34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

The Effect of Aging on Human Brain Spatial Processing Performance

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***Abstract*— Cognitive abilities similar to other mental or physical abilities develop and change during the course of life. Spatial processing is a cognitive ability, which has been suggested to deteriorate by age [1]. The focus of this paper is to study the change of real time egocentric spatial processing in humans by age. For this, an interactive computer game played with a 2DOF manipulandum was designed. The game consists of goal-oriented motor tasks, in which the player must move the robot arm toward a desired spatial cue in a virtual 2D environment in every trial for a total number of 72 trials. The spatial cues are four final destinations and a starting location, which change their position in every new trial of the game. 37 individuals with no cognitive impairment were split into 3 groups according to different age range (children, young, and elderly) and participated in this experiment. Their spatial processing ability was assessed and compared between the age groups. The results show the children (7-12 y) and elderly (65^+ y) performed very similar and significantly worse than the young adult participants.**

I. Introduction

Well-developed spatial processing ability is an important factor of a successful performance in any motor task. Spatial processing is involved in judging an object's size, orientation, distance to other objects and relative location in the horizon coordinate system (i.e. north, south, east, west); this is also referred to as spatial cognition [2], [3]. Location, direction, or the orientation of an object is defined relative to a frame of reference, in which that object is presented. Egocentric orientation involves cues that depend upon the position of the observer (i.e., left-right, front-behind), while allocentric orientation is maintained through the use of either environmental features such as landmarks or the horizon coordinate system that are independent of the observer [4]. Moreover, researchers draw a line between real-time spatial processing and long-term spatial memory that are involved in way-finding and remote object-locating, respectively [5].

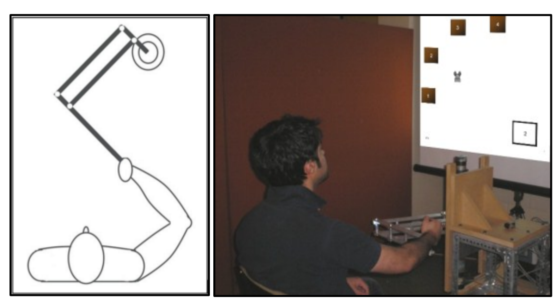
In [12], the effect of age on spatial processing ability was tested between different age groups through observing their performance in memorizing a route using a 2D map and then finding it in a 3D environment. It was found that elderly participants accomplished the goal of the spatial processing tasks slower and with more errors compared to their young participants. Elderly participants tend to be slower than young adults in acquiring spatial cues to find their way in a novel environment (supermarket) [16]. From the neurological perspective, through *f*MRI imaging, less neural activity in the regions of the brain involved in the spatial navigaition were observed in older subjects compared to younger ones [7].

This study aims at investigating an objective measure for the real time egocentric spatial processing. An interactive computer game was designed to address the need for a module to study spatial processing abilities in humans. The developed game consists of repetitive goal oriented motor tasks in which the human subject must reach a desired spatial cue from his/her current location in the virtual 2D environment of the game using a manipulandum. We hypothesize that elderly and children have similar performance, which is poorer than the performance of young adults in terms of precision and success rate (total number of success trials in each experimental session).

II. Method

A. Manipulandum

A robotic arm (Manipulandum) used in this study is a custom designed 2DOF parallel four-bar linkage with two drive motors mounted at the base [6]. The Manipulandum (Fig.1.a) limits the arm reaching movement in a planar space visiting all the points along the line connecting the start point to the end point; hence, resulting in a XY trajectory. Therefore, the Manipulandum controls/limits the number of possible dimensions along which a reaching task can be performed, which in turn helps in having the participants' performance in the experiment to be solely the factor of their spatial processing abilities rather than their motor control abilities. The participants in the study were instructed to grasp the handle of the Manipulandum (Fig. 1.b) and play the game through which the movement trajectories were recorded for subsequent analysis.



(a) (b)

Fig. 1. a) Top view schematic of a subject holding manipulandum, b) Experimental Setup.

B. Interactive Computer Game

The interactive computer game was conceptualized by the authors and developed in C++. The game screen was the

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home for 4 final destinations (rooms) colored in brown, a starting location indicated as a black outlined square and a mouse-shaped cursor. The final destinations 1 to 4 were equally distanced from one another and located at a clockwise angle of 120°, 160°, 200° and 240° from the starting location, respectively. The relative position of the starting location and the four final destinations was fixed throughout the game. Fig. 2 illustrates the position of the 4 rooms and the starting location in the 2D game environment. The starting location and the four final destinations were located on the circumference of an imaginary circle (shown in dashed line in Fig. 2) centered at the center of the game screen. The player should move the cursor to the desired final destination whose number is shown inside the starting location in every new trial of the game for a total number of 72 trials. In every new trial of the game the whole game screen rotates with a clockwise amount of 30º as shown in Fig.3. As a result of this rotation, the final destinations along with the starting location are rotated with the same clockwise amount of 30° and placed at new positions on the circumference of the imaginary circle shown in Fig. 2.

At the beginning of every experimental session, the starting location and the final destinations in the game's 2D environment were shown, allowing the players to familiarize themselves with the game and spatial relation between different objects on the game screen. In order to start a new trial at the beginning of an experimental session or at the end of each trial, the player must move the cursor to its starting location. When the cursor is observed for 200 ms inside the starting location, the desired final destination number (1-4) is shown inside the starting location and a "GO…!" message appears on the game screen (Fig.3). However, as long as the cursor remains inside the starting location, the subject has time to think of the right direction that would lead the cursor to the desired final destination. After the end of each trial through the transition to a new trial and during the new trial up to the point when the cursor crosses the imaginary boundary, only the starting location is visible to the subject (Fig. 3.b). The trial timer and the trial number are shown on the bottom left and right sides of the screen, respectively. At the end of each game session, the total score for that particular session is also shown to the player.

As a visual feedback, when the player crosses the imaginary boundary that indicates the start of the final destinations' region, the final destinations become visible one after another (Fig. 3.c). In a successful reaching trial, the desired final destination turns to red (Fig. 3.d) with a success audio feedback being played, while in an unsuccessful trial a red X (Fig. 3.a) indicative of a failed trial is shown with an associated failure audio feedback being played. The only instruction given to the players was to score by successfully reaching the desired destination. A score is counted for the subject whenever the desired final destination was successfully reached. Through this experiment, the cursor as a virtual object slaves the human subject to play the game as if the subject is moving through a virtual 2D environment. The position of the cursor on the 2D screen is mapped to the position of the robotic arm moving in a planar space through a set of coordinate transformations [7].

C. Subjects

15 young adult subjects (26.6±3.1 y, 7 females), 12 elderly subjects (73.25±7.6 y, 6 females), 10 children (10.14±1.6 y, 6 females) participated in this experiment. The children participants in this study were from the age range of 7 to 12 years old. This age range for children was chosen based on cognitive developmental theories that suggest the period of 7 to 12 years is the stage where rationality and active thinking start to develop in human beings [8], [9]. The Ethics approval was granted prior to recruiting participants by The Biomedical Research Ethics Board of the University of Manitoba.

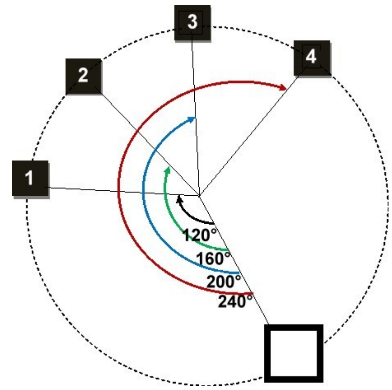
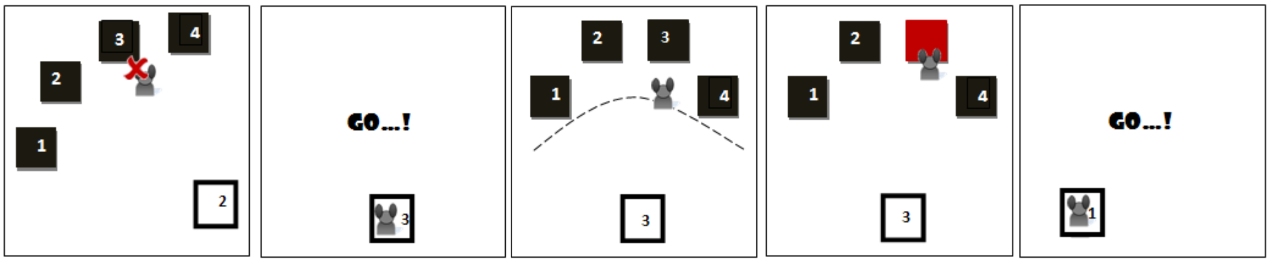


Fig. 2. Game screen layout. Final destinations are shown as brown squares and the starting location is indicated by a black outlined square.

D. Data Analysis

As described before, in every new trial when the subject took the cursor inside the starting location, a desired destination was shown. At this point, the player was given an open time period to think about the correct direction that would lead the cursor to the desired destination. The time the participants spent inside the starting location prior the start of the movement is referred to as the "*thinking time*" here, and was recorded and averaged for every 6 successive trials for the participants of each age group.

The onset angle is the direction estimated by the subjects to reach the desired destination after leaving the starting location; hence, representing how well a player can orient him/herself to a desired final destination after a rotation in a new trial. Ideally, in the case of physically and kinetically unconstrained arm movements, the trajectory between the starting location to the end point (in the case of a correct estimation of the direction, the end point is the desired destination) would be a straight line connecting the starting location to the end point [10], [11]. The absolute difference between the observed onset angle and the actual angle (the angle that leads to the desired final destination) is referred to as "*general angular error*" here, and was calculated for each trial. The individual angular errors were averaged in the bins of 6 consecutive trials for a total number of 12 bins covering all 72 trials for each age group. Furthermore, a full rotation was divided into 12 regions of 30° each, and the angular errors within each region for those trials falling in that region were calculated, averaged for each age group and plotted using a polar plot; this angular error is referred to as "*directional angular error"* in this paper. The Mean Square Error (MSE) (Eq. 1) along with the Standard Error (SE)



(a) (b) (c) (d) (e)

Fig. 3. Details of the orientation game. a) the end of an unsuccessful trial, b) start of a new trial after transition to the new trial by applying a 30° clock wise rotation to the starting location and final destination positions, c) reaching task in the new trial - passing the virtual boundary, d) end of a successful trial, e) transition to a new trial; a 30° clockwise rotation is applied - start of the new trial. The desired final destination number (1-4) is shown inside the starting location.

between the actual onset angle trend and the observed ones were calculated for all the study groups (young, elderly, and children).

$$MSE = \frac{1}{n}\sum_{j=1}^{n}\left(x_{ij} - x_{oj}\right)^2, \quad (1)$$

where n is the number of trials, x_{ij} and x_{oj} are the actual and observed onset angles in j^{th} trial of an experiment.

The statistical student *t*-test was used to investigate significant differences in the MSE of the onset angle and the players' scores between different participant groups. In all instances, the *p*-value was set at 0.05. Furthermore, the correlation between the current and past general angular errors was investigated using autocorrelation of the recorded error sequence. The correlation analysis helps finding whether the subjects were adapting to the clockwise rotational pattern of change in the 2D environment of the game and hence accomplishing the task with less angular error towards the end trials, or they were just simply applying real-time spatial processing without any use of the previous errors (short-term memory effect). In the case of real-time spatial processing, there would be no correlation between the successive errors; hence the autocorrelation function would oscillate within a certain bounds.

III. Results

The thinking time trends looked similar for all the participating groups showing a decreasing pattern toward the end trials. The averaged general and directional angular error trends for different age groups are illustrated in Fig. 4 and 5, respectively. The averaged general angular error trend for the case of young adult subjects was noticeably lower and separated from the elderly and children trends, which were within the same margin (Fig. 4). The young adult group trend (Fig. 5) was clearly demonstrating less directional error comparing to the two other groups. The MSE of the onset angle observed in the games played by young, elderly and child subjects are shown in Table I. As can be seen, there are relatively lower MSE values for the case of young adult subjects compared to those of the other two groups.

TABLE. I
MSE and SE of onset angle trends for all the groups.

Subjects	MSE
Young	0.007 ± 0.01
Elderly	0.033 ± 0.01
Children	0.023 ± 0.01

The averaged success rate in our experiment for young, elderly, and child groups were found to be 40.3, 24.4, 28.3, receptively. The *t*-test results (Table II) among each pair of the subject groups for the MSE and score values showed the performance of children and elderly were similar but significantly different from young adults ($p<0.01$). Correlation analysis was done for successive angular errors for each age group to investigate the short-term memory effect; it showed no specific learning pattern throughout the trials of the game.

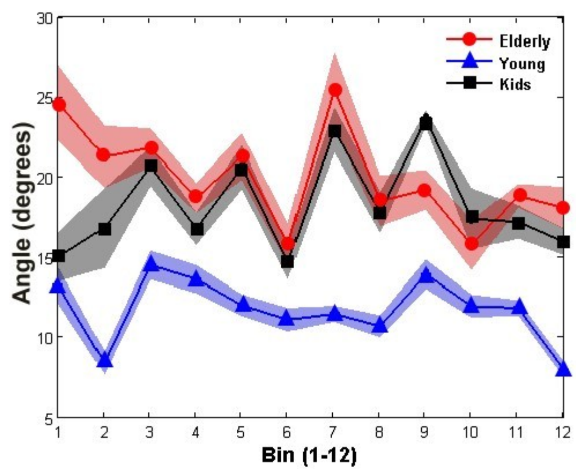


Fig. 4. General angular error averaged for every 6 successive trials for presentation purposes. The shadows show the standard error between the subjects from the same group.

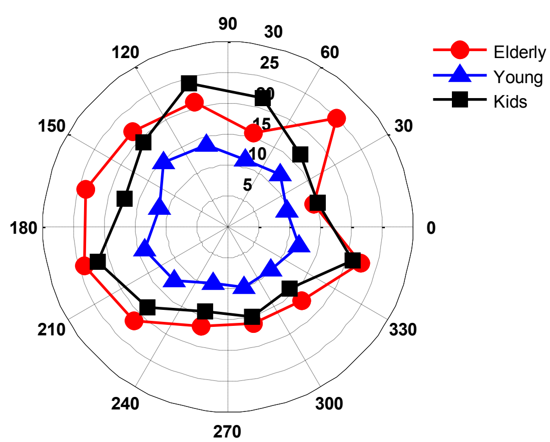


Fig. 5. Averaged directional angular error trends for all groups.

TABLE. II
THE *P*-VALUES OBTAINED BY STUDENT *T*-TEST BETWEEN THE MSE VALUES AND SCORES AMONG DIFFERENT GROUPS. THE * INDICATES THE SIGNIFICANCE OF THE TEST.

	MSE	Score
Young – Elderly	0.011*	0.002*
Young – Children	0.010*	0.004*
Elderly – Children	0.300	0.310

IV. DISCUSSION AND CONCLUSION

This study develops a new and simple interactive computer game accomplishable by different age groups; hence, providing a potential testkit for examining human spatial processing abilities. We examined the potential of the developed game for measuring human cognitive spatial processing. The results show that the game measured varying levels of spatial processing abilities for different age groups. In particular, we tested the hypothesis that young adult group significantly outperforms the elderly and children groups in the spatial processing activities, while the later groups have similar performance in achieving the goal in such activities. The results confirm this hypothesis, which is congruent with the findings in [12-15] suggesting a decline in spatial processing abilities with age. This congruency also validates the applicability of the developed game for assessment of cognitive spatial processing.

Children start to grow a more logical understanding of the concept of time and space during the priod of 7 to 12 years old. This stage is when children pass through the transition from home to school, where they start actively acquiring skills. According to Piaget [18], the age 7 to 12 years is when the active and rational thinking in children start to develop. This stage is where the egocentric thoughts of self diminishes, and the child starts to find a relation between self and other objects in his/her surroundings [8]. Piaget work suggests the age 12 as the maturity age for spatial abilities in humans [19]. Erikson's theory of psychosocial development suggest the age range of 6 to 12 is when children become more aware of themselves and work hard on accomplishing goals of complex tasks [9]. Taking these developmental theories into account, one can elaborate on the poor performance of children compared to young adults in this study. It might be due to the developing and not yet completed underlying cognitive and neural abilities involved in performing spatial processing tasks.

Furthermore, considering the correlation analysis for the general angular error trend, it can be concluded that the spatial processing involved in playing this game is of type real-time spatial processing with the least involvement of memory. This is probably due to the conditional appearance of the special cues in every trial of the game as described in the method section, which results in remapping of the spatial cues relative to the starting location in every new trail.

The similarity between the performance of children and elderly and the significant difference with that of the young adult group is an interesting finding of this study. We believe this method might be useful for early diagnosis of neurodegenerative diseases such as Alzheimer. We hypothesize that patients with Alzheimer disease even at early stages perform significantly poorer than their age-matched normal individuals. Furthermore, it would be interesting to investigate if the designed game of this study can be used as a rehabilitation tool for both elderly and patients with neurodegenerative diseases.

REFERENCES

[1] R. Pak, S. Czaja, J. Sharit, W. Rogers, A. Fisk, *"The role of spatial abilities and age in performance in an auditory computer navigation* task," Computers in Human Behavior, vol. 24, no. 6, pp. 3045-3051, 2008.

[2] E. De Renzi, P. Faglioni, P. Previdi, *"Spatial memory and hemispheric locus of lesion,"* Cortex 13, pp. 424–433, 1977.

[3] A. Postma, E.H.F. Haan, "*What was where? Memory for object locations,*" Q. J. Exp. Psychol. 49A, pp. 178–199, 1996.

[4] J. Hort, J. Laczo, M. Vyhnalek, M. Bojar, J. Bures, K. Vlcek, *"Spatial navigation deficit in amnestic mild cognitive impairment,"* Proceedings National Academy of Sciences, 104: pp. 4042–7, 2007.

[5] D.S. Olton, B.C. Papas, *"Spatial memory and hippocampal function,"* Neuropsychologia 17, pp. 669–682, 1979.

[6] C. MacDonald, S. Balakrishnan and Z. Moussavi. *"Development of a low-cost robotic manipulator and its application to human motor control studies,"* Proceeding of eighth IASTED international conference. Control and applications, May 2006, Montreal.

[7] R. Shadmehr, F. Mussa-Ivaldi, "*Adaptive representation of dynamics during learning of a motor task,"* J. Neurosci.,14 (5), pp. 3208–3224.C, 1994.

[8] J. Piaget, *"Piaget's theory,"* In P. H. Mussen (Ed.), *Carmichael's manual of child psychology,* 3rd ed., Vol. 1, pp. 703-732, New York: Wiley, 1970.

[9] E.H. Erikson, "*Identity and the Life Cycle,"* Psychological issues, Monograph 1, New York: International University, 1959.

[10] N. Hogan, *"The mechanics of multi-joint posture and movement control,"* Biological Cybernetics, vol. 52, pp. 3 15-33, 1985.

[11] P. Morasso, *"Spatial control of arm movements,"* Experimental Brain Research, vol. 42, pp. 223-227, 1981.

[12] G. Iaria, L. Palermo, G. Committeri, J.J.S. Barton, *"Age differences in the formation and use of cognitive maps,"* Behavioral Brain Research, vol. 196, pp. 187-191, 2008.

[13] M. Newman, A. Kaszniak. *"Spatial memory and aging: performance on a human analog of the Morris water maze,"* Aging, Neuropsychology, and Cognition, vol. 7, no. 2, pp. 86–93, 2000.

[14] S.M. Wilkniss, M.G. Jones, D.L. Korol, P.E. Gold, C.A. Manning. *"Age related differences in an ecologically based study of route learning,"* Psychology and Aging, vol. 12, no. 2, pp. 372–375, 1997.

[15] R. Passini, C. Rainville, N. Marchand, Y. Joanette. *"Wayfinding in dementia of the Alzheimer type: planning abilities,"* Journal of Clinical and Experimental Neuropsychology, vol. 17 no. 6, pp. 820–32, 1995.

[16] K.C. Kirasic, *"Spatial cognition and behavior in young and elderly adults: implications for learning new environments,"* Psychology and Aging, vol. 6, no. 1, pp. 10–18, 1991.

[17] SD. Moffat, W. Elkins, SM. Resnick, *"Age differences in the neural systems supporting human allocentric spatial navigation,"* Neurobiology of Aging, vol. 27, pp. 965–72, 2006.

[18] J. Piaget, B. Inhelder, "*The child's conception of space*," New York, NY: Norton, 1967.

[19] H. Bayram YILMAZ, "*On the development and measurement of spatial ability,"* International Electronic Journal of Elementary Education, vol.1, no. 2, March, 2009.