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The Use and Validation of the Spatial Navigation Memory Island Test in Primary School Children

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Abstract

Memory Island (MI) is a human spatial memory assessment, modeled after the Morris water maze, which has been used in adults and the elderly. In this study, we examined whether MI can be used with children and validate the procedure. The objectives of this study were to: 1) examine spatial function with MI in children and 2) determine the associations between MI and other cognitive measures. Seven to ten year old children (N=50) completed MI and a battery of tests of attention, visual-spatial memory, and executive function. Spatial memory, as indicated by the percent time in the target quadrant on MI, was better at age ten relative to ages seven or eight. Target preference also correlated with performance on the Conners' Continuous Performance Test and Backwards Spatial Span. These findings indicate there is rapid increase in spatial memory between ages nine and ten and that MI is a translational neuroscience paradigm which provides information that complements and extends upon that obtained using other neuropsychological paradigms in children.

Keywords

attention; behavior; development; human; learning; memory

1. INTRODUCTION

The Morris water maze has become a valuable instrument over the past thirty years to study the anatomical and neurochemical substrates of spatial learning and memory [11,19,20]. While there are many procedural variations, the test often begins with several short trials where the rat or, more recently, other rodent species, swims in a large pool filled with opaque water to locate a submerged platform [4,10]. Investigations of the ontogeny of Morris water maze performance have revealed that the ability to successfully form spatial memories occurs early in the juvenile period in rats, voles, and mice [6,7,14].

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Memory-Island (MI) is a behavioral neuroscience paradigm developed in our laboratory for humans [1,5,24,26]. The participant first navigates through a virtual world to locate easily visible targets. Next, they receive multiple trials and learn to navigate to a hidden target. Finally, after a retention interval, a memory retention or probe trial (no target present) is completed. Although a virtual environment can never fully approximate a non-computerized one (e.g. tactile feedback), the results obtained using MI show many similarities with those obtained using the Morris water maze. For example, a sex difference in spatial performance is typically reported in the Morris water maze [11] and was identified in the target visible and hidden MI trials [1,24,26]. Similarly, hippocampal damage disrupts performance in the Morris water maze [11] and also in another virtual navigation task in humans [2]. In contrast to the similarities in the data obtained, the Morris water maze typically requires multiple days of training and rodents, particularly mice, find swimming aversive, while MI testing can, depending on the desired difficulty, be completed on a single day and respondents do not find the experience unpleasant [26].

Although MI and other similar tests are becoming increasingly prevalent [1–3,5,18,21,24,26], there is only limited information available on how spatial learning and memory in virtual navigational tests is related to other cognitive measures [3] and no data with children. Correlations between MI and other standardized indices provide convergent and divergent validation for this age and also begin to establish a foundation for other laboratories that might consider adopting this paradigm. Therefore, the objectives of the present report were to: 1) to determine the correlations between performance on MI with that on other validated neuropsychological tests and 2) to characterize spatial learning and memory as assessed by MI in 7 to 10 year-old children.

2 MATERIALS & METHODS

2.1 Participants

Flyers were posted at Oregon Health Science University (OHSU) to recruit healthy children 7–10 years of age. This age was selected based on preliminary observations that some younger children experience difficulties completing MI (Piper et al., 2009). The sample (N=50 with an equal number of girls and boys) consisted of children aged seven (N=12), eight (N=15), nine (N=11), or ten (N=12). The parents of all participants provided informed consent and the children provided their assent prior to participation. Upon study completion, the study participants received a fifty-dollar Toys-R-Us gift certificate. The majority of the children (82%) were classified by their parents as Caucasian with the remainder as Asian (10%), Hispanic (4%), Native American (2.0%), or Pacific Islander (2.0%). All procedures were approved by the Institutional Review Board of Oregon Health and Science University.

2.2 Behavioral Assessments

The children completed a session that averaged about 1 hour 30 min with all tests administered by S.F.A and data processed (i.e. conversion to standardized scores) by M.J.C or P.W.M. The assessments were selected to include standardized measures of attention, executive function, spatial and non-spatial memory. The battery included: 1) MI, 2) Conner's Continuous Performance Test (CPT), 3) Dot Location, 4) Family Pictures, and 5) Spatial Span. The parents also completed the Behavior Rating Inventory of Executive Function (BRIEF). For multipart assessments, individual tests were interspersed so that the child was continuously engaged with the experimenter. Each of these measures is described in greater briefly below and in more detail in [1].

2.2.1 Memory Island (MI)—Testing equipment included a 48.3 cm Dell computer monitor and a Microsoft Sidewinder joystick to determine the speed and direction of movement. The

virtual world simulates an island environment of $347 \times 287 \text{ m}^2$ comprised of four quadrants, each containing a different target item. Children were first asked to navigate to a target location visibly marked with a flag adjacent to the target (visible session). Targets in all four quadrants were used for visible target training in four trials. The starting orientation of the participant was varied in each trial but these variations were kept consistent across participants. These different orientations were intended to prevent the child from using response strategies like always heading in one direction across trials. After being trained to locate the visible targets, the children were trained to navigate to a hidden target (i.e., no flag adjacent to the target) in trials five to eight. In this part of the test, the subjects had to remember where the hidden target is and how to get there. The location of the hidden target, a sculpture, was kept constant for all participants. In each trial of the visible or hidden session, if the child was unable to locate the target within two minutes, a directional arrow appeared to guide them to the target (Fig. 1A). Approximately fifteen minutes following the last hidden target trial, the participant received a 30 second probe trial with the target removed. This interval was chosen to provide a moderate difficulty level based on prior experience with this [24] and other ages [5,26]. In each trial, navigation of the children was recorded in time-stamped coordinate files, which were used to calculate distance traveled (virtual units), latency to reach the target (sec), and speed (virtual units/second). Summary measures of spatial learning performance were the total distance traveled, cumulative distance from the target, and latency during trials 1–8. The primary dependent measures during the spatial memory (probe) trial were the percent time spent in each quadrant and the cumulative distance to the target. These measures were determined based on prior studies with the MI and the Morris water maze [4,5,19,20,24,26].

2.2.2 Conners' Continuous Performance Test (CPT)—The CPT II is 14 min computerized assessment of attention where respondents press the space bar whenever any letter except 'X' is displayed on the computer screen [9]. The inter-stimulus intervals were 1, 2 and 4 seconds with a display time of 250 ms. The primary measures were omissions (failures to respond to target letters), commission errors (responses to the non-target X), hit reaction time standard error (response speed consistency to targets), detectability, d' or the difference between the signal (non-X), and noise (X) distributions, and response style (B , an index of a more risky responses).

2.2.3 Dot Location Test—The Dot Location test is part of the Children's Memory Scale [8]. During this spatial memory assessment, children were shown an array of dots over three trials and then a single distracter array was presented. Subjects were then asked to recall the original dot array for determination of the total score. After an interval of 5 min, the children were again asked to recall the original dot array (long-delay score). The objectives of this visual recall test are to detect changes between training and test images and correctly identify training arrays after the presentation of distracter images. Because there are age appropriate versions of Dot Location (ages 7–8 remembers the location of six dots and 9–10 recalls eight dots), the percentage of correct items (total + long delay) at each age were calculated for the determination of age differences.

2.2.4 Family Pictures—The Family Pictures visual recognition test is part of the Wechsler Memory Scale III. Children were shown pictures of people in a particular scene and asked to remember everything they can about each scene (4 scenes total). Recall was assessed by asking who was in the scene, where they were in the scene, and a basic description of what they were doing in the scene (e.g. eating, gardening, or shopping). After an interval of about 30 min, participants were asked the same questions again. A behavioral coder who was blinded to the study hypotheses gave one point for identifying who was in the picture, one point for the location, and up to two points for the description of their actions.

2.2.5 Spatial Span—The Spatial Span provides a measure of visual-spatial working memory and is a subtest of the Wechsler Intelligence Scale for Children. The child watched an examiner tap a sequence of numbered cubes on the Spatial Span board (number side faces examiner) and then was asked to tap out the same sequence. The test was stopped if a study participant scored 0 on each of two trials containing the same item. In the first test, the child was asked to repeat tapping of the same sequence of cubes as the examiner had shown (Spatial Span Forward) and, in the second test, the child was asked to tap the reverse sequence of cubes compared to what the examiner had shown (Spatial Span Backwards).

2.2.6 Behavior Rating Inventory of Executive Function (BRIEF)—The BRIEF is an 86-item parental questionnaire of executive functioning in the context of the child's everyday activities [15]. Behaviors were rated as never, sometimes, or often a problem (e.g. when given three things to do, remembers only the first or last).

2.3 Statistical analysis

Analyses were conducted using SPSS, version 16.0 and outlier determination by the Grubbs extreme deviate test. For tests with multiple dependent measures, only the primary ones were presented which included MI: total distance traveled to reach the target, speed, mean cumulative distance to the target (for the first two-minutes only) and the total latency on the visible and hidden trials. For the probe trial, the percent time spent in each quadrant and the cumulative distance to the target (virtual units, samples obtained every 0.5 seconds and summed); CPT: percent omission and commission errors, hit reaction time, reaction time standard error, d' , and response style; BRIEF: Global Executive Composite; Dot Location: sum of total and long-delay scores/sum of points possible for each age, Spatial Span: Forward, Backwards, and Total; Family Pictures: Immediate and Delayed. Standardized scores (T_{50} or percentiles corrected for age and sex), when available, were reported for the description of the sample characteristics. As the raw (non-standardized) data for some neuropsychological measures were, as anticipated, not normally distributed, Spearman rho correlations were determined. For the ANOVA with Age (7, 8, 9 or 10) as a between groups factor, variables with non-normal distributions were log transformed. A $p < .05$ was considered statistically significant although statistics that met more conservative thresholds (.01 or .001) were noted. A Power analysis was conducted using G*Power 3[13].

3 RESULTS

This sample was similar relative to population norms (fiftieth percentile or $T_{50}=50$) for attention and executive function measures and slightly above average for Dot Location and Family Pictures (Table 1).

MI includes many dependent measures during the visible, hidden, and probe trials. Analysis of the inter-relationships among these revealed that the percent time in the target quadrant and cumulative distance to the target in the probe trial provided very complementary information (Table 2). A lower total distance traveled during the hidden trials, an index of more efficient learning, was associated with better performance (i.e. more time in the target quadrant or lower cumulative distance) in the probe. In contrast, distance traveled during the visible trials did not predict probe behaviors.

Table 3 shows the associations between performance on the MI test and measures of attention, visual spatial working memory and executive function on established neuropsychological tests. Four patterns were evident. First, Spatial Span Backwards and the reaction time in the attention test each showed several significant correlations with measures of learning and memory on MI. Similarly, the strength of these associations was comparatively large ($r=\pm 0.30$ to 0.60). The strongest correlation was between reaction time and visible cumulative distance. Fig. 1B

shows the scatterplot between cumulative distance to the target quadrant in the probe trial and Spatial Span Backwards. Second, there were many significant correlations with performance during the visible trials, but relatively fewer for performance during the hidden trials. Third, the total distance traveled during the visible and hidden trials, in comparison to the cumulative distance to the targets, showed many associations with the other measures. Fourth, in the probe trial, the percent time in the target quadrant and the cumulative distance to the target provided quite similar information.

Next, examination of whether there were age differences on MI and other tests was completed. The percent time in the each quadrant in the probe trial, the primary index of spatial memory, was examined with mixed (Quadrant $\times$ Age) ANOVA. This analysis revealed a main effect of Quadrant ($F(2,88) = 16.41$, $p < .005$) and an Age $\times$ Quadrant interaction ($F(2,88) = 16.41$, $p < .005$). Figure 1C shows the percentage of total time spent in each quadrant during the probe trial for each age. Ten year-olds spent more time in the quadrant that previously contained the target relative to age seven or eight. Ten year-olds also spent more time in the target relative to the right, left, or opposite quadrants. In contrast, younger-aged children showed evidence of only partial preference for the target quadrant. Similarly, the mean cumulative distance during the probe was significantly smaller at age ten relative to seven, eight, or nine (Table 4).

Consistent with these age differences on probe on MI, ten-year-olds also exhibited better performance relative to younger children on the Immediate and Delayed Family Pictures and Spatial Span tests. Ten year olds also had faster and more consistent reaction times on the attention test. In contrast, there were no appreciable age differences on Dot Location or on the visible and hidden trials of MI (Table 3).

4 DISCUSSION

One objective of this report was to determine if MI is a viable approach to measure spatial learning and memory in children and to characterize behavioral development with this paradigm. Not only was MI completed by all children, this study identified a substantial improvement in spatial memory between ages seven and ten. Further, as the distance traveled to reach the targets was unaffected by age, these findings indicate that differences in spatial memory did not result from age differences in acquisition of the spatial task. A progression in spatial function during early childhood was not unanticipated as neurocognitive performance generally shows substantial improvement in juveniles with slower, more protracted gains during adolescence [27]. Similarly, Overman and colleagues identified enhanced performance with age among preschool children on scaled versions of a radial arm maze and in a dry Morris maze [22]. One striking aspect of the present findings was the pronounced improvements on the cumulative distance during the probe over a relatively small period (ages 9 to 10). The cognitive mechanisms responsible for these group differences could involve age differences in strategy usage such as reliance on landmarks versus the formation of an allocentric map. Although functional neuroimaging studies of seven to ten year old children are, as yet, uncommon, structural investigations have identified changes in forebrain white matter integrity which could also be responsible for the observed age-dependent outcomes [16].

Another objective was to characterize the convergent and discriminant validity of MI. The standard error of reaction time on the Conners' CPT is an index of response speed constancy. Children with more variable attention also showed less efficient spatial learning as reflected by longer distances traveled and higher latencies to find the target items. Participants with more consistent attention also showed enhanced spatial memory and spent more time in the target quadrant during the probe trial. Better spatial memory was found among children that made fewer CPT omission errors. As MI and CPT both require about fifteen minutes of sustained engagement with a computer, perhaps it is not surprising to observe some overlap. However,

MI performance likely requires more component processes than attention. Indeed, moderate correlations were also observed with performance on the Family Pictures test. The Family Pictures paradigm is a part of standardized tests for children and adults [28] and, although it does not involve spatial navigation, Family Pictures does contain a spatial component. Detailed validation information with children is currently unavailable, but one report suggests that Family Pictures provides a generalized index of memory [12].

One of the strongest correlations observed with spatial memory on MI was with Spatial Span Backwards. Spatial Span tests of visual-spatial working memory have a long history in experimental and clinical psychology and have been incorporated into various instruments [17,23]. Performance on Spatial Span tasks engages a diffuse network including the superior frontal and inferior parietal cortex [16]. Backward Spatial Span assesses the ability to manipulate visual-spatial information and requires children to update and reorder the stimuli, whereas this manipulation of information is not necessary for Forward Spatial Span. Interestingly, associations between MI parameters and Forward Spatial Span was uncommon. Successful completion of all MI trials may also require information manipulation in order to form a representation of the virtual environment.

Two other findings were also noteworthy. First, the visible trials were originally conceptualized to be analogous to trials with the visible target of the Morris water maze. However, rather than simply providing a sensory and motor control, these data indicate that performance on the visible trials, specifically the total latency, provides information that is consistent with other measures including parental reports of executive function. This could be because initially the target flags are not within the starting field of view and the child has to learn that they need to progress from just wandering aimlessly, as often happens in the early visible trials, to scanning the distant horizon in all directions (orientating) at the onset of each trial and then navigating directly to their destination. Also, there are four target locations and four corresponding starting perspectives for the visible MI trials which is considerably more difficult than the visible trials of the Morris water maze [4,19,20].

There are other virtual mazes besides Memory Island, and although generally similar, there are some conceptual and procedural differences in these instruments [2,3,21]. The virtual maze utilized by Astur and colleagues [2,3] requires swimming in an environment that approximates the dimensions of a rat sized pool (2 m), has more trials with the probe trial conducted immediately after the training trial rather than after a delay, and the control (target visible) trial is run after the probe. An earlier investigation with the Astur maze with children, ages eight to ten, did not report age differences, but did document pronounced sex differences, particularly in time to reach the hidden targets and in percent time in the target quadrant [21]. Notably, a separate study on this subject is ongoing [24], but a pronounced male advantage during the visible and hidden trials of MI in seven to ten year olds has been documented [1] which indicates that the different virtual mazes produce broadly concordant outcomes.

There are some limitations to this dataset. First, the sample consisted exclusively of healthy children. The use of a homogenous sample may limit the variability on some measures which would restrict the range of scores (e.g. Dot Location) and potentially diminish the correlations (although see the minimum and maximum in Table 1). Further research using MI, as well as this battery of instruments with children with attention problems is currently ongoing. Second, although seven to nine year-old children found MI difficult, the present findings do not indicate that even younger children are unable to form spatial memories using MI. As the Morris water maze can be performed by even preweanling rats when the task is adjusted to match their motor capacities [6], we are currently exploring the capabilities of six-year olds on MI when the interval between the last hidden trial and the probe trial is reduced. Third, information regarding computer and video game experience was not collected in the present study. As this variable

only accounts for 3–5% of the variance in MI performance [26], it is unlikely, albeit not impossible, that age differences in these activities contributed substantively to the present findings. Fourth, the sample was sufficient to detect only moderate sized correlations (± 0.28). A prior report with an almost identical sized sample of adults documented moderate associations with a virtual radial arm maze, the mental rotation test, and virtual maze performance [2]. Because of the large number of assessments conducted and corresponding number of statistics completed (for example, sixteen of ninety-four possible correlations were significant at an alpha of at least .01 in Table 3 alone), the possibility of a spurious correlation certainly exists. However, largely concordant findings to those in Table 2 are reported elsewhere with a community sample that is almost six times as large [26]. The current results will also be used to guide future data reduction procedures to further limit the number of dependent measures on MI. A post-hoc power analysis [13] on the group differences between ages ten and seven (0.95), eight (0.61), and nine (0.71) on probe cumulative distance (Table 4) suggests that the contributions of age to spatial memory, although apparently quite robust (see also Figure 1B), especially relative to other measures, should be viewed with this caveat in mind.

In conclusion, these findings indicate that there are age differences in spatial memory in primary school children on MI and that MI provides a new index of visual-spatial working memory which, in the future, will continue to build upon the substantial knowledge base established with the Morris water maze.

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Fig. 1.

Memory Island screen shot with the target in the inset (A), scatterplot depicting total cumulative distance ($\times 10^3$) to the target in the probe trial and Spatial Span Backwards (B), time in each quadrant during the probe trial by age (C) in 7–10 year old children, ^a $p < .05$ versus target for 10 year-olds, ^b $p < .05$ versus corresponding target within the same age.

Table 1

Behavioral performance of children, age 7–10 (N=50).

	Mean	SEM	Minimum	Maximum
<u>Attention (CPT)</u>				
Hit Reaction Time (Percentile)	46.2	4.4	1.3	99.0
Hit Reaction Time Standard Error (Percentile)	50.3	3.9	4.8	99.0
Percent omissions (Percentile)	46.0	3.6	14.1	99.0
Percent commissions (Percentile)	51.6	4.6	1.0	94.6
Detectability (Percentile)	53.9	4.2	1.0	99.0
Response Style (Percentile)	48.1	3.2	15.7	99.0
<u>Visual-Spatial Memory</u>				
Family Pictures: Immediate (Percentile)	62.3	3.9	9	100
Family Pictures: Delayed (Percentile)	61.4	4.1	9	100
Dot Location (Percentile)	62.1	4.4	9	98
Spatial Span (Total Score)	11.9	0.4	6	19
<u>Executive Function</u>				
BRIEF: Global Executive Composite (T ₅₀)	48.4	1.2	32	71
<u>Memory Island</u>				
<i>Visible (Trials 1–4)</i>				
Total Distance Traveled (virtual units)	1,812.0	32.3	1,655.1	2,998.5
Cumulative Distance From Target (virtual units $\times 10^4$)	4.1	0.5	1.6	10.3
Total Latency (sec)	213.8	8.9	154.7	400.5
<i>Hidden (Trials 5–8)</i>				
Total Distance Traveled (virtual ft)	3,795.2	225.1	1,808.0	8,011.0
Cumulative Distance From Target (virtual units $\times 10^4$)	8.2	0.5	1.7	13.4
Total Latency (sec)	417.1	30.6	163.6	1,230.2
<i>Probe (Trial 9)</i>				
Percent Time in Target Quadrant	53.7	5.4	0.0	100.0
Cumulative Distance from Target (virtual units $\times 10^4$)	2.5	0.2	1.5	10.5

Table 2

Correlation matrix among Memory Island measures among children (N=50).

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
I. % Time in Target (Probe)	1.00							
II. Cumulative Distance from Target (Probe)	-0.87^c	1.00						
III. Distance Traveled (Hidden)	-0.58^c	+0.45^b	1.00					
IV. Cumulative Distance from Target (Hidden)	-0.14	+0.22	+0.29	1.00				
V. Latency (Hidden)	-0.56^c	+0.53^c	+0.91^c	+0.33^a	1.00			
VI. Distance Traveled (Visible)	-0.08	+0.13	+0.18	+0.15	+0.13	1.00		
VII. Cumulative Distance from Target (Visible)	-0.09	+0.32^a	-0.02	+0.61^c	+0.14	+0.21	1.00	
VIII. Latency (Visible)	-0.35^a	+0.42^b	+0.19	+0.28	+0.38^b	+0.45^b	+0.57^c	1.00

Significant relationships are in **bold** with

^a $p < .05$

^b $p \leq .01$, or

^c $p \leq .001$.

Table 3

Correlations between Memory Island performance and other neurobehavioral measures in children (N=50). For Visible or Hidden Distance, the first number is the r_s with total distance traveled and the number in () is with the average cumulative distance from the target of the four trials in the first two-minutes. Cml: Cumulative; CPT: Conners' Continuous Performance Test; RT: Reaction Time; RS: Response Style; Standard Error, FP: Family Pictures; SS: Spatial Span; SE: Standard Error, BRIEF: Behavioral Rating Index of Executive Function.

Memory Island Trial:		Visible		Hidden		Probe	
Measure	Distance	Latency	Distance	Latency	Percent Time in Target	Cml. Dist from Target	
CPT: omissions	+0.38^b (-0.10)	+0.16	+0.24 (0.00)	+0.13	-0.30^a	+0.23	
CPT: com	+0.15 (-0.47^c)	-0.06	-0.25 (-0.19)	-0.37^b	+0.33^a	-0.28	
CPT: Hit RT	+0.20 (+0.56^c)	+0.22	+0.22 (+0.44^b)	+0.28^a	-0.39^b	+0.41^b	
CPT: Hit RT SE	+0.26 (+0.25)	+0.30^a	+0.27 (+0.24)	+0.28^a	-0.43^b	+0.44^b	
CPT: Detectability	-0.21 (+0.28)	-0.09	+0.20 (+0.27)	+0.34^a	-0.12	+0.10	
CPT: RS	+0.36^a (+0.12)	+0.32^a	+0.14(+0.02)	+0.12	-0.26	+0.30^a	
Dot Location	-0.04 (-0.01)	-0.20	-0.20 (-0.20)	-0.19	-0.10	-0.03	
FP: Immediate	-0.28^a (-0.14)	-0.23	-0.07(-0.15)	-0.08	+0.29^a	-0.34^a	
FP: Delayed	-0.28^a (-0.11)	-0.18	-0.02(-0.14)	-0.02	+0.21	-0.23	
SS: Forward	-0.31^a (-0.10)	-0.26	-0.15(-0.06)	-0.15	+0.14	-0.21	
SS: Backwards	-0.42^b (-0.31^a)	-0.46^c	-0.26(-0.33^a)	-0.29^a	+0.45^b	-0.47^c	
SS: Total	-0.37^b (-0.22)	-0.39^b	-0.22(-0.21)	-0.23	+0.34^a	-0.39^b	
BRIEF	+0.26 (+0.03)	+0.32^a	-0.05 (-0.01)	+0.10	+0.24	+0.04	

Significant relationships are in **bold** with

^a $p < .05$,

^b $p \leq .01$, or

^c $p \leq .001$.

Mean (SEM) behavior of children by age. BRIEF: Behavioral Rating Inventory of Executive Function. Variables with an ANOVA main effect of age are in **bold**.

Table 4

	Seven (N=12)	Eight (N=15)	Nine (N=11)	Ten (N=12)
<u>Visual-Spatial Memory</u>				
Family Pictures: Immediate	34.4 (3.2) ^b	38.9 (0.8) ^c	41.5 (1.5)	44.5 (1.0)
Family Pictures: Delayed	36.6 (2.1) ^c	38.6 (0.7) ^c	41.8 (1.5)	44.6 (1.3)
Dot Location (% Correct)	85.0 (4.5)	92.5 (2.3)	78.6 (4.2)	86.9 (3.4)
Spatial Span: Forwards	5.1 (0.3) ^c	6.5 (0.3)	6.0 (0.5)	7.4 (0.5)
Spatial Span: Backwards	5.1 (0.3) ^c	4.5 (0.4) ^c	5.6 (0.3) ^b	7.4 (0.5)
<u>Attention (Continuous Performance Test)</u>				
Hit Reaction Time (ms)^f	+6.19 (0.05) ^c	+6.15 (0.04) ^c	+5.99 (0.06)	+5.89 (0.05)
Hit Reaction Time Standard Error (ms)^f	+2.45 (0.12) ^a	+2.47 ^a (0.10) ^a	+2.41 (0.14)	+2.05 (0.12)
Percent omissions ^f	+0.97 (0.31)	+1.23 (0.30)	+1.27 (0.30)	+1.06 (0.20)
Percent commissions ^f	+4.09 (0.08)	+4.03 (0.12)	+4.16 (0.14)	+4.30 (0.08)
Detectability ^f	-1.13 (0.28)	-0.90 (0.24)	-1.76 (0.50)	-1.52 (0.25)
Response Style ^f	-0.71 (0.15)	-0.33 (0.19)	-0.28 (0.23)	-0.85 (0.26)
<u>Executive Function (BRIEF)</u>				
Global Executive Composite (total)	113.9 (6.4)	113.5 (5.6)	109.5 (5.1)	106.7 (4.9)
<u>Memory Island</u>				
<u>Visible</u>				
Distance Traveled (virtual units)	458.7 (15.7)	453.4 (10.7)	468.4 (30.2)	434.3 (5.7)
Cumulative Distance (virtual units/sec)	539.0 (60.4)	540.9 (47.9)	494.2 (53.0)	501.5 (52.4)
Speed (virtual units/sec)	8.3 (0.6)	9.5 (0.4)	9.3 (0.3)	9.8 (0.4)
<u>Hidden</u>				
Distance Traveled (virtual units)	986.0 (138.9)	964.0 (115.6)	1,043.6 (130.2)	835.8 (80.7)
Cumulative Distance (virtual units/sec)	838.2 (51.9)	766.2 (58.0)	816.8 (66.1)	722.6 (76.5)
Speed (virtual units/sec)	8.8 (0.6)	9.9 (0.4)	9.7 (0.3)	10.3 (0.4)
<u>Probe</u>				
Speed (virtual units/sec)	9.8 (0.7)	10.8 (0.4)	10.0 (1.0)	10.5 (0.7)

Cumulative Distance (virtual units/sec)	Seven (N=12)	Eight (N=15)	Nine (N=11)	Ten (N=12)
	856.3 (51.7) ^c	734.4 (33.2) ^d	810.5 (60.8) ^d	633.1 (25.6) ^d

^a p<.05,
^b p<.01, or
^c p<.005 versus age 10;
^d Log transformation,
^e one outlier (Grubbs p < .01) removed.

Table 5

Comparison of different instruments to assess spatial learning and memory.

	Morris Water Maze	Memory Island	Virtual Water Maze
Species Tested	various rodent [4,8,11,15,20,21]	human [1,5,25,27]	human [2,3,22]
Diameter	0.9–2.1 m [4,8,15,21]	≈317 m [1,5,25,27]	≈2 m [22]
Start Location	Perimeter, compass points [12]	Center, facing compass points [1,5,27]	Perimeter, compass points [2,3,22]
Trial Order	Visible -> Hidden -> Probe [5] Hidden -> Probe->Visible [12]	Visible -> Hidden -> Probe [1,5,25,27]	Hidden -> Probe->Visible [2,3,22]
Trials (# Visible/Hidden/Probe)	Variable [12]	9 (4/4/1) [1,5,25,27]	18–22 (1, 16–20, 1) [3,22]
Visual Cues in Probe	Distal [21]	Proximal and Distal [1,5,25,27]	Distal [2,3,22]
Dependent Measures	Speed, Latency, Distance, Cumulative Distance, % Time in each quadrant [12]	Speed, Latency, Distance, Cumulative Distance, % Time in each quadrant [1,5,25,27]	Speed, Latency, Distance, Heading error, Proportion of Distance in correct quadrant [2,3,22]