

Do Older and Young Adults Learn to Integrate Geometry While Navigating in an Environment of a Serious Game?

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ABSTRACT: We evaluated the outcomes of an intervention using a serious game designed to be played on iPads for improving spatial reorientation by training users to integrate geometry of the environment, instead of relying solely on featural cues. Using data logged online through a clinical study of using this game, the effect of training among 16 older adults (69.3 ± 6.4 years, 4 males), who played the game repeatedly (self-administered) over a period of 8 weeks, was investigated. The game contains a hexagonal room with 3 objects, textured walls, and grids on the floor, which are removed one by one as the participant played the game. In each level, the room also rotates such that the viewpoint of the user is different from that of the previous level. Participants cannot play a higher level unless they make no mistake during the trials of the lower test level. In addition to data of older adults available from that clinical trial, we recruited 16 young adults (27.3 ± 5.6 years, 4 males) to play the game for 5 sessions and compared their results with those of the older adults. We evaluated the error type made in each test level and the scores for each session among older adults. Further, we compared the frequency of each error type between young and older adults during the test levels that a landmark adjacent to the target was removed over the first 5 sessions. The results of older adults' performance suggest they learned to make fewer mistakes over the sessions. Also, both young and older adults learned to integrate the geometrical cues rather than relying on the landmark cue adjacent to the target to find the target. Overall, the results indicate the designed hexagonal room game can enhance spatial cognition among all age groups of adults.

KEYWORDS: Serious game, aging, spatial cognition, landmarks, geometry

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Introduction

Serious games are designed to engage participants' interest to a task for testing some hypotheses.¹⁻⁴ Although experiments not employing gamification element also allow researchers to investigate their hypotheses,⁵⁻⁸ several studies show that engagement in the game improves participants' performance during the experiments.⁹⁻¹² These games have been used not only for education,¹³⁻¹⁵ but also for enhancing human skills such as working memory, executive function, and cognition.¹⁶⁻²³ While there are numerous numbers of studies reporting on improvement of working memory and executive functions after an intervention^{16-20,24-34} (see reviews^{35,36}), the effect of training with a serious game on spatial cognition has received relatively less attention. Nevertheless, studies suggest that spatial cognition is commonly enhanced by repeated exercises of some serious games.^{16,19,21-23,37,38} These studies employed tasks that had an independent outcome measure than what was practiced. Examples of such tasks include mental rotation^{16,37} and multi-domain task that contained navigation and memory/executive functions^{19,38} to investigate the effect of an intervention; both near and far transfers are reported. However, the process of gaining the abilities to perform better during the training program involving navigation remained unaddressed.

Investigating human spatial cognition across different age groups is crucial for a better understanding of the aging effect, particularly during learning a new task. Previous findings suggest that aging leads to a decline in spatial cognition during wayfinding and route learning tasks.^{39,40} An example is Morris Water

Maze test that trains participants (or animal subjects) to learn the location of a hidden target before probe trials; during the probe trials, the target is completely removed, and the quadrant of the environment that participants (or animal subjects) spend their time most is examined.⁴¹⁻⁴³ This test is widely used as an independent outcome measure in spatial training programs.

To address the decline associated with aging, researchers have also designed experiments to investigate individuals' navigation performance during the testing phase that the environment is manipulated. Another example is the reorientation paradigm that manipulates either geometry (eg, the shape of the environment, or the proportion of wall lengths) or feature (eg, landmarks or color of wall) to test which one plays more of an important role in recovering direction.⁴⁴⁻⁴⁷ The research outcomes of these studies commonly suggest that older adults require a greater number of training trials to learn the location of the target, and they make more mistakes during testing phases.^{39,48}

In the above-mentioned studies, the learning phase following by a control trial is to ensure that the participants have learned the task, whereas the testing phase is to address the research question. In these studies, the frequency of mistakes (errors) was investigated along with the duration and total traversed distance.^{43,49} However, the type of mistakes that participants made during the experiments was not investigated or reported. Investigating the error type may hint participants in different age groups rely on what type of cues (geometrical versus featural) more often and whether they can learn to integrate the geometry of the environment. Our previous study⁵⁰



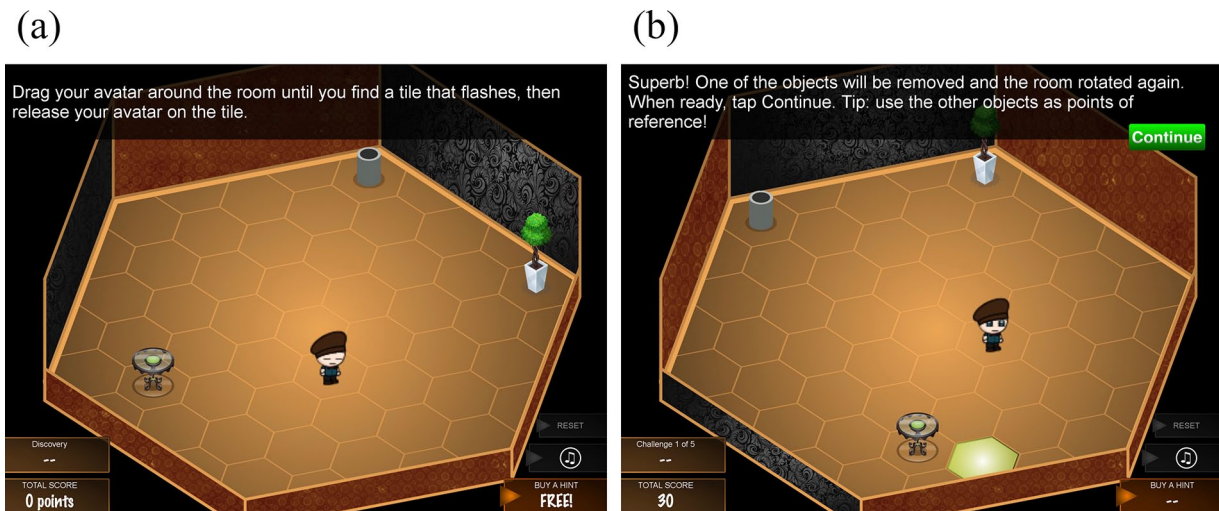


Figure 1. Screen captures of the spatial game. The environments presented in (a) and (b) are identical, except the angle of the camera. Note that the target tile is highlighted once it is found, as shown in (b).

showed that the older participants (50–86 years old) could distinguish the objects they observed during a navigational task from the objects they did not observe; though, not all of the older adults remembered the geometrical component of the environment. Another study suggested older adults preferred to use non-geometrical (ie, featural) cues⁵¹; however, which of the non-geometrical cues was preferred most, and whether the older adults could learn to integrate the geometrical cues were not clear. A study using a maze experiment showed that the participants remembered the landmarks placed at a decision-making point (eg, an intersection to make a turn) better than those placed at non-decision making points (eg, between intersection).⁵² Moreover, older adults made more errors than young adults during their search for the target's location in a landmark-less environment.⁵³

In a recent clinical trial study,⁵⁴ a series of serious games designed as an app for iPads was used to train older adults; one of the games was a 2D spatial game. This game was designed to improve people's encoding of geometrical cues rather than the landmark adjacent to a hidden target to find the target in a hexagonal shape room. The viewpoint of the subject changed in each trial and the landmarks were removed one by one. As the goal of the games were training and not assessment, there was also a hint button that could be used by users to highlight the target by flashing the tile of its location; the usage of the hint button had a penalty score but could be used as often as a user wished. In addition, if users made mistakes more than 3 times, or pressed the hint button, the trial was repeated exactly the same until they find the target without any mistake and using the hint. In this study, we used performance data of that hexagonal room spatial game and investigated 3 hypotheses: (1) the older adults remember a landmark located next to the hidden target better than other landmarks located far from the target, (2) the older adults can learn to integrate geometrical cues rather than relying solely on the landmark located next to

the hidden target by repetition and training, and (3) the young adults learn to integrate the geometrical cues rather than relying solely on the landmark next to the target, quicker than the older adults.

Methodology

In this study, we used the available data that was logged during a self-training program as part of a clinical trial⁵⁴ on the effect of self-administered cognitive brain exercises through a series of serious games. The cognitive exercises included 7 different games, out of which 1 was designed for improving spatial cognition; in this study, we used performance data of only that game. The spatial game's environment and its scoring system are described below.

The spatial game experiment

The spatial game's environment is a 2D view of a hexagonal virtual room with a tiled floor developed for iPads, in which the participants are instructed to find a hidden target tile by dragging an avatar on the screen (Figure 1). Once the avatar is dragged to the target tile in 1 move (without stopping at different tiles), the avatar goes back to the start location and the target tile is highlighted with an awarding sound as shown in Figure 1(b).

Users observe the environment from a third-person-view. The game has been designed for iPads because most older adults use iPad versus Android devices; also touch-screen feature of the game coordinates users' vision and what they want to point out enhancing user experience.⁵⁵ Thus, users would be more engaged in the game compared to employing a mouse or a keyboard in navigation with 2D desktop virtual environment, which would require familiarization.^{56–58}

The target tile is assigned to either of the 2 tiles located in front of the center of a wall. As the room contains 6 walls, there

are 12 possible tiles, and the target tile is assigned among those tiles randomly. Within the environment, there are 3 landmarks: 1 is placed adjacent to the target, and the other 2 are placed farther such that all the landmarks are distributed across the environment evenly (see Figure 1(b) as an example of landmarks locations). Tiles with a landmark and half tiles adjacent to each wall are not used as target tiles. Figures 1(a) and 1(b) show the first 2 trials of the game, in which only the viewpoint of the player has been changed by a simple clockwise rotation. After that, if the user finds the target tile without stopping at different tiles, 1 of the landmarks is removed and the room is rotated again too.

The program tracks the tile that players choose, and records it as correct or erogenous with a score (described in Scoring System section). The errors are further grouped into 3 types: Nearby Error, Nearby Corner Error, and Side Error as shown in Figure 2. To understand the error type, consider dividing the entire room into 6 equal segments by the red lines as shown in Figure 3. Assuming the target is the green tile in Figure 3, Nearby Error is when a tile in the adjacent tiles of the target's segment (ie, the blue tiles in Figure 3) is chosen. Nearby Corner Error is when either of the 4 tiles that crossed the segment containing the target and the adjacent segments (ie, the yellow tiles in Figure 3) is chosen. Side Error is when other tiles (ie, the white tiles in Figure 3) are chosen.

A session of the game consists of 6 different levels of training and 5 test levels. The order of these levels is fixed. During a session, the avatar is always located at the same tile at the beginning of each level, and the players are asked to find the target that its location is fixed across the levels. The angle and the position of the camera are randomly changed between the

levels. Thus, the absolute position of the iPad's screen does not help the players to find the target.

Training trials. At the very first training trial, players are asked to drag the avatar around the room until they find a tile that flashes, then release the avatar on the tile, and learn (encode) the location of the target tile. The environment initially at the start of the game contains 3 landmarks, 6 textured walls, and grids shown on the floor. During this first training trial, no point or penalty is assigned; thus, players can freely search for the target tile. Upon finding the target tile, a flashing light is



Figure 2. A screen capture of the hexagonal room with arrows indicating types choices: The green, blue, and yellow arrows indicate the Correct (ie, target tile), Nearby Errors, and Nearby Corner Errors, respectively. The ones without an arrow indicate Side Errors.

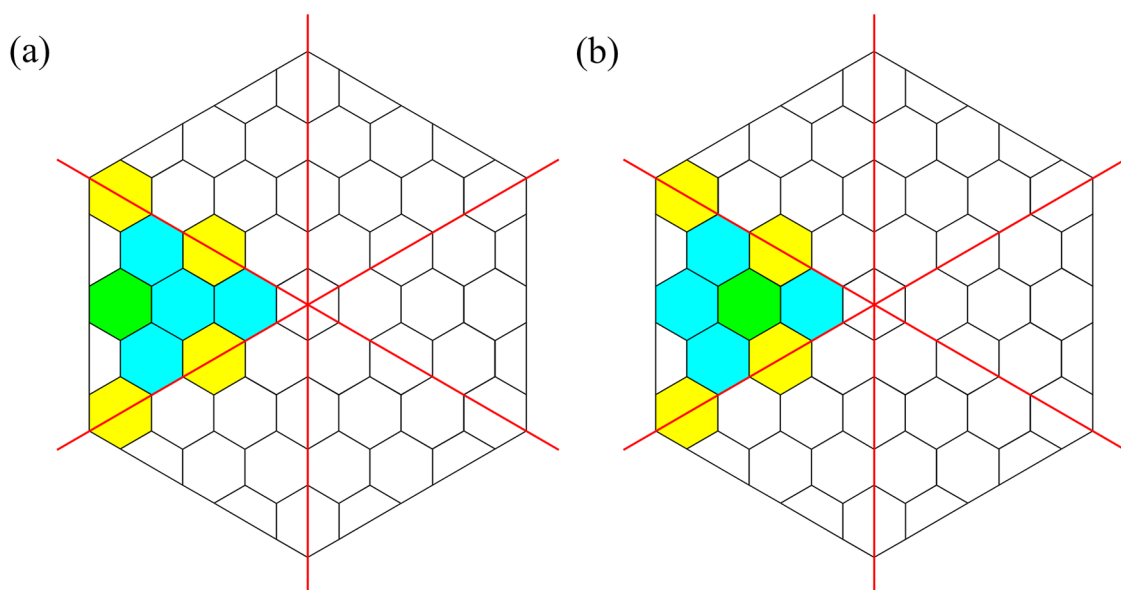


Figure 3. Top-view of our hexagonal room environment. In each of the 6 equal segments of the room, a target tile is either besides the middle of the wall (a), or 1 tile closer to the center of the room (b). Assuming the Green tile is the target tile, the 3 error types are shown by color: Nearby Error with blue, Nearby Corner Error by yellow, and Side Error by white color. The red lines are to visualize segmentations purpose, and invisible during the game.

Table 1. The difference across the test levels.

TEST LEVEL	THE NUMBER OF LANDMARKS AVAILABLE	TEXTURE OF THE WALLS	GRIDS ON THE FLOOR
Rotation only	3	Not changed	Available
Rotation and one landmark removal	2	Not changed	Available
Rotation and two landmarks removal	1	Not changed	Available
Rotation and texture removal	1	Uniformed	Available
Rotation and grids removal	1	Uniformed	Removed

displayed and rewarding audio is played. Then the trial is repeated to ensure that they encode where the target is; this repeated training trial is served as a control trial. After this very first training and control trials, when a player makes a mistake, and cannot find the target during or before the third drag, the target tile is highlighted, and the trial is repeated; then, the trial will be repeated until the player drag the avatar to the target tile with no mistake. There is no limit on the number of times that a trial will be repeated, while there is a penalty score associated with mistakes after the very first training trial. As the goal of the game is training (not assessment), the trial at the same level will be repeated until the player makes no mistake. Only after a trial with no mistake (also called a control trial) the player will be presented with the next challenge (next level trial).

Test trials. Test trials are the trails at every different level that challenge the player with a new perturbation (eg, rotation of the viewpoint, removing objects, etc.). The game has 5 levels to train players to encode the environment by integrating geometry rather than relying on the object next to the target solely; the game is designed to strengthen the integration of the geometrical cues of the environment. The first test level is only the rotation of the room, during which the environment is rotated by placing the camera at another position; in other words, only the viewpoint of the player changes. The second test level is rotation and 1 landmark removal, during which the environment is rotated, and the landmark adjacent to the target tile is removed (see a table in Figure 1(b)). The third level is rotation and 2 landmarks removal, during which the environment is rotated and 1 of the remaining 2 landmarks is removed. The fourth test level is rotation and texture removal, during which the environment is rotated, and the texture of the walls is removed; all walls of the room at this level have only 1 of the 3 textures; the choice of the texture is randomized between the sessions. The last test level is rotation and grids removal, during which the environment is rotated and the grids (the tiles) on the floor of the environment are removed. See Table 1 for a summary of changes across the test levels.

The order of the levels is fixed across the sessions; as a player proceeds in the game, an extra spatial perturbation is added for each level. The degree of the rotation (ie, $\pm 60^\circ$, $\pm 120^\circ$, and

$\pm 180^\circ$) is selected randomly between the levels. Within each level, however, the degree of the rotation is fixed when a player makes mistakes and trials are repeated. Similar to the training level, trials for each level are repeated until a player makes no mistake. In other words, when a player makes no mistake during the first trial of each level, a player receives only 1 trial and proceeds to the next test level. For each level, the target tile is highlighted when a player makes mistakes and cannot find the target during or before the third drag.

Scoring system. Upon passing a training trial with no mistake (ie, a control trial), always 5 points are allocated regardless of the frequency of incorrect choices that were made before. During each of the test levels, a total of 25 points are allocated at the beginning; players obtain a score between 5 and 25 points depending on their performance within the level. Penalty (ie, deduction of the score) for dragging the avatar to 1 of the incorrect tiles (ie, making an error) is defined as follows: Each of the Side Error, Nearby Error, and Nearby Corner Error has penalty scores of -5, -2, and -1 point(s), respectively. A trial is repeated until a player drags the avatar to the target tile with a single move (no error) during the trial. The points are calculated across the trials within a level. As an example, a score of 19 points is given for a level, when a player makes a Side Error during the first trial (-5 points), a Nearby Error (-1 point) during the second trial, and no errors during the third trial within the same level. If the score is less than 5, the players are given a minimum of 5 points at the end of the level to encourage them to proceed to the next level. During each session, with 1 training and 5 test levels, the maximum and the minimum possible scores are 130 and 30 points, respectively. The difficulty levels and scoring system were designed to train players to encode an environment with a special focus on learning to integrate the geometrical cues rather than featural cues of the environment solely in order to enhance their reorientation skills in any new environment.

Study participants

Data of 16 older adults (69.3 ± 6.4 years, 4 males) who participated in the clinical trial of the application⁵⁴ were used in this

Table 2. The number of the older participants over the sessions.

THE NUMBER OF SESSIONS	THE NUMBER OF THE OLDER PARTICIPANTS
5	16
10	14
15	12
20	10
25	8
30	7
35	6
40	5
45	5
50	5
55	4

study. The older adults played the game over a maximum period of 8 weeks up to 83 sessions (varied among the participants—see Table 2 for details) at their own pace as they were doing it at their home (part of the clinical trial design⁵⁴). In addition, 16 young individuals (27.3 ± 5.6 years, 4 males) were recruited and were asked to play the same game for 5 sessions in 1 day. The reason for a different protocol for young adults was mainly due to time constraints and difficulties in recruitment as the designed games were for older adults and would be boring for young adults. We chose 5 sessions per day as overall, young adults master games quickly.

Both groups' performances in the spatial game were analyzed. No participant was paid as compensation for participating in this study. All participants signed a consent form approved by the Biomedical Research Ethics Board of University of Manitoba prior to their participation. All study participants observed a demonstration of how the game should be played by a tutor. During collecting data, no supervision or help was provided to the participants.

Data analysis

First, we investigated whether the older adults overall learned to find the target tile as the game's level was increased gradually over the sessions; for that, we compared the average total scores of the older adults over the sessions. Next, we investigated the frequency of each error type for each test level during the first and the last 3 sessions of the older adults and compared them to the total score of each test level. As the older adults played at least 7 sessions, no overlapping session existed when the first and last 3 sessions were compared. These comparisons allowed us to highlight which error types changed under which test levels by practice over the sessions. Finally, we investigated whether the older adults learned to

encode the environment differently from the young adults by comparing the error distributions between the 2 age groups during "Rotation and one landmark removal" level of the first 5 sessions. In other words, we investigated if there were a difference between the age groups at that level. We employed repeated measure ANOVA with Greenhouse Geisser correction for the first 2 investigations and Chi-square test for the last investigation.

Results

Average scores over sessions

Figure 4 depicts the average scores of the older adults over the sessions. The higher scores indicate that the participants learned to find the target tile with a lesser frequency of errors. The maximum possible score of the game was 130. Note that the number of participants over the sessions was different because it was a self-training program and therefore participants played the game different number of sessions and days.

Among the older adult participants, we observed a gradual improvement in the scores over the first 20 sessions, and then almost plateaued. The Repeated measure ANOVA did not show a significant change of the scores ($F(3.350, 13.398) = 1.646$; $P = .224$), meaning that the overall performance did not improve significantly over sessions. However, particularly after the 15th sessions, the scores were better than those during the first several sessions. The findings suggest the older adults eventually learned to integrate the geometry of the environment, rather than relying solely on the featural cue that was placed adjacent to the target location of the environment to find the target tile.

Errors between the first and the last 3 sessions of each participant

Next, we investigated the error type during each test level over the first and last 3 sessions. Figure 5(a to c) compares the scores of the first and the last 3 sessions of the older adults. On average, all error types decreased after participating in several sessions.

For Side Error type, a two-way Repeated measure ANOVA did not reveal significant interaction term between the sessions and test levels ($F(2.493, 44.138) = 0.972$, $P = .413$), but revealed a significant main effect of the sessions ($F(1,15) = 5.371$, $P = .035$), and test levels ($F(2.240, 33.595) = 3.525$, $P = .036$). The pairwise comparisons showed a significant difference between "Rotation only" and "Rotation and one landmark removal" test levels. The older adults made Side Errors less frequently during the last 3 sessions than the first 3 sessions, and more frequently during "Rotation and one landmark removal" test level than "Rotation only" level; that was expected as there are 2 perturbations in the latter condition.

For Nearby Error type, a two-way Repeated measure ANOVA did not reveal any significant term for interaction between the sessions and test levels ($F(2.148, 32.219) = 1.69$,

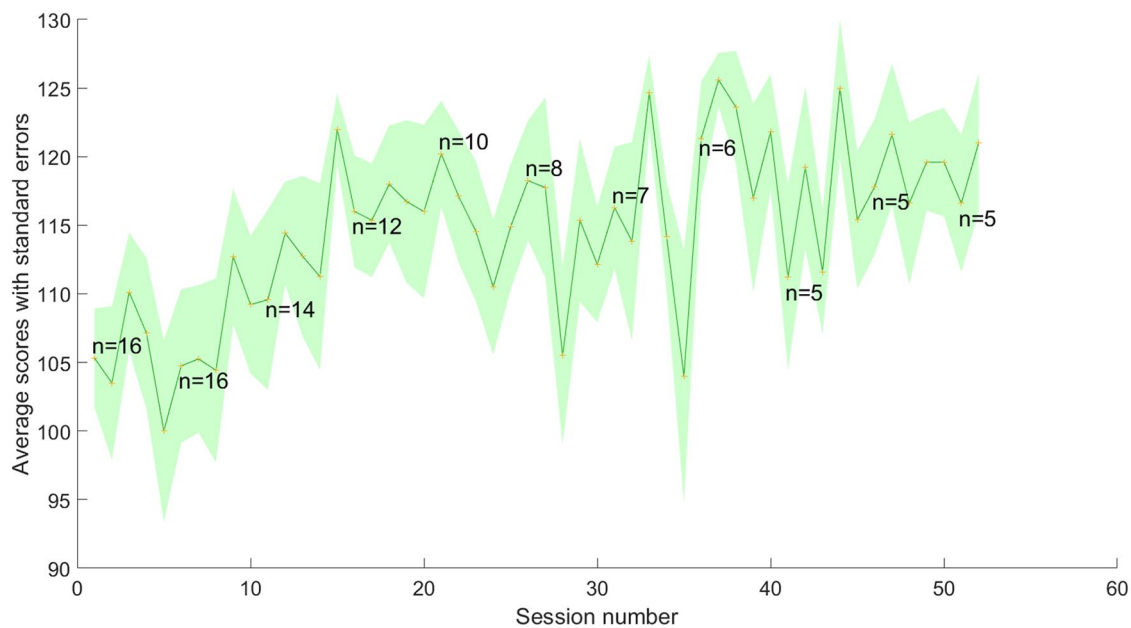


Figure 4. The average scores of the older adults. The solid line presents the average and the shaded area presents the standard error of the scores for each session. The number n presents the number of participants whose data were available at that session.

$P = .198$) and main effect (sessions: $F(1,15) = 3.637$, $P = .076$; test levels: $F(2.678, 40.176) = 1.853$, $P = .158$). The frequencies of the Nearby Errors during the first and last 3 sessions, and across different test levels did not differ statistically.

For Nearby Corner Errors, a two-way Repeated measure ANOVA did not reveal a significant interaction between the sessions and test levels ($F(2.112, 31.680) = 1.078$, $P = .355$) and the main effect of test levels ($F(2.030, 30.453) = 1.732$, $P = .194$), but revealed a significant main effect of sessions $F(1,15) = 7.857$, $P = .013$. The older adults made Nearby Corner Errors less frequently during the last 3 sessions, compared to that of the first 3 sessions.

Altogether, these results suggest that the older participants learned the correct segment by reducing the Side Errors; they also learned the location of the target within the correct segment by reducing the Nearby Corner Errors. As “Rotation and one landmark removal” was the first test level that the participants had to stop relying on the landmark to find the target within a session, we also investigated the error types distributions of this test level between the 2 age groups. We compared not only the Side Errors, but also the other error types over the first 5 sessions.

Errors during the first 5 sessions of “Rotation and one landmark removal” level between the young and older adults

Figure 6 depicts the frequencies of participants who made zero error, and each of the Side Errors, Nearby Errors, and Nearby Corner Errors during “Rotation and one landmark removal” level over the first 5 sessions. Figure 6(a) shows the frequency of the zero error (ie, the number of the participants who did not make any mistakes). By contrast, the second and third plots show the frequencies of errors of older and young adults, respectively.

As can be seen, the number of zero errors at this level increased, while the Side, Nearby, and Nearby Corner errors decreased during the sessions in both older and young adults. This suggests both age groups learned to find the target without relying on the landmark adjacent to the target in the first 5 sessions.

Chi-square tests did not reveal a significant difference in the frequencies of the errors (including zero error) between the young and older adults during the first 5 sessions ($\chi^2(3) = 0.655$, 0.064, 0.523, 0.805, and 0.816 for the first to fifth session, respectively).

For the older adults, the frequency of the Side Error reduced after the third session. It indicates that they still relied on the landmark adjacent to the target tile during the second session. Within the correct segment, they reduced their frequency of errors (ie, the Nearby and Nearby Corner Errors) during the second session. In terms of the correct response without making any mistake, they showed a slower improvement; the number of participants who did not make any mistake increased during the fourth session.

On the other hand, the young adults showed a greater frequency of errors, particularly the Side Errors during the first session. However, by the second session, the frequency of their errors reduced much more than that of the older adults. Also, it should be noted that a greater number of the young adults made a correct choice without making any mistakes during and after the second session. This indicates that the young adults improved their performances quicker than the older adults did.

Discussion

Overall, through practicing with the spatial hexagonal room game, the older adults improved their performances by learning how to find the target under different test levels over

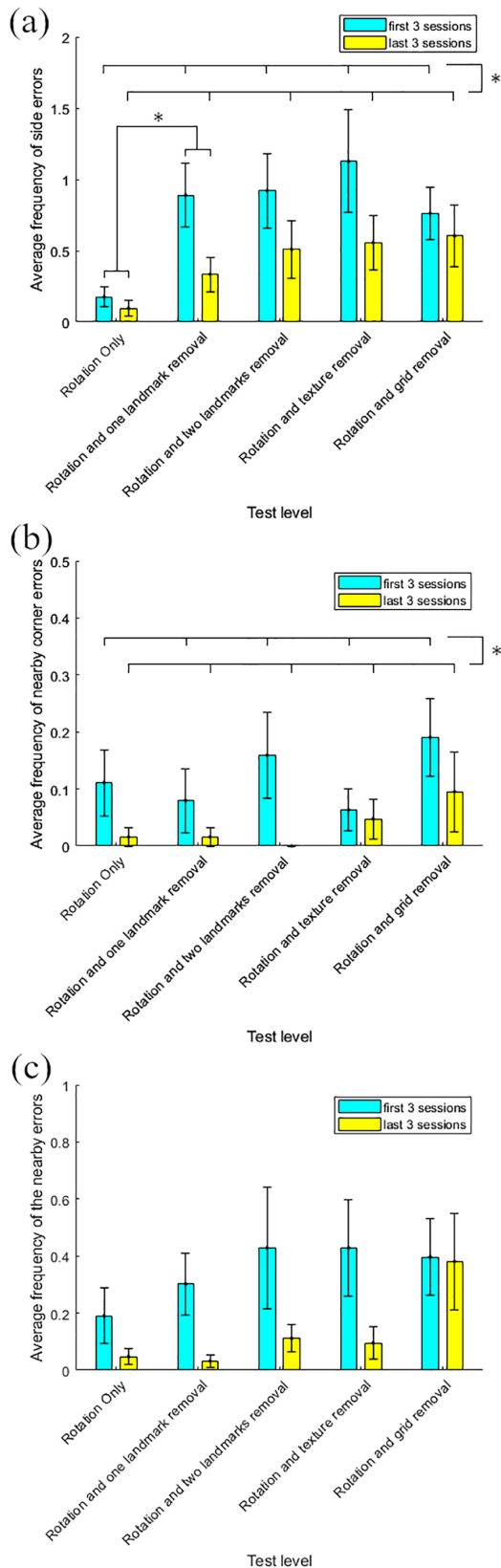


Figure 5. Comparisons of the average frequency of: (a) Side Errors (b) Nearby Errors, and (c) Nearby Corner Errors of each test level made by the older adults. The blue and yellow ones show the average frequencies during the first and the last 3 sessions respectively. The error bars represent standard errors.

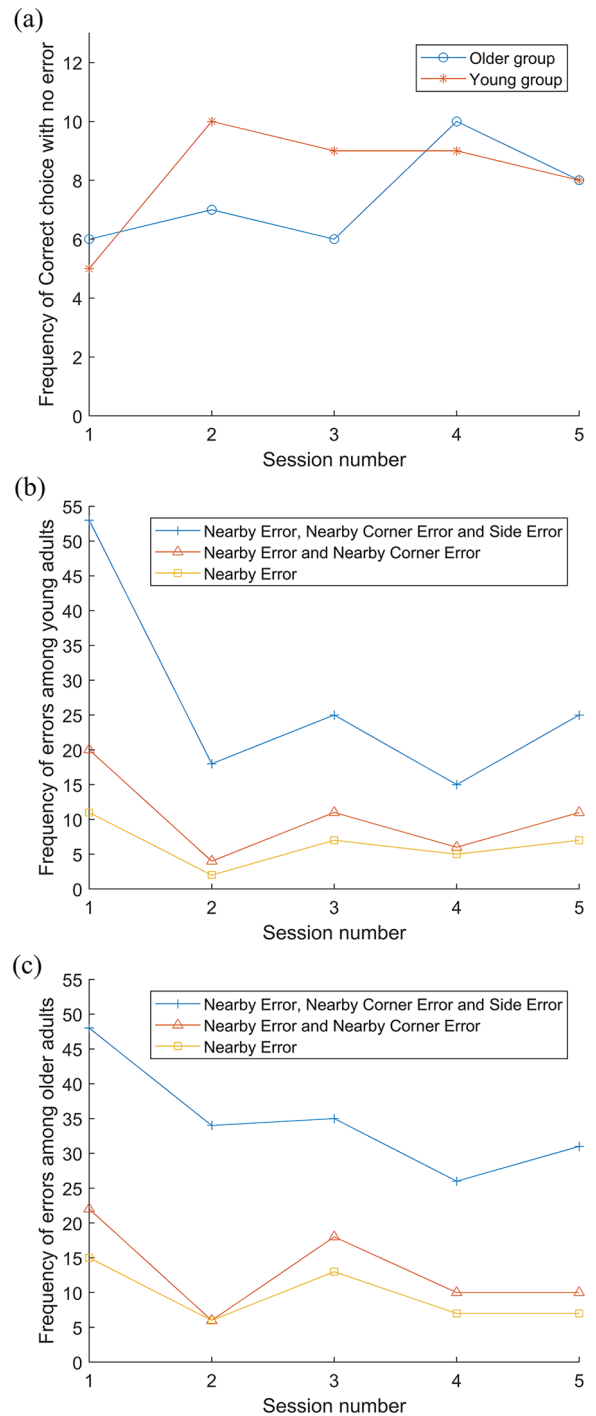


Figure 6. Frequencies of: (a) correct choice with no error, (b) Nearby Error, Nearby Corner Error, and Side Error over among the older adults and (c) those among young adults during the first 5 sessions at “Rotation and one landmark removal” level.

self-administered sessions. A major limitation of this study has been the small number of study participants; as it was self-administered and there were more games than the spatial room in their intervention, only 16 older adults completed more than 5 sessions of the spatial game. In addition, since the older adults of this study played the game at their own pace with no supervision, it is possible that at some sessions, they

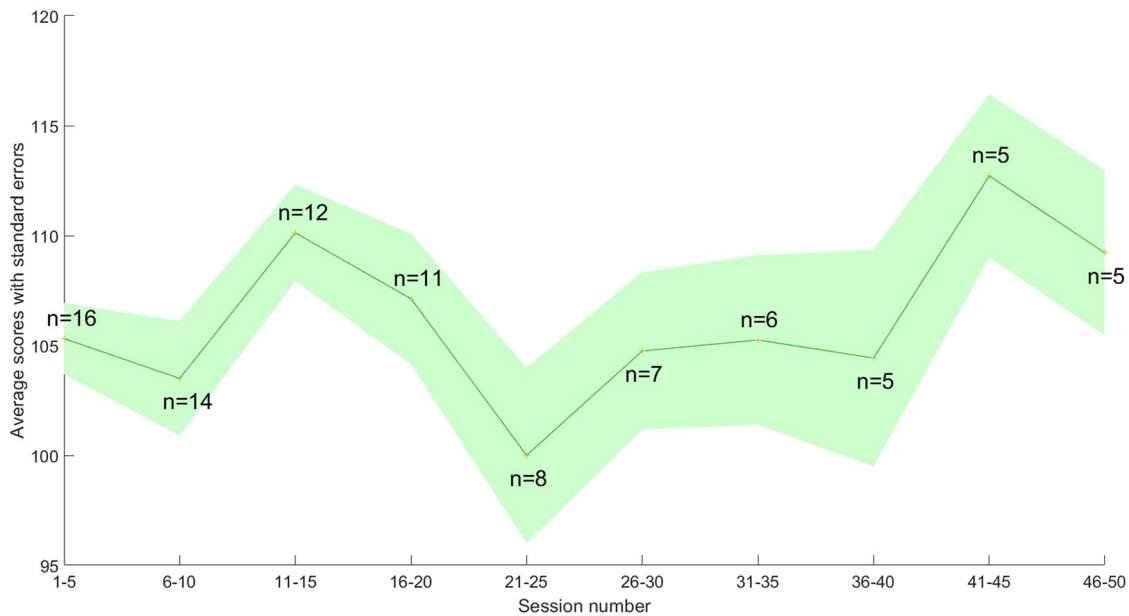


Figure 7. The average scores for each 5 sessions of the older adults. The solid line presents the average and the shaded area presents the standard error of the scores for each session. The number n presents the number of participants whose data were available at that session.

were distracted. That plus the small number of samples could be the reason for the fluctuation or a decrease in scores in some sessions, especially during the 28th and 35th sessions shown in Figure 4. It should be noted that the numbers of the participants in those 2 sessions were 8 and 6, respectively. Some participants did not play more than 15 sessions. Thus, the decline in those 2 sessions does not mean the participants declined their performances after some point. In fact, overall the average scores were consistently above 110 (out of 130 max) except in those sessions, whereas the average scores during the sessions before the 10th session were below 105. As the difficulty level of each session for each participant differed, averaging every 5 sessions can probably contrast the learning effect in a better way; Figure 7 depicts the average scores for each of the 5 sessions.

With regards to the reliance on featural cues during the first test level that the environment was simply rotated, players still could not rely solely on the landmark adjacent to the target that gives a strong clue for the location of the target tile. A player had to identify the direction of the target relative to the landmark. Therefore, this hexagonal room game, including its “Rotation only” level, may serve as a training tool for participants (older adults in particular) to integrate the geometry of the environment to find a target.

We investigated the frequency of each error type, and whether they were reduced over the sessions. Interestingly, the frequency of errors did not reduce within the “Rotation and floor grids removal” test level (last and highest test level). This suggests the participants learned to integrate the geometrical components (and not relying on landmarks only) after several sessions, but they could not learn to locate the target tile without the grids. It is possible that the users who reached this level

were relying on counting the tiles with respect to the geometry of the environment to find the target. Thus, when the grids were removed their counting cue was perturbed.

In a future study, we should address how counting the grids would help to find the target, and would change a navigation strategy. During the “Rotation and floor grids removal” test level that removes the grids on the floor, a very slow dragging of the avatar can still reveal the grids pattern because the movement of the avatar looks jumpy between the hidden tiles; thus, it is possible some used this strategy to still count and find the target. More importantly, grouping error types did not allow for the evaluation of the players’ localization performance with a finer granularity. To overcome this shortcoming, the trials of the last test level should be replaced such that the avatar moves continuously regardless of the tiles’ pattern employed during the training level to allow participants to estimate the target tile location; we can then measure Euclidian distance between the target location and the location that they think is correct.

As for the comparisons between the 2 age groups, the young adults made a greater frequency of mistakes initially. Perhaps the young adults preferred to use the landmark adjacent to the target tile to locate the target during the training level and did not pay attention to encode the environment for geometry integration; for them, it was only a game while for older adults it was training too. Also, the older adults might have a greater number of trials during the training level to encode the location of the target. It worth noting that the protocol differed between the older and young adults in terms of the number of sessions per day. The older adults played 2 sessions per day on average, whereas the young adults played 5 sessions in 1 day only. Since the location of the landmarks, combination of textures, and the relationship between the start and target tiles differed for each session, we

assume that the carryover effect for the older adults did not differ from that for the young adults. All of the older adult participants were enrolled in a training program and they desired to excel by practice. On the other hand, the young participants were confident of their spatial skills and participated in the study only for a day for a research curiosity. Thus, it can be expected that young adults were careless and faster in their initial moves in the game compared to older adults. Nevertheless, another study suggests older adults require both geometrical and featural spatial components to locate the target.⁵⁰ Therefore, before proceeding to the test levels, the young adults might have learned the featural cues (ie, landmarks) alone, whereas the older adults learned the geometrical component as well. This could explain the greater frequency of the errors during the very first trial that the participant could not rely on the landmark. After the first session, however, the young adults learned to reduce the frequency of mistakes quicker than the older adults. In other words, the young adults learned to integrate the geometry of the environment more effectively than the older adults, suggesting a greater amount of flexibility in their navigation strategy.

The presented study required participants to mentally rotate the environment to locate the target tile as the camera position changed. This task needed to combine both the feature and geometrical available cues; this is an ability required to solve mental rotation tasks and has been reported to decline by aging.^{59,60} The observations that the older adults reduced the frequency of error during the test levels suggest that they were able to learn and enhance their spatial skills; that is indeed encouraging. To address whether they improved beyond the practiced game, a future study should employ another independent mental rotation assessment, and investigate the correlation of the performances between the presented game and that mental rotation assessment.

Integration of the cues available during the training level resembles the ability tested by Morris Water Maze task, during which older adults showed a decline in their performance.^{42,43,61} Namely, it was reported that older adults learned a target's location with a longer traversed distance.⁵¹ Thus, a comparison of the performances between older and young adults during training trials should be investigated in a future study as well. Currently, the game does not log the number of times a level is repeated; it only logs the scores. Particularly during and after the second session, older adults may exhibit difficulties in finding the target with a greater number of trials required during the training level before proceeding to the test levels.

Limitations of the study

Aside from the small sample size of the study, another limitation of the current study is the duration and number of sessions. Since the protocol of the study using the spatial game was self-administered, each participant played a different number of sessions (see Table 2). On the other hand, the young adults, who were recruited later for comparison, played all 5 sessions within 1 day.

These may lead to different learning outcomes for participants of the 2 age groups. The main reason for different the different protocol among young and older participants was that the older adult data used in this study was only 1 part of a previous study (the referred clinical trial), in which they were instructed to play some of the 7 different serious games on a daily basis. In this study, we focused only on the outcomes of 1 game of those 7 games; and the young participants were recruited later to compare the outcomes. As the games were designed for cognitive training of older adults, we could not enforce the young participants to play the game for the same duration that older adults played the game; they were becoming masters of the game quickly within 5 sessions. Future studies should address these limitations by having a controlled and supervised number of sessions over a fixed period of time.

Conclusion

We demonstrated that the designed serious spatial game using a virtual hexagonal room has the potential to be used as a training tool to enhance the use of geometrical components of an environment. Although the young adults learned and adapted faster, the results show that the older adults also learned to integrate the geometrical component into target finding over 15 sessions. Overall, all participants, particularly the older adults, found the designed game easy to use, engaging and beneficial to their orientation skills in general.

Author Contributions

KK contributed to the data collection, the statistical analysis, and writing the manuscript. ZM contributed to the design of the experiment, discussing the results, and writing the manuscript.

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