0.03	p=0.03	p=0.004*
41-50	R=.921	R=.954	R=.967	R=.832	R=.973	R=.961
	F=16.8	F= 20.8	F= 43.07	F=14.9	F=36.11	F=74.77
	p=0.03	p= 0.05	p= 0.007*	p=0.03	p=0.03	p=0.003*
51-60	R=.910	R=.917	R=.933	R=.901	R=.997	R=.991
	F=14.2	F= 11.06	F= 41.55	F=27,3	F=361.3	F=316.9
	p=0.03	p= 0.08	p= 0.008*	p=0.01	p=0.003*	p=0.0001*
61-70	R=.904	R=.971	R=.968	R=.863	R=.992	R=.972
	F=28.1	F=33.6	F= 92.0	F=18.9	F=128/0	F=106.8
	p=0.01	p=0.03	p= 0.002*	p=0.02	p=.008*	p=0.002*

Note. ** p<0.01

Convergent validity was examined by conducting multiple Zero Order correlation analyses between the PSMT and the RAVLT and BFLT-E learning indexes. To control for type 1 error, the analysis was conducted using a two-tailed significance and adjusting the alpha levels using a Bonferroni correction. Table 5 shows that the PSMT simple designs learning scores (Trials 1-5) significantly correlated with the BFTL-E and the RAVLT learning indexes. However, the complex designs only correlated with the RAVLT. Table 6 shows that that the PNMT complex and simple delayed retention index (PSMT-Delay) significantly correlated with the Rey Osterith Complex Figure Test immediate (r= -.204, p<.05) and delay recall scores (r=-.435, p<.001). All the total delayed recall indexes (with the exception of the BFLT-E) were highly inter-correlated making it difficult to establish the ability of the measures in distinguishing between verbal and nonverbal memory abilities in the general population. When the results were re-analyzed with education being a covariate the results remained unchanged.

Table 5

Correlations between the PSMT, AVLT and BFLT-E Learning Indexes

PSMT	RAVLT (n=65)	BFLT-E (n=58)
Simple	-.551**	-.379**
Complex	-.364**	-.217
Total	-.559**	-.394**

Note. Alpha= 0.00833333

Table 6

Correlations Between the PSMT , ROCF, AVLT, and the BFLT-E Delayed Recall Indexes

PSMT	ROCFT (n=140)	RAVLT (n=65)	BFLT-E (n=58)
Simple	-0.251**	-0.393**	0.402**
Complex	-0.435**	-0.336	-0.198
Total	-0.439**	-0.395**	-0.325

Note. Bonferroni adjusted alpha levels was determined as 0.00208333

Norms for the PSMT total learning and delay trial were computed following the 4-step procedure described by Van der Elst et al. (2011) and Guàrdia-Olmos, Peró-Cebollero, Rivera, and Arango-Lasprilla (2015). We confirmed that demographic variables (with the exception of age) did not add to the predictive value of the test score and therefore were not included in the regression. Prior to beginning the four-step procedure we examined the statistical assumptions of regression for our models. Normality of the residuals was assessed using P-P Plots and Histograms (of the residuals). Multicollinearity was assessed using Variance Inflation Factor and Tolerance statistics (both of which were 1 for both regressions). Homogeneity was assessed by using a scatter plot of the predicted values and the standardized residuals. Independence of the error term was assessed using Durbin-Watson Tests (both values were above 1). No violations of the assumptions were found; therefore, it was deemed to be okay to proceed with performing regressions. The final regression model can be seen in Table 7.

After confirming that the statistical assumptions of regression had been met, we began the four-step procedure. First, the predicted value was obtained by using the regression equation. After obtaining the predicted value it was used to calculate the residual residuals (observed score-expected score). Third, the residuals were standardized (Z = residual/standard deviation of residual). Following this, the standardized residual is converted to a percentile by treating it as a Z score and obtaining the probability of it in a normal distribution. We used class mark age values starting with 20 years ± 5 years until a class mark of 90 years old. Please see Tables 2 and 3 for the norms.

Table 7

Final Regression Model for the Norms

Sub-score	Variable	B	SE B	Std. B	T	SD (Residual)	R^2
PSMT Total Learning	(Constant)	124.486	5.471	37.41621	22.754*		
	Age	0.878	0.117	19.847	7.483*	33.10752	0.217
PSMT Delay	(Constant)	12.717	1.324	9.301	9.601*		
	Age	0.238	0.028	19.847	8.368*	8.015	0.257

Discussion

The aim of the present study was to investigate a newly developed test for the assessment of spatial learning and memory utilizing allocentric cues. The study confirmed the main hypothesis, that participants in all age groups that were assessed using the new measure showed a significant logarithmic learning curve similar to the Rey Auditory Verbal Learning Test (Poreh, 2005), Rey Visual Design Learning Test (Rey, 1964; Strauss, Sherman, & Spreen, 2006) and BFLT-E (Glosser, Cole, Khatri, DellaPietra, & Kaplan, 2002) as well as the learning curve of rodents performing the Morris Water Maze (Morris, 1981; Morris, 1984). It was also confirmed that much like the aforementioned test, after the first random search trial, older participants exhibited a less steep learning curve than younger participants. Specifically, the 70+ age group and 60–69 age group exhibited more search behaviors than the 17–19 and 20–29 age groups. These findings are consistent with Tulvin, Mandler, and Baumal (1964) and Poreh (2005, 2012, 2014) as well as with animal studies conducted by Hodges (1996) which confirmed that the logarithmic learning curve remains relatively unaffected across the life span. Additionally, the rate of learning over the five trials was not found to be different for male and female participants, and was unaffected by level of education. These two findings are expected and similar to those reported in previous verbal learning studies, and are consisted with the argument that performance on this test is less effected by demographic variables than the more traditional spatial retention, learning, and memory measures such as the ROCF and the BFLT-E.

The results of the present study did not support hypothesis number three (i.e. variance will be shared with other nonverbal measures but not the Rey Auditory Verbal Learning Test). When interpreting the meaning of this finding, it should be noted that the present study used neurologically healthy individuals who do not typically exhibit a significant dissociation between tests of verbal and non-verbal memory. The authors believe that a dissociation will become more apparent when research is done using individuals who have neurological disorders such as left and right medial temporal lobe epilepsy.

Unlike traditional visuospatial measures, the PSMT can be easily computerized, allowing for automatic tracking of search paths throughout each of the trials, and providing an unprecedented resolution and objectivity. Additionally, it allows for the adaptation of methodology to include additional variables such as a two-target technique using the same principles as well as the development of parallel forms. The use of a pointing device also allows for its use in fMRI, MEG, and other functional imaging studies, which might be useful for exploring place cells in humans, much like those proposed by O'Keefe and Nadel (1978).

Some of the limitations of the present study are worth mentioning. First, the sample within each age group was relatively small. Second, we did assess the test-retest reliability of the new measure, nor did we assess the discriminate validity of this new measure. Finally, since the PSMT is a test of Allocentric spatial memory the results may not carry over to spatial tasks that rely on Egocentric cues (i.e. position relative to one's body; Feigenbaum & Morris, 2004). Therefore, additional studies are needed to investigate these properties. Specifically, future studies might be needed to assess whether the new test is sensitive to lateralized brain injury and/or lateralized hippocampal atrophy. Additionally, future research is needed to assess the strategies that people use to remember and memorize the location of the targets. We hypothesize that much like rodents the strategies might include a praxic strategy, where the person learns the location of a target square in the geometric design, a taxic strategy where the person uses cues or visual proximal guides to reach the target, or a spatial strategy in which the person finds the target according to the spatial configuration of the distal cues. To examine the utility of these strategies, each subject's response needs to be encoded with the distance to the target serving as the variable. The calculation of the distance is carried out by calculating the distance from the target using basic Pythagorean Theorem. Finally, future studies should also assess the ecological validity of this test by comparing results on the test to real world spatial/navigation tasks.

In sum, the findings in this study are encouraging and suggest that the PSMT could potentially serve as an accurate measure of spatial learning and memory. Although there are other measures of nonverbal memory currently in use, such as the ROCF or the BFLT-E, the simplicity of the PSMT makes it an improvement over existing clinical measures. Furthermore, the PSMT can be used in fMRI studies as well as in conjunction with more traditional measures of nonverbal and verbal memory to better diagnoses of visual-spatial memory deficits in patients with executive function or grapho-motor deficits.

About the Authors

Amir Poreh, Ph.D., is with the Department of Psychology, Cleveland State University, and the Department of Psychiatry, Case Western Reserve School of Medicine. Correspondence concerning this article should be addressed to Amir Poreh, Department of Psychology, Cleveland State University, 2121 Euclid Ave., UN 711, Cleveland, OH 44115, US.
Email: aporeh@gmail.com

Max Teaford, MA, is with the Department of Psychology, Miami University.

Author's Comment on the Development of a Computerized Version of the PSMT

Several variants of the test were developed for the PSMT, including tests with 5, 6 7, 8, and 10 cards as well as variants that included 7, 9, 10, 12 squares, and 3, 4, 5 and 6 repeated trials. The cards included random or geometrically organized arrays of squares/triangles/circles and other geometric designs. Of the 50 designs, 9 designs were eventually chosen. The final version of the test included 4 cards with geometric arrays (easy allocentric cues) and 5 cards with random arrays (complex allocentric cues (see Figure 1a and 1b). The nine cards, each with 9 squares, are presented in the same order over five trials (, (t1, t1… - t5,) established a learning curve. After a 30min delay a 6th trial (t6), allowing for assessing of retention. In the later version of the test, a dedicated computer software was developed. A copy of the software can be obtained at no charge from the author of this paper via email; Amir Poreh <aporeh@gmail.com>.

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