Aging and the Effects of Exploratory Behavior on Spatial Memory

Kaitlin M. Varner, Stephen Dopkins, and John W. Philbeck

The George Washington University

Author Note

Kaitlin M. Varner, Department of Psychology, The George Washington University; Stephen Dopkins, Department of Psychology, The George Washington University; John W. Philbeck, Department of Psychology, The George Washington University.

Correspondence concerning this article should be addressed to Kaitlin M. Varner, Department of Psychology, The George Washington University, 2125 G St NW, Washington, DC 20052.

Email: kmvarner@gwu.edu

Abstract

The present research examined the effect of encoding from distributed viewpoints on scene recall in a group of ~~relationship between exploratory behavior and memory for the explored domain in~~ younger (18-22) and older (65-80) adults. Participants completed a visual search task, during which they were given the opportunity to examine a room in either a clockwise or counterclockwise direction. ~~flexibility in exploratory style was assessed in terms of willingness to alternate between different search patterns.~~ Subsequently, participants were tested for spatial memory of the domain in which the search task was completed. As a group, older adults demonstrated more unequal distribution of their direction decisions ~~decreased willingness to alternate~~ as well as decreased spatial memory for the domain. In addition, more equal direction decision distribution ~~higher levels of alternation~~ was ~~ere~~ associated with lower levels of accuracy in that memory. These findings suggest that, in older adults, flexibility in exploratory style may have a negative effect on memory for the domain of exploration.

Keywords: *exploratory behavior, spatial memory, alternation, flexibility*

Aging and the Effects of Exploratory Behavior on Spatial Memory

Older adults face deficits in a variety of spatial cognition tasks (Antonova et al., 2009; ~~Iachini, Ruggiero, & Ruotolo, 2009;~~ Iaria, Palermo, Committeri, & Barton, 2009; Jansen, Schmelter, & Heil, 2010; Kirasic, 1991; ~~Thomas et al., 2002; Meadmore, Dror, & Bucks, 2009;~~ Moffat & Resnick, 2002, Newman & Kaszniak, 2000; Parkin, Walter, Hunkin, 1995). Furthermore, older adults do not have the same patterns of brain activation as younger adults when completing spatial tasks (~~Antonova et al., 2009; Iachini et al., 2009;~~ Klencklen, Després, & Dufour, 2011; ~~Maillet & Rajah, 2011;~~ Meulenbroek, Petersson, Voermans, Weber, & Fernandez, 2004; Moffat, Elkins, & Resnick, 2006). Many researchers suggest that these findings are associated with a reduction in available cognitive resources (Craik & Byrd, 1982; Hasher & Zacks, 1979; Salthouse, 1996).

The Selection, Optimization, and Compensation (SOC) theory provides a framework for understanding how older adults respond to this reduction in resources (Baltes, 1997). The theory maintains that motivation is a key aspect of human development. Specifically, development is a balance between *optimization* (maximization of gains) and *compensation* (minimization of losses) and this balance shifts with age. The theory posits that younger adults have more cognitive resources available to them, and are likely to be motivated by acquisition of new skills and knowledge that may prove to be useful over their lifespans. As a result, younger adults are expected to emphasize the *optimization* end of the spectrum. On the other hand, older adults have fewer cognitive resources available to them. Additionally, the window of time in which newly acquired skills and knowledge may prove useful for future behavior is more limited as compared to younger adults, due to differences in the expected remaining lifespan. Instead it is more useful to maintain what is already in place. Thus, older adults are more motivated toward *compensation*, in which they work to counteract internal and external losses (Freund, 2006).

One field of research that may demonstrate different developmental motivation in older adults is the exploration of spatial domains. Spatial exploration is an important factor in spatial cognition; it is necessary to achieve short- term goals, such as completion of a search. It is also essential for long-term goals. If an organism does not explore, it is unlikely to acquire knowledge that is necessary for survival, such as the knowledge of the layout of its native domain. At the same time, if considered through the lens of SOC theory, older adults may limit spatial exploration to what is necessary and sufficient for a particular task, rather than engaging in more generalized exploration of a new space.

If older adults engage in compensatory behavior and limit spatial exploration, this could affect formation of incidental memories for spatial domains. Compensatory behavior during the search task could have two possible effects on incidental spatial memory: 1) to the degree that compensatory behavior increases availability of cognitive resources, it may allow for better spatial memory, or 2) to the degree that compensatory behavior produces less varied or impoverished encoding, it may result in poorer spatial memory. The present research examines whether or not older adults are more likely than younger adults to engage in compensatory behavior during an exploration task, and how this compensatory behavior affects incidental spatial memory for the domain of the exploration task. This study consisted of two parts. First, older and younger adults performed a visual search task. After completing this portion of the experiment, participants were tested on their incidental memory for the domain of the search task. We hypothesized that older adults would show compensatory behavior in the search task. Additionally, we hypothesized that behavior during the search task would affect incidental

Comment [s1]: more

memory for the domain of the search task, and sought to determine whether the effect of compensatory behavior on incidental memory for the search task domain was positive or negative. For the first portion of the experiment, it was important to find a way to index compensatory behavior in the visual search task. To this end, this study used a human analog of the rodent spontaneous alternation task. Spontaneous alternation is a stereotypic behavior frequently examined in rodents as a measure of both exploratory behavior and cognitive functions such as working memory and decision-making (Dember & Fowler, 1958). Spontaneous alternation is measured inside a maze with multiple arms. The animal is given an opportunity to explore the maze, and it will eventually enter one of the arms. Once the animal has examined the end of a particular arm, an experimenter removes the animal from the maze, and replaces it at the starting point. On the subsequent trial, young, healthy rodents typically will examine a different arm from the one they previously examined. This pattern will continue on all subsequent trials, with rodents exploring an arm of the maze that is different from the one they most recently entered (Dember & Fowler, 1958). Such spontaneous alternation is a well - documented pattern in young, healthy rodents, and is frequently used to examine the psychological impact of pharmacological interventions (Hughes, 2004). One of the major explanations for this behavior is exploratory drive. The animal is intrigued by novel stimuli, and subsequently explores alternating arms based on recent novelty or lack of it (Dember and Fowler, 1958; Lalonde & Badescu, 1995).

Studies of a variety of aged mice and rat strains have shown decreased rates of spontaneous alternation (Lalonde, 2002). One study examining behavior of mice at 3, 11, 17, and 22 months showed that all three older age groups demonstrated a significantly lower rate of alternation in a Y-maze than the youngest age group. The three older groups were not

Comment [s2]: yeah I think you're right; an added plus - if we take this out that will shorten the intro

Comment [KV3]: Maybe this should all be cut? It seemed like this confused reviewer 2 in terms of what our experimental set up was (and why wasn't it more equivalent to this)? I could just use the stuff about older mice and note that animal studies support the idea that exploration of a novel environment may be limited in older mice.

statistically separable from one another (Lamberty & Gower, 1992). Another study demonstrated decreased spontaneous alternation rates as well as an overall decrease in exploration of novel objects and locations in aged rats, although this decrease was modulated by the complexity of the environment (Willig et al., 1987).

We assessed an analog of spontaneous alternation as part of our visual search task. In a spontaneous alternation task, animals are required to choose from among the arms of a maze in order to complete an exploration task. In the present experiment, human participants were required to choose the direction of search from two available alternatives (clockwise and counterclockwise) in order to complete a search task. Participants searched for a target object while seated on a chair mounted on a motorized turntable, with their view of the experimental room bound by two curtains. ~~To begin the experiment, participants were placed inside an experimental chamber, formed by a curtain on a circular track. At the center of the circle was a chair mounted on a motorized turntable, upon which participants were asked to sit.~~ On each trial of the search task, participants were asked to locate a target hidden in the room outside the experimental curtain. ~~To carry out each of these trials, participants completed a series of *turns* that provided them with views of the room outside the curtain. On each *turn*, the chair rotated participants to face a certain direction in the experimental chamber. Participants were then exposed to a particular sector of the experimental room by pulling back the experimental chamber curtain. Participants were asked to visually search the available sector for the target object. After the search was complete, the curtain was drawn again, and the participant began a new turn.~~ After searching an available view of the room, participants directed the chair ~~movement of the chair~~ to their next view by choosing whether to rotate in a clockwise or counterclockwise direction. ~~Participants' choice of clockwise or counterclockwise rotation~~

Comment [s4]: This paragraph will have to be re-framed if we take out the stuff on alternation.

Comment [KV5]: So, reviewer 2 gives kind of conflicting comments, in one it says intro is too long and some of this info should be in methods, but then in the immediately succeeding comment it says that the predictions are hard to understand bc the method is not fully explained? So maybe we want to move some of this to Methods? I tried to be a bit more concise but maybe it will need further work.

~~determined their exposure to the experimental room. If participants chose to rotate clockwise, there was a particular structure of sectors associated with that decision, and the sectors to which participants were exposed were chosen from that structure by a pseudorandom process of sampling without replacement. If participants chose counterclockwise, there was a separate structure of sectors available to them (Figure 1). These sector structures will be elaborated on further in Methods, but overall the structures were arranged such that, for the purposes of the search task, it was never disadvantageous for participants to alternate.~~ Participants' distribution of direction choices(i.e. how often they selected either ~~degree of *alternation* between~~ clockwise and counterclockwise~~-~~) was~~rotations was~~ taken as an index of *flexibility* in exploratory behavior. We hypothesized that older adults' tendency toward compensatory behavior would be reflected in less even distribution between the viewpoints ~~a low rate of alternation~~ (and thus a low degree of exploratory flexibility) relative to younger adults.

Across the successive views provided during participants' search for the target object, participants were exposed to the entire room that surrounded the experimental chamber, and thus were provided the opportunity to learn the layout of the objects in the room. Participants were not directed to attempt to remember the experimental room, in an effort to avoid alteration of participants' normal exploratory behavior. Subsequently, participants were moved to a new location and asked to complete a spatial memory task, to measure how many of the object locations in the experimental room they had incidentally learned and remembered. Similar to previous spatial location memory paradigms (Cherry & Park, 1993; Thomas et al. 2002), participants were given a sheet with an outline indicating the walls of the room, along with two-dimensional representations of the major objects in the room. Participants were asked to place the objects into their correct locations. Distance between participants' responses and the actual

Comment [KV6]: I didn't use disparity of viewpoint bc the reviewer for the other MS noted this may not be appropriate…but I didn't think their suggestion "distribution of viewpoint" works as well for this paper bc the viewpoints were not as restricted.

Comment [s7]: Yeah I think we need something a little different

Comment [s8]: If we're going to move some of the detail of the method into the method section, we have to get across the crucial conceptual aspects of the method. What's currently here doesn't do that; it doesn't give any sense of why participants would alternate or what was at stake in alternating. Maybe we should try making the key points here in the abstract and then giving concrete details in the method. I think some of the crucial points are that subjects had on each trial to find a target in a spatial domain; that they were provided with a series of windows onto the domain; that subjects were allowed to select from two different sets of windows that carved up the domain in different ways; that the same window was never opened twice within a given set; that the windows in each set differed in size; that the boundaries of the windows in the two sets differed; that the advantage of switching between sets was that subjects were more likely to be given a large window; that the disadvantage of switching between sets was that subjects might see parts of the domain under one set that they had already seen under the other set; that the advantages and disadvantages of switching were balanced locations of the objects was used as a measure of how well participants remembered the experimental room.

Previous research on spatial memory across the lifespan indicates that older participants will likely have less accurate incidental memory for the spatial domain than younger participants (Antonova et al., 2009; Caine et al., 2011; Iachini et al., 2009; Iaria et al., 2009; Kirasic, 1991; Thomas et al., 2002; ~~Light & Zelinski, 1983;~~ Moffat & Resnick, 2002, Newman & Kaszniak, 2000~~, Waddell & Rogoff, 1987~~). In the present research, it is predicted that participants' distribution of direction choices ~~level of alternation~~ during the search task (and by extension, their flexibility in exploratory style), will have implications for performance in the spatial memory task. Two specific effects of less distribution between direction decisions ~~lower levels of alternation~~ are explored in this research. Less distribution between the two available direction choices ~~Lower levels of alternation~~ may result in higher levels of memory to the extent that there is competition for resources between exploratory and memory encoding processes. For example, participants will need to combine information from each sector in order to understand the locations of the objects relative to one another. This may be a less cognitively complex task when the room is experienced in one direction, whereas alternating between directions may result in some form of interference. On the other hand, less distribution between direction choices ~~lower levels of alternation~~ may be associated with lower levels of spatial memory to the degree that alternating provides participants with exposure to a greater *variety* of views of the experimental room. Although participants' overall amount of exposure to the experimental room will be equated, the frequency of switches between the two available directions ~~alternation~~ may affect encoding variability, which can significantly improve memory (Eysenck, 1979). Thus, if older participants avoid distributing their direction choices~~alternating~~, they may decrease their encoding variability and significantly limit their ability to recreate the experimental room.

Methods

Participants

28 younger participants were undergraduate students at The George Washington University, and received course credit for their participation. The age range was 18-22 years. 19 older participants were recruited from the community through an advertisement in a local news flyer and were paid $20 apiece for their participation. The age range was 65- 80 years. All participants were required to achieve a score of 10 on a Landolt ring acuity test, which is equivalent to 20/20 acuity. Older participants were required to achieve a score of 25 out of 30 on the Mini Mental State Examination (Folstein, Folstein & McHugh, 1975) (Range=26-30, Mean=29.87).

Apparatus

The 6x6m experimental room contained the experimental chamber, which was roughly cylindrical and 3m in diameter. The chamber was surrounded by a group of objects (several chairs, three tables, a large computer set-up, a cabinet, and a group of wooden boards). The target object (a 3” x 3” x 3” red cube), which participants were asked to locate, was hidden among the objects outside of the experimental chamber. The target was hidden in a different location for each trial (Figure 1).

Participants were seated in a common wooden chair that was affixed to the top of a rotation platform that added approximately 7” to the height of the chair. Chair motion was remotely controlled using a computer located outside the experimental chamber. All rotations

Comment [KV9]: Both reviewers asked about the inequality in N between older/younger subjects. Actually, it’s only 24 younger subjects (who have both complete alternation & error data and are not controls), and 18 older subjects (with the one subject mentioned here not having any error data bc they refused to place any objects). I still am not sure there’s a good reason for that 6 person difference, other than the study being so difficult to run , and we actually did see some issues with homoscedasticity due to the different size groups. I’m not totally sure what to do about all that…but something to consider.

Comment [s10]: I think we should equate the N’s in the two groups. I guess the first thing to try is excluding enough of the young to get equal N’s.

Comment [s11]: I think that, if we take out all the information that we previously had in the intro about the setup of the experiment, and put that information into the method section, it would be better to present the information as early as possible in the method section because knowing the setup makes it easier to make sense of the other details (e.g. the details of the apparatus). So I would advocate moving the information that was previously in the intro into the design section and putting that section before the apparatus and procedure sections.

Comment [KV12]: Added a little schematic of the room, I thought maybe this would help. I have a picture of the chair I could add too?

Also Reviewer 2 noted that Figure 2 was unhelpful. I’m still trying to think of a way to improve.

Comment [s13]: I think one main problem with Figure 2 is that none of the sectors seems larger than any other used in the experiment were capped at a maximum acceleration of 90^{O}/s/s and a maximum velocity of 90^{O}/s –these parameters allow for movements that are well above the vestibular threshold. For a more in-depth description for the apparatus and velocity profiles used here please see our previous work (Arthur et al., 2007).

For the recall task, participants were given a large sheet of paper, which contained a to-scale representation of the experimental room and icons representing the major objects from the previous room. The bases of these icons were to-scale.

Design

As mentioned previously, participants were seated in an experimental chamber formed by a black curtain (Figure 1). Participants were informed they were going to complete a series of trials, with each trial ending once they had located a target object. To carry out each of these trials, participants completed a series of *turns* that provided them with views of the room outside the curtain. On each *turn*, participants selected a direction for the chair to rotate in, and subsequently they were rotated to face a certain direction in the experimental chamber. Participants were then exposed to a particular sector of the experimental room by pulling back the experimental chamber curtain. Participants were asked to visually search the available sector for the target object. After the search was complete, the curtain was drawn again, and the participants began a new turn.

The boundaries of the sectors were different depending on whether the participant chose to make a clockwise or counterclockwise rotation (Figure 1). A MATLAB program was used to determine which sector to present on each turn. Using the participant's directional decision as input, the program sampled without replacement the sectors that were available to a given participant on each trial. This was done in such a way as to equate as nearly as possible the

Comment [s14]: I guess if we want to avoid trouble we should just copy that info and not refer the reader

Comment [KV15]: Reviewer 2 noted this (and the discussion of the simulation) was very confusing. I realize this person had a lot of difficult understanding in general, but I added a little for clarity in the design section.

Comment [s16]: I don't think this is all the info from the intro. Why don't we try copying al that info here and giving a more abstract summary in the intro.

Comment [s17]: I guess we should give in text more info on the number of trials and turns, in response to reviewer 2 complaint. (I know we give this info in a table but I guess we should put in it the text).

number of times that different sectors of the room were visible. For this purpose, the experimental chamber was divided into small units, known as "slices," such that each sector was a combination of slices. There was typically some remaining inequality at the end of the preset trials due to subject's directional decisions, so a final trial was done after subjects had completed the preset trials in order to ensure exposure to the different slices was equated. In this trial, participants could experience up to 10 turns, with the specific number being determined by the program based on their decisions during the previous trials. The target was always visible on only the last turn of each trial, with the exception of the final trial, in which the target never appeared. Table 1 provides a summary of the number of trials and the number of turns in each trial in for a sample participant. [1]

The views of the room that participants were exposed to were always floor to ceiling. The curtains were opened to provide a view that ranged from a minimum of x degrees to a maximum of x degrees. Depending on the available sector, participants could often see both corners of the room and the doorway through which they entered the experimental room. This information combined with the knowledge of how far they had rotated from the starting point allowed the participants to orient themselves in both the search task and subsequent reconstruction task.

Comment [KV18]: Need to dig up these numbers somewhere.

Comment [s19]: Is this in response to the complaint of R2 that older subjects may not have been as able as younger subjects to assess their degree of rotation in the chair? If so I don't know that this really deals with the complaint. We could run a very short follow-up study to verify that older subjects could do this as well as younger sujects.

Procedure

Participants were brought into the chamber while blindfolded and seated in the rotational chair, facing a clearly labeled starting point, which we considered to be 0º. Participants were told that they would complete a series of trials, each of which would be composed of a series of turns. Participants were told that their goal on each trial was to find a target object hidden outside the curtain, that each turn would provide an opportunity to search for the target and that once the target was located, a trial would be complete. In order to prevent uncontrolled views of the room, participants were not given any practice trials.

On each turn, participants were asked to decide if they would like to turn clockwise or counterclockwise. They were instructed to remain blindfolded while the chair was rotating and the curtain was being moved to prevent uncontrolled glimpses of the room. When the rotation was complete and the curtain was opened, participants were asked to remove the blindfold and search the given sector of the room for the target object. Participants made a determination on the presence or absence of the target object. This completed one turn. Before beginning a new turn, participants were rotated back to 0º, their initial position at the start of the experiment.

Comment [s20]: We need to say something more here about what we told subjects regarding the advantages and disadvantages of switching or not switching between directions of rotation

Once all trials were completed, within approximately five minutes the participants were led out of the experimental chamber while blindfolded and brought to a separate room where they were asked to complete a test of their incidental learning of the experimental room. They were provided with the to-scale model of the room, as well as the icons representing objects from the experimental chamber. The model was labeled with four lines representing the walls of the experimental room, the doorway they entered the room through, and a marker, which indicated where the chair they were sitting in was placed. An experimenter instructed participants to place as many of the objects as they could remember back into the model, and indicated to them the direction the chair was facing when testing began to help orient them. All objects presented were in the experimental room, we did not present participants with any distractor objects.

Results

In order to construct an index of the degree to which participants distributed their direction choices~~alternated~~, participants' decisions to turn clockwise were recorded as 1, and

Comment [s21]: I wonder if we should use a different word than direction, as direction doesn't really get at the key thing they were choosing counterclockwise decisions were recorded as 2. These direction ~~alternation~~ choices ~~decisions~~ were then averaged and the absolute value of the difference between each participant's average and 1.5 was calculated. This was done in order to collapse across turning directions, such that the absolute difference for each participant represented the participant's distance from equal ~~"perfect"~~ distribution~~alternation~~, regardless of the participant's specific clockwise and counterclockwise choices. That is, if a participant always chose to rotate clockwise or counterclockwise, the participant's average direction choice ~~alternation decision~~ would be 1 or 2 and the participant's absolute difference would be 0.5. If a participant rotated clockwise exactly half the time and counterclockwise the other half, the participant's average direction choice ~~alternation decision~~ would be a 1.5, and the associated absolute difference would be 0. The direction choice ~~alternation~~ index for a given participant was then .5 minus the participant's absolute difference. Notice that, with this adjustment, the direction choice~~alternation~~ index increased as the distribution of direction choices becomes more equal (i.e., the participant chose clockwise and counterclockwise at similar frequencies)~~with increases in the degree of alternation~~. Using a generalized linear model analysis, the relationship between age group, sector condition, and the direction choice ~~alternation~~ index was examined. The generalized linear model was used because the range for the direction choice index ~~alternation index~~ was restricted between 0 and .5 and because the variance in the direction choice ~~alternation~~ index was not the same in the old and the young. The direction choice~~alternation~~ index was significantly smaller in older adults (Mean=.28(SE=.05)) than in younger adults (Mean=.4(SE=.02)) (β=0.0595, χ^2= 6.87, p=.0087), indicating that older adults were more likely to unequally distribute their direction choices, such that they chose one direction over the other repeatedly, rather than switching from one direction to another.

Performance on the visual search task was nearly perfect, with very few subjects ever missing the target, therefore no statistical analysis was run on this data. To examine each participant's error on the spatial memory task, an error score was computed for each object. This was achieved by measuring the x and y coordinates of the overhead map view of the lab for each of the four corners of the base. After determining these values, a centroid was calculated for each object's coordinates. That is, an average of the x and y coordinates was taken for each object. These averages were then compared with the objects' true coordinates in the experimental room (transformed for scale). Using a generalized linear model analysis, the relationship was examined between age and total error in locating objects during the spatial memory task. Total location error (using the scale of the experimental room) was greater in older adults (Mean=2.75m(SE=0.21m)) than younger adults (Mean=1.91m(SE=0.2m); β=17.3525, χ^2= 8.34, p=.0039).

Comment [s22]: I think we should try some other analyses of error in spatial memory. We could head off criticisms like that of reviewer 1 if we could find at least two that showed the same effect.

Finally, the relationship between distribution of direction choices~~alternation~~ and performance on the spatial memory task was considered. Separate generalized linear model analyses were run on each age group to determine if participants' direction choice ~~alternation~~ index significantly predicted accuracy on the spatial memory task. Separate analyses were run since an interaction between the effects of age group and direction choice ~~alternation~~ was found to be significant (β=.54, χ^2=6.53, p=.01). In older adults, it was found that error in locating the objects on the spatial memory task increased as a function of participants' direction choice ~~alternation~~ index (β=96.1596, χ^2=6.7, p=.0096).This relationship indicates that to the degree that older participants' equally distributed their direction choices ~~alternate more~~, their accuracy on the reconstruction task decreased. In younger adults, error in locating the objects on the spatial memory task was not significantly affected by their direction choice index ~~alternation index~~ (β=53.3992, χ^2=0.54, p=.4608)

Discussion

The present study was designed to answer two key questions: (1) whether older adults engage in more compensatory behavior than younger adults during an exploration task and 2) how this compensatory behavior affects incidental spatial memory for the domain of the exploration task. Specifically, we asked whether older adults demonstrate a less flexible style of exploration than younger adults when directing a visual search task, as indexed by their distribution of direction choices ~~level of alternation~~ and (2) whether there is an association between distribution of direction choices ~~level of alternation~~ and incidental spatial memory for the domain in which the search task is performed. To answer these questions, participants completed a visual search task, followed by an incidental spatial memory task. Participants' distribution of direction choices ~~willingness to alternate~~ during the search task was taken as an index of flexibility in exploratory style. Subsequently, the association between participants' distribution of direction choices ~~willingness to alternate~~ and their performance in the spatial memory task was examined.

Results from the visual search task show that older adults tend unequally distribute their decision choices, and preferentially select one direction over the other more often ~~indicate that older adults alternate significantly less~~ than younger adults. To the extent that th~~is~~e distribution of decision choices ~~level of alternation~~ reflects flexibility in exploratory behavior, this finding shows that flexibility in exploratory behavior is reduced in older adults when compared against younger adults. SOC theory provides a way to frame these results. On this view, older adults are motivated to minimize expenditure of resources. Exploration of a new domain is likely to be

Comment [s23]: Maybe flexible is not the best word; something like venturesome? (although not that word in particular) seen as having limited usefulness for future tasks, which may drive older adults to limit resources allocated towards the search task. On the other hand, since younger adults demonstrate are more likely to equally distribute their decision choices~~higher levels of alternation~~, they may instead be motivated by optimization and thus work to maximize potential gains by utilizing a strategy that allows them to gain as much knowledge as possible on the task at hand. Although our data do not speak to this issue, these differences may occur at an unconscious level.

Comment [s24]: I think we need to qualify more our interpretation of the results in terms of SOC theory

As predicted based on previous research (Antonova et al., 2009; Caine et al., 2011; Cherry & Park, 1993; Iachini et al., 2009; Iaria et al., 2009; Kirasic, 1991; Thomas et al., 2002; ~~Light & Zelinski, 1983;~~ Moffat & Resnick, 2002, Newman & Kaszniak, 2000~~, Waddell & Rogoff, 1987~~), older adults demonstrated poorer spatial memory than younger participants. The relationship between unequal distribution of decision choices ~~reduced alternation~~ and memory for the spatial domain was also examined. Older adults demonstrated reduced accuracy as their distribution of direction choices became more equal ~~alternation~~ . ~~index increased.~~ That is, older adults show improved performance on the memory task when they~~-~~ engaged in less equal distribution of their decision choices ~~alternated less~~. This finding can also be understood through the lens of SOC theory. In preferentially selecting one direction~~limiting alternation~~, older adults engaged in compensatory behavior. The effect of compensatory behavior was positive, such that it increased the availability of cognitive resources, and allowed for better spatial memory. The fact that the relationship is present in the older but not the younger subjects may reflect the fact that resources are limited in older but not younger subjects.

In light of the effects of alternation on performance in the memory test, an unequal distribution of decision choices ~~low level of alternation~~ would have been reasonable had older participants known they were going to be tested. Since older adults were unaware their spatial memory would be tested, their preference for one direction ~~low level of alternation~~ may have reflected an unconscious attempt to form a better memory of the domain, simply for the purposes of the search task. Alternatively, their unequal distribution of decision choices ~~low level of alternation~~ may have reflected a general motivation for conserving resources, which was not strategically tied to any particular task. In the present case, this conservation of resources paid off unexpectedly in terms of performance in the spatial memory test. In general, such a conservation of resources may pay off in terms of making resources available for unexpected needs. In sum, this particular research demonstrates in terms of one concrete task why older adults may be motivated, perhaps unconsciously, to conserve resources, and how this conservation of resources can have an effect on incidental spatial memory encoding.

Previous research has found that older adults demonstrate significantly decreased performance on a variety of spatial cognition tasks (Antonova et al., 2009; Iachini et al., 2009; Iaria et al., 2009; Kirasic, 1991; Thomas et al., 2002; Meadmore et al., 2009; Moffat et al., 2006; Moffat et al., 2001; Moffat & Resnick, 2002, Newman & Kaszniak, 2000) and older adults often show different neural activation when completing spatial tasks (Klencklen et al., 2011; Maillet & Rajah, 2011) Some writers have concluded that older adults' reduced performance on spatial tasks may be indicative of loss of neural structures. In the current study, older adults do show an overall decrease in performance, as previous research would predict. However, this study demonstrates a need for deeper examination of reduced performance on spatial tasks, particularly tasks involving exploration and spatial memory. If older adults are motivated by compensation and prefer to conserve resources, they may (consciously or unconsciously) limit exploratory behavior, which can then directly influence the completeness or detail of their spatial memories. A more complete understanding of the relationship between compensatory-based motivations, exploratory behavior, and spatial memory could also account for differences at a neural level that have been seen in a variety of spatial cognition studies (Antonova et al., 2009; Iachini et al., 2009; Klencklen et al., 2011; Maillet & Rajah, 2011; Meulenbroek et al., 2004; Moffat et al., 2006), as compensation behaviors may recruit different brain areas than optimization behaviors used by younger adults. In future studies, it will be important to account for potential differences in motivation and to create tasks that allow older adults to demonstrate ways in which they compensate in order to effectively use limited resources.

Word Count: 4395

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Notes

1. The fact that the sector boundaries were different for clockwise and counter-clockwise rotation meant that alternation came at a cost, since alternation could result in redundant views of the room; that is, alternation could result in participants seeing again part of the room that they had already seen, and that they had already seen did not contain the target. At the same time, because the sectors were unequal in size, alternation was beneficial in that it increased the likelihood of encountering a large sector during the search task, which would have a relatively high likelihood of containing the target. Simulations were conducted verifying that the benefit of unequal sector sizes ultimately outweighed the cost of redundant views of the chamber. A given simulation consisted of 1000 runs, in each of which the participant completed as many trials as was necessary to see all of the slices in the chamber. For alternating participants, the direction of rotation was randomly determined on each trial. For non-alternating participants, the direction of rotation was constant across trials. After determining the direction of rotation for a given trial, the participant was exposed to a sector chosen at random from those available given the participant's direction of rotation. Each simulation produced an average number of trials needed to see all slices of the chamber. The average number of trials needed to see all slices of the chamber was essentially equivalent for alternating and non-alternating participants.

Comment [KV25]: One reviewer suggested actually including data that shows the equivalence statistically, I don't have that data. Not sure what your thoughts are on it.

Comment [s26]: Yes I'll dig up more detail on that; also I think we should move the general points about advantages and disadvantages to the intro were we go over the design in the abstract; maybe it will be easier to understand when presented in the abstract.

Table 1

Sample participant's trials with the associated number of turns in each trial

Trial Number	Number of Turns
1*	5
2*	4
3*	5
4*	3
5*	5
6	Between 1-10

Note. A (*) indicates that on the final turn of that trial, the target object was present. On the final trial, the target object was not present and the participant completed any number of turns up until 10 to ensure all possible sectors of the room were seen an equal number of times.

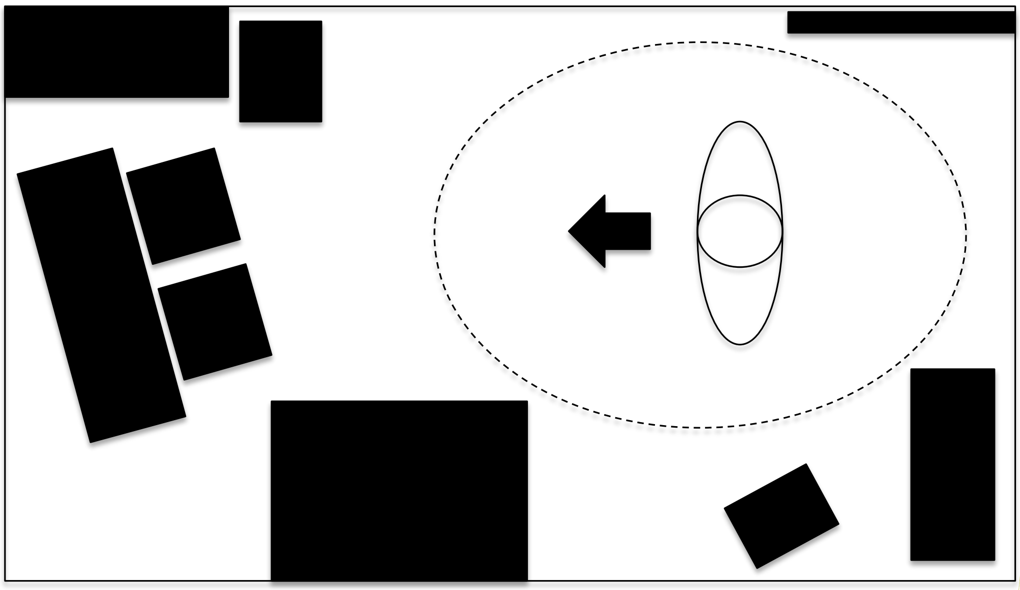

Figure 1. Bird's eye view of the experimental room layout. The dotted line represents the experimental chamber formed by a black curtain. To begin each turn, subjects were returned to zero, which was in the direction indicated by the arrow. Black rectangles indicate the furniture in the room that participants were tested on the location of during the reconstruction task.

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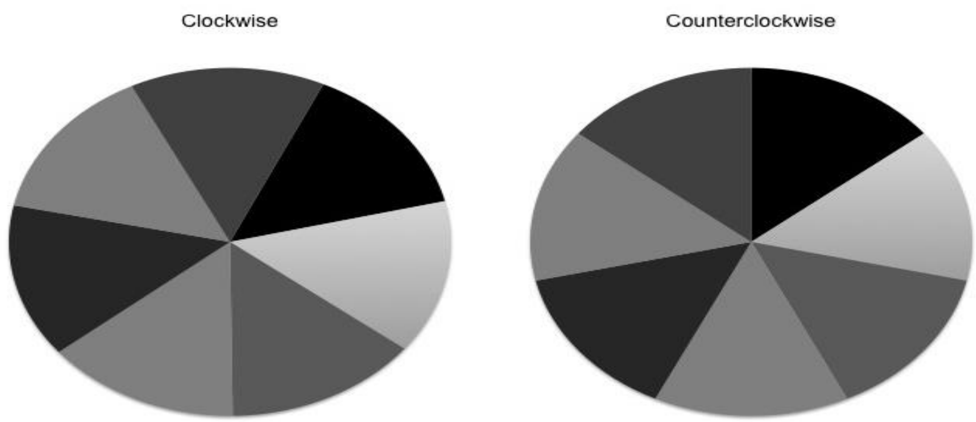

Figure 2~~1~~. Sector structures associated with clockwise and counterclockwise decisions.

Comment [s27]: This can’t be the one with the unequal sector sizes.