Spatial working memory performance in real museum environment versus computer simulation: a comparison between healthy elderly and young adults

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ABSTRACT

In recognition of the limited ecological validity of testing in a laboratory setting, we compared spatial memory performance of healthy young and older adults in a real museum setting and on a computer simulation. In the museum, participants physically moved between display stations to locate hidden tokens; an ongoing representation of previous searches had to be remembered. A comparable task was implemented via mouse actions on a computer simulation. Nine older (60-80 years) and 20 younger (20-45 years) adults performed both tasks. The younger group was superior to the older group in terms of success and time, and all participants were more efficient within the simulated task. The feasibility of using realistic tasks in a physical location to study spatial memory is discussed.

1. INTRODUCTION

Remembering where things are, object–location memory, is essential for daily-life functioning (Postma et al, 2008). Spatial memory is a complex multidimensional process which includes a variety of components that help people to orient and act in space (Kessels et al, 2001). This cognitive process is crucial for activities such as finding your way to locations such as a supermarket and subsequently knowing where to find specific products, e.g., grocery items. Spatial memory includes the ability to remember the spatial layout of environments, to know how to travel from one place to another, to remember the locations of objects within a specific environment, to have knowledge about the spatial arrangements of objects relative to each other, and to know one's own location in the environment. Object–location memory is considered to constitute a special class of episodic memory, reflecting a form of contextual memory in which object (identity) information is bound to location information (King et al, 2004). Object–location memory appears to rely on three distinct processing mechanisms: object processing, spatial-location processing and object to location mapping (Postma et al, 2008). When spatial memory involves remembering changes in the environment, it is considered to be dynamic (i.e., spatial working memory). Postma et al. (2008) suggested that dynamic spatial memory often engages a "from within the environment" perspective (which mainly involves egocentric representations of space). The challenge of dynamic spatial memory is illustrated by what occurs when one gets lost when traveling from one place to another which requires one to relocate oneself in the environment, to update spatial knowledge about the changing environment, and to re-plan the route ahead. This involves sequences of different spatial environments as well as sequences of spatial decisions.

Conscious retrieval of object–location associations are a notable feature of the hippocampus and specific impairments of learning and memory associated with aging have been shown to be related to hippocampal damage (Postma et al, 2008). Altered synaptic plasticity in the elderly may result in changes in the dynamic interactions among cells in hippocampal networks, causing deficits in the storage and retrieval of information about the spatial organization of the environment (King et al, 2004).

It is well documented that both cognitive and motor learning abilities decline with normal aging, impeding the performance of complex cognitive skills (Salthouse, 2009; 2010). However the extent and type of these changes is variable. Declines in domains such as memory and speed of sensory processing, and deficits in attention such as the ability to sustain information processing over time, suppress irrelevant information or switch between activities have been reported (Coubard et al, 2011; Deary, 2009). Given that cognitive processes such as working memory are engaged during the early stages of motor learning (Anguera et al, 2010), age-related declines in motor behavior and learning may be due, in part, to reductions in cognitive ability.

Performance in ecological environments imposes increased perceptual and attentional loads due to the inherent sensory richness of realistic settings (Sweller, 1994). That is, the extraneous cognitive load, the load that does not contribute to the learning process itself, in real environments is usually high (Sweller et al, 1998). In diverse experimental settings it has been demonstrated that relative to young adults, the performance of older adults showed cognitive deficits when task demands increased and when high extraneous cognitive load was imposed (Lorsbach and Simpson, 1988; Van Gerven et al, 2002). Hippocampus-related memory tasks, and specifically, object-location dynamic memory tasks, have been poorly studied in ecological settings. The testing of such paradigms under realistic conditions may not only lead to novel interventions for age-related cognitive impairments, but may also contribute to an improved understanding of the mechanisms of learning and plasticity in the mature brain.

Thus, the present study aims to investigate the impact of age and environmental factors (i.e., a real museum versus computer simulation) on visual-spatial working memory of healthy older and young adults. In particular, two research questions were addressed: 1. To what extent do older adults maintain their cognitive capacity during a dynamic spatial working memory task as compared to young adults? 2. How is this capacity, measured in frequency of success, affected by performance of the task in a realistic environment where demands for a cognitive task solution are similar to a computer simulation, but differ in the extraneous task demands involving physical interaction with targets and walking around a large hall of real museum exhibits?

2. METHODS

2.1 *Participants*

Twenty young healthy male (9) and female (11) younger adults (M=28.5, SD=6.48 years) and 9 healthy male (3) and female (6) older adults (M=70.0, SD=5.20 years) were recruited through advertisements in the local media (university web sites, local newspaper ads and bulletin boards). Participants were excluded if they scored less than 21 points (out of a total 30) on the Montreal Cognitive Assessment (MOCA) (Nasreddine et al, 2005). They were paid ILS 70 (~$20) for partaking in the study; this amount included reimbursement for travel to the museum via public transportation.

2.2 *Instruments*

2.2.1 Assessments and Questionnaires

- *Demographic questionnaire*. The items documented participant gender, age, level of education, prior usage of simulations, etc.
- *Montreal Cognitive Assessment (MOCA).* (Nasreddine, 2005). This is a screening instrument for mild cognitive dysfunction, translated into many languages including Hebrew. It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visual-constructional skills, conceptual thinking, calculations, and orientation. The total possible score is 30 points; a score of 26 or above is considered normal but a cut-off score of < 21 appears to yielded good sensitivity and specificity (Lee, 2008).

2.3 *Setting and materials*

The experiments were conducted in two settings. The computer simulation experiment was conducted in a small, quiet room (such as in a typical laboratory setting) adjacent to but separated from the museum space which was where the Hecht museum experiment was conducted. The museum experimental environment was instrumented with sensor technologies designed to support objective and unobtrusive monitoring of museum visitors (Kuflik et al, 2012). These included a computer to run the experimental task and iPods at each station (museum exhibit). For the computer simulation environment, a computer with a 15 inch screen and a standard computer mouse was used for the delivery of participants' responses.

2.3.1 Spatial memory task: 'Travelling salesman problem'. The tasks were a modified version of the "Travelling salesman problem", so called because it refers to the need by travelling salesmen to remember which houses they have already visited including cases of no response or where they have made a sale. The task was transformed into a spatial search activity that assesses the ability to retain and manipulate information in spatial working memory. The participants were required to maintain and update an ongoing representation of previous searches in different locations and to develop an appropriate search strategy to be successful in the task (Owen, 1996).

All participants performed the task at both settings: via a computer simulation, (Simulation), and in the museum setting (On-site), in an order that was counterbalanced within each age group. The spatial working memory task required the participants to search a set of targets by "opening" (i.e., by clicking on the mouse button in the simulation setting or touching the iPod target with a finger in the museum setting). A click/touch caused the target to reveal whether it was empty or contained a token. During any given search, there was a single token hidden within only one of the targets. The participants had to successively open the targets until they located the token. Then another token was hidden. Once a token had been found within a target, that target could not be used to hide a token until the end of that round and the participant was not supposed to check it again. This requirement meant that the participants had to remember which targets had been opened so that they would not return to one that had already been visited. When all tokens were found, the round was over.

Two types of errors are possible in this task:

- a between-search error occurred when participants returns to a target in which they had previously found a token
- a within-search error occurred when a participant returns to a target within the same search.

Graphic display of the target content was similar in both settings. Empty targets were designated by an empty black frame shown above the target; errors were designated by a red "X" symbol shown above the target and the found token was designated by a green "*checkmark*" symbol. The salient instruction was that once a token had been found at a particular target (green "*checkmark*"), the target should not be checked again until the end of the round. The Frequency of success and Normalized time per target were computed for each round. Normalized mean time per target indicates the time it took to complete a given level divided by the number of clicks during this level (as the number of clicks made by participants during a given round was variable, depending on the individual search strategy).

Each participant performed three rounds of increasing difficulty in each setting; in the first round there were four target locations, in the second round five target locations and in the third round six target locations. In both settings, the target locations were pseudo-randomly arranged for each round to prevent transfer of previous knowledge to the next level. In the case of an error, the current round was aborted and the participant was given a second try to complete the current level. Before commencement of the actual experiment with four, five and six targets, three training rounds with three targets were performed in each setting, to familiarize the participant with the task.

Computer simulation setting: For the computer simulation setting, participants were presented with targets on a computer screen (see Figure 1). The search to successive targets was performed by navigating with a standard computer mouse and clicking the left button.

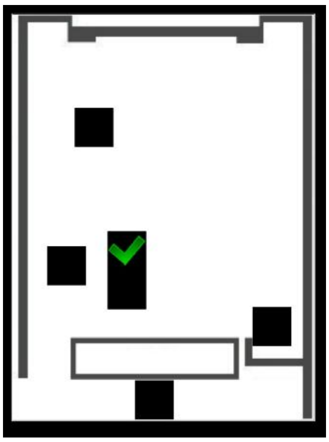

Figure 1. *Computer simulation setting screen example. Level 2: Five targets with one of the targets revealing a token (green "checkmark" symbol above the target), when participant clicked on this target.*

On-site museum setting: The on-site version of the task had the same structure and sequences of spatial arrangements of targets as the computer simulation. For the on-site task setting, participants were presented with targets on a touch-sensitive iPod screen, with each iPod placed on a stand at different specific locations in the museum space (see Figure 2, left and right panels). While the location of the iPods in the museum was real (stands with iPods were distributed among museum exhibits in a 40 by 40 meter hall), the tokens were virtual (i.e., they appeared on the iPod screen, if the target was opened by participant). iPod locations were spaced 2 to 30 meters from each other. On each iPod only one target (black square) was presented. Upon touching the surface, information regarding the target (i.e., existence of the token) was delivered in the same way as in the simulation setting. Participants were required to search through the iPods for a green "checkmark" token by touching each iPod to reveal its contents.

Figure 2. *On-site (museum) setting.* Left, *Experimental area in the museum,* Right, *Participant's hand selecting a target while searching for a token.*

2.4 Procedures

Ethical approval was obtained from the Institutional Review Board of the University of Haifa. Each participant was invited for a single, 60-75 minute session which started by signing informed consent, an explanation of the experiment and basic instructions. Participants were randomly assigned to first perform the simulation or the on-site task. The participants completed the questionnaires at the conclusion of the experiment.

3. RESULTS

The young adults group performed significantly better than the elderly group in both tested settings (simulation and on-site). This advantage was expressed in terms of both the frequency of success and the Normalized mean time per target (see Fig.1). Descriptive statistics for both measures are presented below.

Frequency of success. Differences between the age groups in frequency of success were found to depend for both setting, and level of difficulty (Table 1). When the round included only four targets, in the computer simulation setting, both young and older adults succeeded in finding all the tokens. In contrast, during the four-target round in the on-site setting, the older adults failed to complete the round significantly more frequently than the young adults. When the round included six targets, in the computer simulation setting, the older adults failed to complete the round significantly more frequently compared to young adults; for this level, there were no significant differences between the groups for the on-site setting. In the intermediate difficulty level (five-target round), there were no significant differences between the groups in the frequencies of success for either the computer simulation setting or the on-site setting. Nor were significant differences found in the frequencies of success within each age group between the computer simulation setting and the on-site setting.

"Normalized time per target". In a 3 ways repeated measures ANOVA, a significant main effect was found for group ($F_{(1,27)}$=35.86; p=.0001) and for setting ($F_{(1,27)}$=457.34; p=.0001). There was no interaction effect for the different difficulty levels with age group or setting in terms of the normalized time per target measure, meaning that increased cognitive load had no effect on the mean performance time. However, there was a significant interaction effect for age group and setting ($F_{(1,27)}$=7.28; p=.012); further analysis showed that differences between the age groups in the Normalized time per target measure were found in all levels within each setting with the older adults being slower than the young adults. (Figure 3, Table 2). In addition, in both groups significant differences were found between the two settings at all the difficulty levels.

Table 1. *Number (percent) of healthy young* (N =20) *and older adults* (N = 9) *who succeeded during the first trial in the simulation and on-site task*

Level	Simulation Young Adults n (%)	Simulation Older Adults n (%)	χ^2	On-site Young Adults n (%)	On-site Older Adults n (%)	χ^2
4 targets	20 (100)	9 (100)	-	20 (100)	7 (77.8)	4.77*
5 targets	18 (90)	6 (66.7)	2.37	13 (65)	3 (33.3)	2.52
6 targets	17 (85)	2 (22.2)	10.83**	14 (70)	4 (44.4)	1.72

n – Number of participants who successfully completed a level; % - percent of participants who successfully completed a level; * $p \leq .05$, ** $p \leq .00$; - no statistics were computed as success rate was 100% in both groups

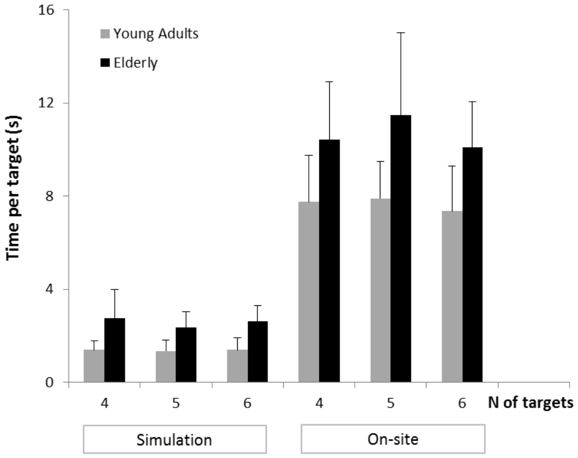

Figure 3. *Mean time (in seconds) per target, calculated as the mean time to complete a given level / by the number of clicks during this level. Black– elderly group (n = 9), Grey – young adults group (n = 20). Bars – SD. Results are shown for the three difficulty levels (N of targets) during the Simulation and On-site Museum performances.*

Table 2. *Means and standard deviations (SD) for the normalized performance time (seconds per click) of young and elderly subjects on a spatial memory task in a simulated environment compared to an on-site environment in different levels.*

Level	Simulation Young Adults Mean ± SD	Simulation Older Adults Mean ± SD	F *df*(1,27)	η^2	On-site Young Adults Mean ± SD	On-site Older Adults Mean ± SD	F *df*(1,27)	η^2
4 targets	1.40±0.38	2.74±1.24	20.14*	0.43	7.76±1.99	10.44±2.48	9.62***	0.26
5 targets	1.35±0.48	2.35±0.68	20.66*	0.43	7.90±1.59	11.50±3.53	14.72**	0.35
6 targets	1.40±0.50	2.62±0.68	29.30*	0.52	7.36±1.93	10.10±1.97	12.32***	0.32

*$p \leq 0.000$, ** $p \leq 0.001$, *** $p \leq 0.01$

4. CONCLUSIONS

The objective of this study was to test the ability to retain and manipulate information in spatial working memory in healthy young and older adults. Our results demonstrated the validity of the developed task that was applied in two experimental settings: the real museum space and the computer simulation. We showed that the paradigm implemented is a sensitive research tool that highlights cognitive and working memory differences in performance between the healthy young and older adult populations. Specifically, our results suggest that both age groups were sensitive to the increasing difficulty of the task, but responded in a different manner. At the easy level of the simulation setting, the older group did not show any deficit in the frequency of success to complete the round. As expected from the literature (e.g., Coubard et al, 2011; Deary, 2009), older adults were slower to complete all tasks than the young adults.

The study results suggest that healthy older adults maintain basic cognitive abilities required for successful performance in object–location memory task. However, the speed of performance as well as sensitivity to cognitive demands of the task are significantly altered by age with the older participants being generally slower in both settings and at all difficulty levels and less tolerant to increased extraneous cognitive load.

In rehabilitation, functional activity in real life situations is the most relevant outcome to measure (American Occupational Therapy Association, 2008). The current study implemented a test of spatial working memory in healthy participants from two age groups in experiments that tested the Living Lab approach to realistic and meaningful data collection (Følstad, 2008). Our results highlight the importance of experimentation in ecologically relevant settings: differences were found in the way the real setting affected the cognitive performance of older and younger adults. Such differences are expected to be even more apparent in clinical populations. A deeper understanding of age- and medical condition- induced constraints on working memory management may help in making an optimal use of the available cognitive processing capacity.

Acknowledgements: The authors wish to thank the Hecht museum at Haifa University for permitting us to use the museum space to run the experiments; Michael Sambur, Inna Belinki, Yaniv Nisenboym, Keren Tzitiad and Zohar Herling for their help in the software programming and data collection. Furthermore, the Caesarea Edmond Benjamin de Rothschild Foundation Institute for Interdisciplinary Applications of Computer Science (C.R.I.) is gratefully acknowledged for funding this project.

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