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PLACE LEARNING IN REAL AND COMPUTER-GENERATED SPACE:

PERFORMANCE OF YOUNGER AND OLDER ADULTS

by

Holly Elizabeth Laurance

_____

A Thesis Submitted to the Faculty of the

DEPARTMENT OF PSYCHOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF ARTS

In the Graduate College

THE UNIVERSITY OF ARIZONA

1997

UMI Number: 1387969

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Acknowledgements

I would like to thank my committee members, W. Jake Jacobs, Lynn Nadel, and Alfred Kaszniak, for their support and understanding, especially during the 30 days of chaos. I also give my heart-felt thanks to Kevin G.F.(!) Thomas for giving me words when I had none left to give. A special thanks to Jake and Kevin for their major contributions to ideas, and endless hours of editing.

I would also like to thank the many individuals involved who helped with all the boring stuff and allowed me a little sanity: Brady Butterfield, Melody Vaughan, and Heidi Goldsmith. Also, I give my thanks to Courtney Baker and Thomas Brunner who damaged knee caps to sort ps files.

Many thanks to my family and friend (Lucia Natera) for their support and understanding. Also, a big thank-you to Lucia for keeping me grounded in reality and waking me up from my naps. And thanks for the one and only thing that could really keep me awake- Diet Pepsi.

Last but not least, I thank myself for obtaining the impossible goal.

For my parents

"How much longer?"

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ABSTRACT

In accordance with spatial mapping theory and findings from the Morris Water Maze (WMW), we predicted that older humans would differ from younger humans on a place learning task. Using a computerized version of the MWM entitled the Computer-Generated Arena, we compared performance of adults 22-29 years of age (yoa) with adults 64-81yoa. We found that 22-29yoa adults located an invisible target more quickly and accurately than 64-81yoa adults. Additionally, removing sets of distal stimuli severely disrupted performance in 64-81yoa adults, but not 22-29yoa adults. In a post C-G Arena puzzle task, both groups of adults accurately recreated the spatial configurations of stimuli, but the 64-81yoa adults did not place the target accurately within that space. This suggests that 64-81yoa adults can accurately map a novel space but may not be able to place learn. These results correlate highly with performance in a real-world MWM task testing the same population.

Place Learning in Rats and Men

Spatial learning and memory is critical for many everyday activities, including (a) successful navigation through the world, (b) locating objects, and (c) recalling the place where events transpired. The study of spatial cognition has therefore played a recent and prominent role in cognitive neuroscience. The use of animal experimentation, involving mainly rodents and primates, makes possible well-controlled studies of both behavioral properties and neurobiological underpinnings of spatial cognition.

O'Keefe and Dostrovsky (1971) discovered neurons in the hippocampal formation that appear to be selectively active when rats locate and re-locate a specific place in a maze. Thus, it appears the hippocampus is active during spatial functioning. Subsequently, O'Keefe and Nadel (1978) proposed that the hippocampus forms cognitive maps, that allow the acquisition and retention of information about location in a spatiotemporal context (see also Nadel & O'Keefe, 1974).

Over the past 25 years experimental explorations of cognitive mapping theory have used a variety of behavioral techniques (see Nadel, 1991, 1994). Morris (1981) developed one such technique, the Morris Water Maze (MWM). The MWM consists of a large circular pool of opaque water placed in the center of a rectangular experimental room. The walls of the experimental room contain various items visible from the surface of the pool. Under some experimental conditions, a platform is placed just above the surface of the water, rendering it visible from the surface of the water. Under other experimental conditions the same platform is placed just beneath the surface of the water, rendering it invisible from the surface of the water.

Morris' (1981) original study consisted of several phases. During the first phase, Pretraining, rats were placed in the swimming pool with no platform present and were permitted to swim for several minutes. These Pretraining trials gave the rats practice swimming in the pool. During the second phase, Escape Acquisition, rats received training trials during which a platform was placed in the pool. On each training trial, the rats were released from one of four randomly chosen start locations. Rats in the experimental group searched for a platform placed just beneath the surface of the opaque water. The platform remained in a fixed location for 28 Escape Acquisition trials distributed over 5 experimental days (8 for the first four days, four on the fifth day). During the third phase, Test, four rats in the experimental group received a trial during which the platform was removed from the pool. This Test trial permitted Morris to observe which quadrants of the pool the rats searched, when they searched those quadrants, and how much time they spent searching each quadrant. The remaining four rats in the experimental group received a Test trial during which the platform was moved to another location. This Test trial permitted Morris to examine behavior of the rats as they learned the location of the platform placed in a new location.

Morris (1981) recorded the time rats required to find the invisible platform (escape latency) for each trial of the Escape Acquisition phase. Morris also videotaped the movement of the rats in the pool during the last four Escape Acquisition trials and the Test trial. Using the videotape record, Morris traced the path taken during the search. From these tracings, he determined the length of that search path and the time spent searching each of the four quadrants in the pool. He also determined the angle between

the platform and the path direction at one radius of the pool to obtain a heading direction. By this measure, a heading direction of zero degrees indicated the rat was moving directly toward the platform and a heading direction of 180 degrees indicated the rat was moving directly away from the platform.

Morris (1981) reported that, with one exception, all the rats "could swim easily and effectively" (p. 243) during Pretraining. He also reported that the escape latency decreased significantly over Escape Acquisition trials 1-6 and stabilized on trials 6-20. Further, Morris reported the rats generally took the shortest path between the start point and the platform across trials 17-20. Moreover, Morris reported the rats generally showed a heading direction of zero degrees on Escape Acquisition trial 20. Finally, Morris reported that, during the test trial, rats spent more time searching the quadrant in which the platform was located during Escape Acquisition than any other quadrant.

Compared against results obtained from appropriate controls, this pattern of results indicated the rats learned the location of the platform in the pool during Escape Acquisition. He argued that "rats learn to find an object that they cannot see, hear, or smell, by locating its position in familiar place" (p. 252). This he called place learning.

Morris (1981) interpreted these data within the context of cognitive mapping theory, arguing that place learning is a valid measure of the theoretical construct of a cognitive map as specified by O'Keefe and Nadel (1978). Morris strengthened this claim by (a) using that model to specify a sub-domain of possible observations related to a cognitive map, and (b) using those specifications to design an experiment examining the relationship between results predicted by the theory and those obtained in the MWM

procedure. In short, Morris (1981) examined the construct validity of his procedure using cognitive mapping theory as specified by O'Keefe and Nadel (1978).

Cognitive mapping theory predicts organisms navigate successfully in the environment by forming and using a spatial map of that environment. According to O'Keefe and Nadel (1978; see also Nadel, 1991, Nadel & O'Keefe, 1974), when an organism is placed in an environment, it acquires a map representing that space. Such a map allows an organism to conceptually piece together the environment so every object stands in some relation to every other object, whether or not the objects have ever been experienced in spatial or temporal contiguity. It is the relations among these objects that specify places in the environment. Thus, a spatial map consists of information about specific objects and specific places in the environment. Using such a spatial map permits an organism to locate itself in a familiar environment without reference to any specific cue or to any individual entity in the environment. Use of a spatial map also permits the organism to go from one place to another without any specific set of inputs (cues) or outputs (routes). The representation of the map is characterized by a non-egocentric stationary framework, through which the organism moves.

In contrast to cognitive mapping theory, traditional stimulus-response (S-R) or stimulus-stimulus (S-S) conditioning theories (see e.g., Guthrie, 1930, Hull, 1937, Spence & Lippitt, 1946) deny the existence of place learning and spatial maps. Rather, these theories claim that the existence of place learning is a matter of simple S-R or S-S connections. By these theories, an organism moves through the environment in response to a succession of external stimuli (e.g., sights, sounds, smells, pressures) and internal

stimuli (e.g., information from the skeletal muscles and the viscera). Stimuli that are crucial for successful movement are paired with appropriate responses more often than with inappropriate responses. Thus, by this theory, learning consists of the respective strengthening and weakening of connections between incoming stimulation and outgoing messages to the skeletal system, resulting in stimulus-guided movement through an environment.

Cognitive mapping theory predicts an organism will generate novel routes in a familiar environment. Provided the environment remains constant, a spatial map allows an organism to locate a particular place, independent of the location the organism enters the environment, any specific subset of stimuli in the environment, or the route required to reach that place. O'Keefe and Nadel (1978) called this behavioral flexibility. This means the rat in the MWM will generate novel routes starting from novel locations, to locate the place of a learned platform based on the spatial map acquired previously during training.

S-R theory, on the other hand, predicts the rat cannot generate such novel routes. Rather, S-R theory predicts that an organism must use a motor strategy to locate a place in the environment (Potegal, 1968). Thus, according to S-R theory, the rat could not immediately generate a novel route to the location of a previously learned invisible target when started from a novel location. Instead the rat would, for example, swim off at the same angles from the side of the walls from different start locations.

Morris (1981, Experiment 2) examined these predictions using the MWM. As before, the procedure consisted of Pretraining, Escape Acquisition, and Test trials.

Immediately following Pretraining, rats received 15 Escape Acquisition trials over 3 days. On each trial, the rats were released from the same start location. They searched for a platform hidden just beneath the surface of the opaque water. As before, the platform remained in the same place across all Escape Acquisition trials. Three Test trials immediately followed the Escape Acquisition trials. Six rats (Group Same-Place) received test trials identical to the Escape Acquisition trials, except the rats were released from three novel start locations for the three test trials. These trials permitted Morris to examine whether the rats learned the place of the platform with respect to extra-maze cues and independent of route traveled. Six other rats (Group New-Place) received three test trials during which they were released from three novel start locations. In this condition, the platform was moved each trial corresponding to the angular relationship held constant throughout training. For example, the rat was started in each training trial in the north quadrant with the platform located diagonally in the south quadrant; for one test trial, the rat was started in the east quadrant so the platform was subsequently located diagonally in the west quadrant. These test trials permitted Morris to examine whether the rats were learning to swim away from the walls at particular angles. The remaining six rats (Group Control) received test trials identical to the Escape Acquisition trials. These trials provided Morris with a baseline to assess test performance of the other two groups.

Cognitive mapping theory predicts that rats started from novel start locations during test trial will move directly to the invisible platform. This view argues that knowledge about the location of a platform does generalize to novel start locations. S-R

theory predicts the angle the rats will move from novel start locations during test trials will be the same as that angle moved from familiar start locations. Thus, they would not move directly to the invisible platform. This view argues that knowledge about the location of a platform does not generalize to novel start locations.

The same dependent variables used in Morris' Experiment 1 were used in his Experiment 2. He reported that escape performance stabilized by Escape Acquisition trials 12-15, with all rats showing escape latencies on those trials comparable to the experimental rats in Experiment 1. Although the rats started each Escape Acquisition trial from the same place, the rats learned the location of the invisible platform at comparable rates in Experiments 1 and 2. Two data patterns supported the notion that rats learn location of the platform relative to distal cues: (a) the rats in Group Same-Place moved directly to the platform from three novel start locations during test trials, and (b) rats in Group New-Place searched the training platform quadrant first during test trials. Thus, performance by the rats in the MWM provides data consistent with predictions derived from cognitive mapping theory.

Morris (1981) suggested this pattern of results offers support of cognitive mapping theory. Rats did not perform in the manner predicted by S-R theory. They did not swim off at particular angles from the side walls (see performance of rats in Group New-Place), nor toward a specific cue (see performance of rats in Group Same-Place). The data are consistent with the interpretation that stored representation of the distal room cues and the relations among them permit generation of novel directional behavior.

The MWM, therefore, appears to be a valid measure of the construct of spatial learning and memory as specified within the framework of cognitive mapping theory.

Since 1981, a large body of research has shown remarkable correspondence between cognitive mapping theory and patterns of data in the MWM (see Brandeis, Brandys, & Yehuda, 1989, for a review). Studies conducted using various experimental manipulations of this task have shown the rodent learns and remembers spatial configurations of distal stimuli (i.e. the outer room walls) to locate the platform successfully (Morris, 1982, 1983). These studies have demonstrated the importance of distal cues and relations among them by showing that elimination of some but not all distal stimuli does not impair knowledge of the location of the platform (Fenton, Arofo, Nerad, & Bures, 1994). Studies using other spatial tasks have shown that when distal stimuli are transposed, the time required to find the platform is increased (Suzuki, Augerinos, & Black, 1980). Use of the MWM provided a powerful methodology to examine the processes underlying spatial learning and memory as specified by cognitive mapping theory. Thus, the development of spatial tasks for humans similar to the MWM task may well benefit the study of spatial cognition and cognitive mapping theory in humans.

Our laboratory recently developed a computer-generated version of the MWM entitled the C-G Arena (Jacobs, Laurance, & Thomas, in press, Jacobs, Thomas, Laurance, & Nadel, 1997). In the C-G Arena task, a computer monitor displays a color view of a circular arena contained within a square room from the perspective of one standing on the floor of the arena. The walls of the square room contain various items

visible from the arena floor (e.g., a door or window). When a person stands against and facing the arena wall, the lower half of the computer screen displays a small portion of the room wall. When against the wall but turned away from it, a large portion of the arena, the surrounding room, and part of a gray ceiling are displayed. Under some experimental conditions, a blue square target is visible on the arena floor; under other experimental conditions, the target is invisible.

Participants are teleported within the computer-generated world to start positions along the arena wall. They are then allowed to search for a target on the arena floor. The participants move within this computer-generated world using a joystick or keyboard to move and turn. Participants know they have found the target when a blue square becomes visible on the arena floor and a computer-generated tone sounds each time they turn or move.

Typical task procedures parallel those found in the animal literature. Thus, we include several types of trials. Practice trials use a large visible target in the center of the arena. The purpose of practice trials is to let participants become familiar with the procedures of the task. A set of Acquisition trials involves the use of an invisible target located in the center of one of the arena quadrants. The purpose of these acquisition trials is to let participants learn the location of the invisible target with respect among relations of distal cues (objects on the walls) and the layout of the room. If learning occurs during these trials, then, theoretically, the participant formed a cognitive map of the computer-generated space. Test trials involve manipulations of the distal cues. The purpose of these test trials is to test the flexibility and stability of the cognitive map formed during

acquisition trials. An example of a test trial would be to eliminate distal cues from the walls housing the arena. A probe trial involves the removal of the target without the participant's knowledge. The purpose of a probe trial is to observe which quadrants of the arena the participants searched and how much time they spent searching each quadrant.

A number of experiments have shown that human performance in the C-G Arena directly parallel behavior of rats in the MWM (Jacobs et al., in press, 1997, Thomas, Jacobs, & Nadel, 1997, Thomas, Laurance, Brunner, Baker, Luczak, & Jacobs, 1997). More importantly, data from both the C-G Arena and the MWM directly parallel predictions of cognitive mapping theory. For example, our laboratory has shown (a) humans learn to locate a place based on distal cues alone, (b) place learning based on distal cues alone does not disengage when proximal cues are present, and (c) place learning generalizes from familiar to novel start locations (Jacobs et al., in press). Our laboratory has also shown that, in the C-G Arena (a) changes or transpositions in relations of distal cues disrupt place location, while (b) removal of single set of distal cues does not disrupt place location (Jacobs et al., 1997). We also found that humans exploring and learning distal cues in an environment without learning about a specific place, eases subsequent learning about a place within that environment--latent learning. Additionally, humans can learn about spatial relations and places by observing someone else successfully perform in the virtual arena--observational learning. Moreover, some humans can learn about spatial relations and places by standing and rotating in a particular place--placement learning (Thomas et al., 1997). The similarity of results

obtained in humans and rats from formally identical behavioral tasks demonstrates the C-G Arena has construct validity within the context of normal spatial mapping. This similarity of results also suggests that direct comparisons might be made with other findings from the animal literature.

The use of the C-G Arena task in which the environment can be strictly controlled by the experimenter may rule out several potential confounds found in real world tasks in both the animal and human literature. Examples of such confounds include deficits in swimming efficiency, motor coordination, and spontaneous exploration. Differences between groups may be due to changes in functioning having nothing to do with spatial cognition. The MWM has yielded insight into spatial learning and memory, but its procedures contain some confounds (e.g., swimming efficiency) which may have nothing to do with cognitive mapping. The C-G Arena controls for these confounds in that no movement through space occurs. Thus differences in motor functioning do not play a role.

Our laboratory has shown that place learning and spatial mapping occurs (a) without vestibular input, (b) without motor input, and (c) in the absence stimulus flow patterns (Cutting, Springer, Braren, & Johnson, 1992, Cutting, Vishton, & Braren, 1995, Cutting, Vishton, Fluckiger, & Baumberger, 1997, Priest & Cutting, 1985). Even without these types of information, human place learning occurs as predicted by cognitive mapping theory. This pattern of results supports the notion of construct validity of the computer-generated world in regards to the measurement of spatial cognition and mapping.

Place Learning in Aged Rats and Men

The MWM has also been used to examine the effects of age-related changes on cognitive mapping and place learning. The MWM appears to be reliably sensitive to age-related changes in spatial performance in rats (see Gallagher & Pelleymounter, 1988, for a review; see also Brandeis, Brandys, & Yehuda, 1989). Overall the data show that aged and young rats learn and utilize spatial information in quite different ways.

Gage, Dunnett, and Bjorklund (1984), for example, used the MWM to compare place learning in young and aged rats. Housing the pool in an environment rich in distal cues, Gage et al. (1984) placed rats of varying ages in the MWM with a platform just beneath the surface of the water. The rats were allowed to swim freely for up to 120 seconds or until they found the platform. If the rat did not find the platform in 120 seconds, the experimenter captured the rat and placed it on the platform, where it remained for 60 seconds. Each rat received 8 trials per day for 5 days. On the first 36 trials, the platform remained in a constant location in the center of one of the quadrants.

For the final four trials, or transfer trials, the platform was moved to the opposite quadrant. If the rats utilized distal cues to find the invisible platform, then they should show a preference for the original quadrant; if they utilized proximal cues, then they should swim directly to the new quadrant location. Escape latency, path length, time spent in each quadrant, and swim speeds were recorded.

Gage et al. (1984) report that aged rats (24 months old) required significantly more time to find the invisible platform than young rats (3 month old). Aged rats also took significantly longer search paths than younger rats. Nonetheless, both young and

aged rats showed an initial preference for the target quadrant over the other quadrants, with no significant difference between the two groups. This result suggests both groups of rats used distal cues to guide their search for the target. When the target was shifted during the transfer trials, an analysis on time spent in each quadrant indicated the aged rats did not focus their search in the target quadrant as persistently as did younger rats. Also, the younger rats showed they could quickly learn the location of the new target. The younger rats' mean latency for the four transfer trials decreased significantly; whereas the aged rats' mean latency decreased only slightly. According to the analyses, there is more variability in the performance of older rats during acquisition, and no preference for the appropriate quadrant during testing.

Thus, Gage et al. (1984) showed, for the first time, a difference between performance of young and aged rats in the acquisition of a spatial learning task utilizing the MWM. Aged rats did not locate the target as often as do young rats in spatial tasks. Results from previous studies had suggested similar differences in performances of aged rodents with respect to the radial-arm maze. These results might have been confounded by adopted measures such as food deprivation and shock to motivate learning in aged rats. In comparison, use of the MWM in the Gage et al. (1984) study allowed for a relatively non-traumatic procedure.

According to the patterns of behavioral data found in the rat literature, it appears older rats have difficulties place learning (see e.g., Gallagher & Pelleymounter, 1988 for a review, see also Burwell & Gallagher, 1993, Rapp, Rosenberg, & Gallagher, 1987, Pelleymounter, Smith, & Gallagher, 1987). It takes older rats considerably more time

and more trials to locate a place in space, whereas younger rats appear to be rapid in their place learning (Brandies, Brandys, & Yehuda, 1989). Since it is difficult to obtain place learning baseline measures in older rats, the experimental manipulations that have been conducted on younger populations of rats are not possible with older rats. A comparison of performance in manipulated conditions such as novel start locations or cue removal therefore has not been conducted.

As yet, we do not as yet know if the construct validity demonstrated in the C-G Arena can extend to aged human populations. Nor do we yet know if the C-G Arena shows similar data patterns found in actual world procedures. Recently, Newman and Kaszniak (1997) designed a task that extended the MWM to humans in real space. Their apparatus consisted of a large tent enclosure 7.3 meter in diameter that housed their human life-sized version of the MWM arena. The enclosure was octagonal in shape. Inside the tent, white fabric lined the ceiling, and artificial grass lined the floor. The walls of the enclosure were black plastic 2.5 meters in height and 3 meters in length. Six abstract distal cues were placed along the periphery of the enclosure and mounted on easels. The six cues were colored geometric shapes, i.e., a blue heart, red square, yellow triangle, pink cross, orange diamond, green circle. A pole designated as a target, was a lightweight 94.5 cm PVC pipe.

Participants in their study were assigned into one of two groups on the basis of age: younger adults (18-30 years) and older adults (over 60 years of age). Each participant received one demonstration of the task. The participants watched as an experimenter entered the tent and place the pole in a specific place on the floor.

Immediately after this demonstration, each participant received one practice trial to gain an understanding of the task procedures. This trial involved the participant imitating the experimenter by entering the tent enclosure and placing the pole in the same location just demonstrated. After this trial, the six distal cues were placed in a new configuration. The participants then received three Learning trials. For each Learning trial, the pole was placed in the correct location within the tent arena by the experimenter. Each participant would then enter the tent and were asked to study the relation of the cues to the pole's placement. After exiting the tent, they were given the pole and asked to re-enter the tent and place the pole in the correct location. They were only given this help for these first three learning trials. For the remaining trials, the pole was not placed in the tent beforehand. Rather, they participants had to remember the location based on distal cues to successfully place the pole in the same location.

Immediately after the three Learning trials, each participant received a probe trial in which two of the six distal cues were removed. This was done to eliminate reliance on a single set of cues. If certain cues are removed, the participant needs to know the location of the pole relative to all six cues in order to successfully place the pole. The probe trial also assessed the accuracy of the participant's spatial map of the area. If the participant was not using all six distal cues in placing the pole, then performance would be less accurate when cues are removed.

Immediately after the probe trial, each participant received three acquisition trials followed by another probe trial. Each participant went through three series of three acquisition trials followed by a probe. For each series, the participant was started at a

single start location, novel to any of the other start locations in other series. If the participant had an accurate map of the environment, then there would be no difference in latency to place the pole in its correct location (a) between acquisition trials and probe trials, (b) despite being started from novel locations, or (c) having cues eliminated from the area. Additional behavioral measures such as distance traveled and accuracy of pole placement were taken. Accuracy of pole placement refers to an error score. The error score was the angle difference from the center of the room between where the participant placed the pole and the correct placement position of the pole.

Results showed place learning occurred in the younger adults as evidenced by a decrease in error score in pole placement between the practice and the first learning trial. In contrast, the older adults showed no improvement in error score of pole placement between the practice trial and the first learning trial. Also, younger adults showed a significant improvement in error score of pole placement across the three learning trials, whereas the aged group did not show change in error scores. Also reported was a group difference on both probe and acquisition trials. The aged group showed higher errors in pole placement than the younger group on both acquisition and probe trials. Newman and Kaszniak's (1997) findings suggest adults over 60 years of age have less accurate and more fragile cognitive maps than adults between the ages of 18 and 30. These results parallel results found when the performance of young and aged rats are compared.

The continued availability of the participants used by Newman and Kaszniak (1997) allow us to directly compare their performance in the actual world and the C-G Arena. If place learning in the C-G Arena accurately reflects place learning in the actual

world, then we expect a high positive correlation between the data obtained from participants in the Newman and Kaszniak task and the data obtained from the same participants in the C-G Arena.

Our laboratory has already examined the performance of a sample of humans between the ages of 70 and 84 in the C-G Arena. The results suggest the C-G Arena may be sensitive to age-related changes in place learning (Thomas et al., 1997). The study showed that orderly acquisition did not occur in older adults but did so in younger adults. Older subjects took longer to find an invisible target than did younger subjects. In addition, the time required to find the target did not decrease across trials for the older subjects but did so for the younger subjects. Finally, those in the aged group did not preferentially search the quadrant in which the target was located when tested in a standard probe trial (i.e., no target was located in the arena for that trial) whereas the younger subjects did. These data patterns lead to the suggestion that aged humans and aged rats perform comparably in place-learning task (Gage et al., 1984, Newman & Kaszniak, 1997, Thomas et al., 1997).

When compared to findings from the animal literature, it appears that performance in the C-G Arena has face, construct, and content validity. The purpose of the present study, then, is to examine place learning in older adult humans using the C-G Arena. The present study will compare place learning in young and aged humans in the actual world (Newman and Kaszniak, 1997) to place learning in the C-G Arena. If comparable results are found, then to the extent that performance in the Newman and Kaszniak task reflects performance in the real world, so too does performance in the C-G

Arena. Thus, if similar data patterns are found, we may be able to suggest that the C-G Arena is externally valid assuming that performance in the tent is externally valid.

In accordance with spatial mapping theory and with findings from the MWM using aged rat and human participants, we predict the individuals in the older group differ from the younger group of adults. Specifically, we predict that the individuals in the aged group will be slow to acquire a spatial map of the arena, as reflected by (a) more time to locate the target, (b) the absence of orderly learning curves reflected by an insignificant change in latency across trials, (c) lack of target quadrant preference reflected by a even distribution of search across the quadrants on the probe trial, and (d) improper spatial configurations of the arena. All of these findings should correlate positively with data patterns found in the actual world task conducted by Newman and Kaszniak (1997). Moreover, the C-G Arena should rule out factors (e.g., motor movement) that may have nothing to do with spatial learning and memory.

Method

Participants. The participants were assigned to one of 2 groups on the basis of age. Eight individuals (3 males, 5 females), between 22 ands 29 years of age ($M = 26.1$), recruited from the University of Arizona Psychology Department, were assigned to Group 22-29yoa. Eight individuals (2 males, 6 females), between 64 and 81 years of age ($M = 73$), recruited from the Tucson area were assigned to Group 64-81yoa. Participants were recruited from three studies previously conducted by Newman and Kaszniak using the procedures outlined above.

Interview phase. Each participant underwent a brief interview to ensure the following factors were not present (Newman & Kaszniak, 1997): (a) cognitive or neurological disorders including dementia and prolonged unconsciousness, (b) systemic illnesses, cardiac arrests, and hyper- and hypo-tension not controlled by medication, (c) medications that may interfere with cognitive performance, (d) clinical depression, and (e) evidence of motor or visual deficits that could interfere with performance on this task. If any one of these six factors was detected during the interview as not being comparable to the previous study, the participant was excused from the study.

Apparatus. A personal computer and custom-designed software generated a display on a computer monitor. The monitor displayed a multi-colored view of a circular arena contained within one of three square rooms, a waiting room, a demonstration room, and an experimental room, from the perspective of one standing on the floor of the arena. The monitor did not display a representation of the participant.

The virtual space. The C-G waiting room, demonstration room, and experimental room each consisted of a 1500x1500x475-unit room, each housing an arena. The ceiling of each room was light gray and the floor dark gray. A circular purple wall 460 units in radius and 30 units high enclosed the central portion of the room floor, thus defining the arena. The purple arena wall and floor were featureless and contained no cues distinguishing a location. The computer screen showed a perspective as if the participant was 15 units from the arena floor. When a person stood against and facing the arena wall, the purple wall filled the computer screen. When against the wall but turned away from it, a large portion of the arena, the surrounding room, and part of a gray ceiling were displayed. The arena was divided into four imaginary quadrants named Northeast (NE), Southeast (SE), Southwest (SW), and Northwest (NW). The quadrants were not part of the computer-generated display. A square target was or was not part of the display, depending on the experimental conditions (see Figure 1 for a representation).

The C-G waiting room. The waiting room consisted of a computer-generated display of a square room housing an arena. The four walls of the room were featureless red, yellow, blue, and green, respectively. No target was present in this room.

The C-G practice room. The practice room consisted of a computer-generated display of a square room housing an arena. The walls of the practice room were light gray and were arbitrarily designated North, East, South, and West. The North wall displayed three doors. The East wall displayed a single centered window against a textured background. The South wall displayed two windows. The West wall displayed a brick wall
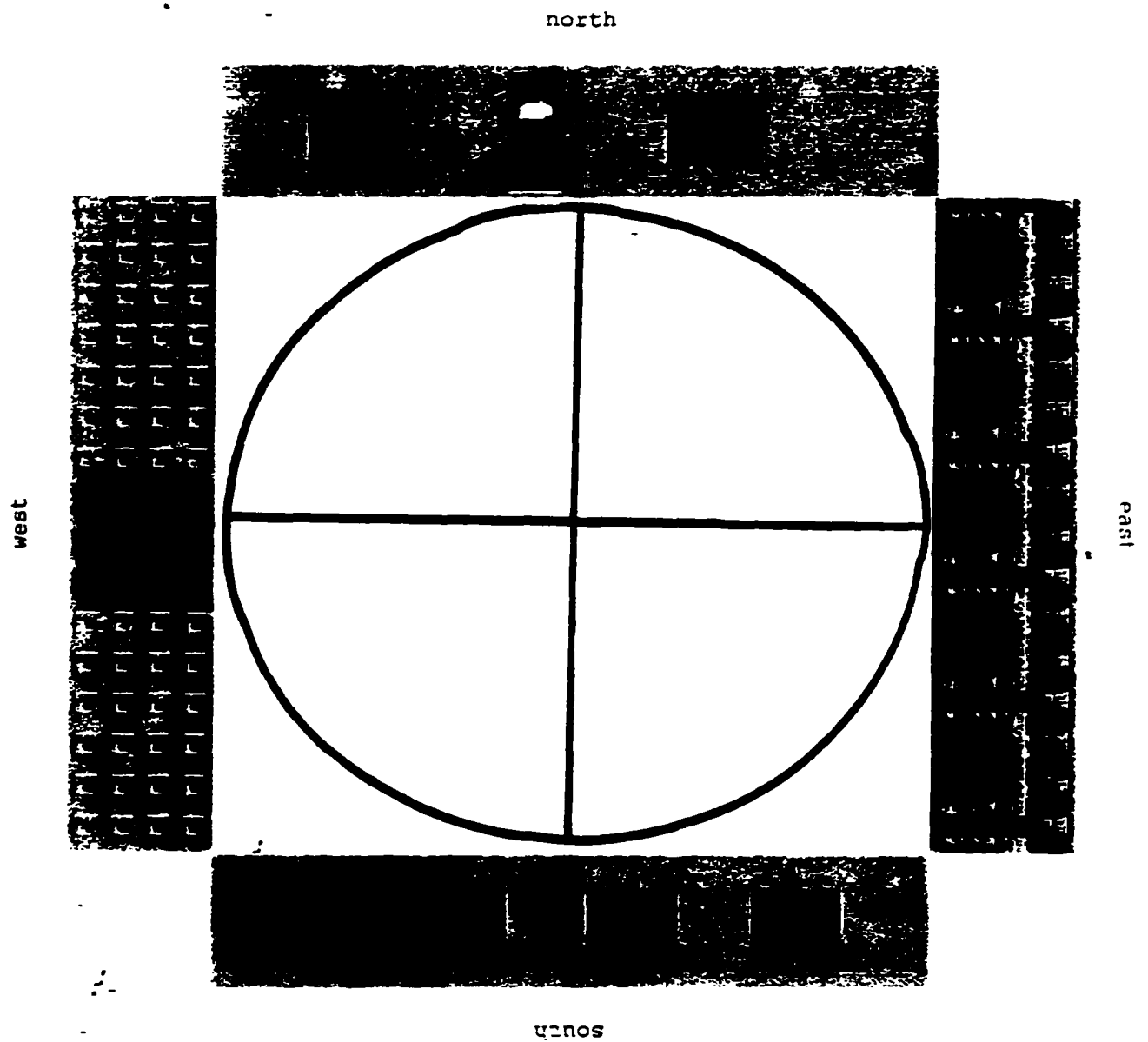
Figure 1. A representation of the C-G Arena.

The C-G experimental room. The experimental room consisted of a computer-generated display of a square room housing an arena. The walls of the experimental room were light gray and were arbitrarily designated North, East, South, and West. The North wall displayed a door flanked by on either side by two windows. The East wall displayed six and one-half black arches. The South wall displayed three centered windows. The West wall displayed a brick wall.

Target. A 142x142 unit square target was located on the floor of the C-G practice and experimental rooms. The target was centered in one of the imaginary quadrants of the arena, and its center was approximately 234 units from the closest part of the arena wall. The target was or was not part of the display, depending on the experimental conditions. When the target was part of the display, it appeared plain blue. When the participants walked across the space occupied by the target, the target became visible (if not previously visible) and a brief computer-generated tone sounded with each movement. When the participants stood on the target, the computer screen continued to display a view as if the eyes of the participant were 15 units from the floor of the room (i.e., standing on the target did not raise the view of the participant).

Movement in virtual space. The participants moved through the computer-generated space using a joystick. Pushing the joystick forward moved the participant forward 4.0 units per movement. Pulling the joystick backward moved the participant backward at the same rate. Pushing the joystick left or right turned the participant in the corresponding direction 1.0 degrees per movement. Holding the joystick in one position produced repeated corresponding movements. Participants were transported

("teleported") from the waiting room to the experimental room by striking the space bar on the computer keyboard. Once in the experimental room, the participant could only teleport back to the waiting room by simultaneously standing on the target and pressing the spacebar. Striking the space bar while in the waiting room teleported the participant to the experimental room and began the next trial.

Task. Each participant was teleported to random start positions within 2 units of the arena wall for several trials. Once in the C-G practice or experimental room, they searched for either a visible or invisible target on the arena floor for a limited time per trial. Their task was to turn away from the arena wall, locate the target, and stand on it. Once on the target, striking the space bar ended the trial and teleported the participant to the C-G waiting room. Striking the space bar while in the waiting room teleported the participant to the practice or experimental room and began the next trial. Each participant experienced a series of 20 trials. If the participants did not find the target, stand on it, and strike the space bar within a limited time, the trial terminated and the participants were returned to the middle of the waiting room.

Procedure

Instruction phase. Upon entering the laboratory, each participant received standardized verbal instructions about movement and the task (see Appendix A). Instructions included information about the arena, movement within the computer-generated space, and the object of the task. Also, each participant was informed about all of the experimental conditions except that the target would be removed during the probe

1997, and Skelton, Bukach, Laurance, Thomas, & Jacobs, 1997). Each participant sat at a table on which 3-dimensional representations of each of the following was placed: (1) the four distal walls of the C-G practice room, (2) separate pieces representing the objects on those walls, and (3) a blue square piece representing the target were located.

An 11x17 sheet of paper was placed on the desk with the outline of a purple circle drawn in the middle representing the arena wall. The pieces of the puzzle were placed in a standardized location on top of the paper on the desk and covered. The experimenter uncovered the pieces and read standardized instructions (see Appendix B). The participants were instructed to put together the pieces on the desk to re-create the correct spatial relations among the C-G Arena walls, the objects on the walls, and the target location. The time each participant required to complete the task was recorded. There was no time limit to this task.

Four measures of puzzle task performance were taken: wall placement, object placement, object accuracy, and target placement. For wall placement, one point was awarded for each wall that was correctly placed in relation to the other walls for a maximum score of 4. For object placement, one point was awarded for each object that was placed on the correct wall for a maximum score of 6. For object accuracy, one point was awarded to each object placed in the correct location on the correct wall for a maximum score of 6. For target placement, two points were awarded if the target was placed in the correct quadrant, one point was awarded if the target was placed in either of the adjacent quadrants, and no points were awarded if the target was placed anywhere else.

Acquisition phase. Immediately following the Puzzle task, each participant

received a series of eight acquisition trials in the C-G experimental room. Each trial

began in the waiting room. When the participant pressed the space bar, they were

teleported to the experimental room. The participant entered at one of the four compass

points (north, south, east, and west), facing and within 2 units of the arena wall. Each

participant started at each of the start points twice during the 8 trials. Once in the arena,

the participants searched for an invisible target on the arena floor. The 142x142-unit

target was centered in the NW quadrant of the arena, with its center approximately 234

units from the closest part of the arena wall. The participant found the target by moving

around the arena floor until a beeping sound was heard and the target became visible.

While on the target, striking the space bar ended the trial and teleported the participant to

the middle of the C-G waiting Room. Striking the space bar while in the waiting room

teleported the participant to the C-G experimental room and began the next trial. For the

first three acquisition trials, the experimenter helped the participant locate the target after

180 seconds if not found by the participant. For the remaining trials, the participant was

automatically teleported to the middle of the waiting room if he/she did not find the

target, stand on it, and strike the space bar within 180 seconds.

Test phase. Immediately following the Acquisition phase, the participants entered

the test phase. The test phase consisted of four test trials interspersed with a trial

identical to those occurring during the Acquisition Phase (test - acquisition - test).

During each test trial, the stimuli on two distal walls of the experimental room were

removed, i.e., the stimuli on two distal walls of the experimental room were replaced with

white non-textured walls. The participant had 180 seconds to locate the target, stand on it, and strike the space bar. If the participant did not locate the target within that time limit, the trial terminated and the participant was teleported to the middle of the waiting room. The participants were told at the beginning that this removal would occur (see Appendix A). The order and assignment of which walls were removed and replaced with the white walls were random and counterbalanced. This test procedure is designed to examine if the participants are using the relationship between distal cues, or a single cue to locate the target.

Probe trial. Immediately following the Test phase, each participant received a single probe trial. The probe trial was identical to the acquisition trials except the target, unknown to the participants, was removed from the arena. The duration of the probe trial was 180 seconds, after which the trial terminated and the participant was teleported to the middle of the waiting room.

Final trial. The last 120 second trial, the 20th, was identical to a practice trial with a visible target located in the middle of the arena floor. The trial and the experiment terminated either (a) when the participant stood on the target and pressed the space bar, or (b) if the participant did not locate the target within 120 seconds. This trial was included because termination of the task to a blank screen after the probe trial occurs without warning and appeared disconcerting to some participants (Skelton, Bukach, Laurance, Thomas, & Jacobs. 1997).

Experimental puzzle task. Immediately following the Final trial, each participant completed a second puzzle placement task. The task was identical to that described for

the Practice puzzle task, but with pieces representing the objects and walls of the C-G experimental room.

Spatial questionnaire. Immediately following the puzzle task, each participant completed a spatial questionnaire designed to collect information about target location and search strategies, by asking the questions: "Did you know the location of the target? How did you know where the target was? Briefly explain."

Data collection. The dependent variables gathered from the computer task included: (a) the time required to find the target, (b) the path taken in the arena, (c) the distance traveled from the start point to the target, and (d) the time spent in each of the arena quadrants. Other measures gathered for analyses included: (a) answers to the questionnaires and (b) data on the puzzle task configurations. The Type I error rate was set at 0.05 for all statistical decisions.

Each participant also filled out several questionnaires reporting past and current medical history, demographic data, and stress-oriented questions (see Appendix C). Also, the Beck Depression Inventory (BDI) was given to each participant to rule out clinical depression.

Results

Participants

The BDI and a brief questionnaire regarding medical history, and prescribed medication that could effect performance yielded no significant differences between the two groups. One-way analysis of variance (ANOVAs) were conducted on a variety of subject-related factors (e.g., medical history; see Appendix C) to make sure that no major changes have occurred since the participants were run through the Newman and Kaszniak actual space study. No significant differences were found.

Practice Trials

The panel labeled "Practice" Figure 2 illustrates the mean time required by each group to find the visible target on the two practice trials. It appears the participants in both groups found the visible target quickly and consistently. A repeated measures split-plot ANOVA conducted on the mean time participants in each group required to find the target on the two practice trials supports this impression. The analysis detected no significant Group effect, $F(1, 14) < 1$, no significant Trials effect, $F(1, 14) < 1$, and no significant Group x Trial interaction, $F(1, 14) = 1.26$. Each subject located and stood on the target within 60 seconds on both Practice trials. The results indicate the 22-29yoa adults and the 64-81yoa adults understood and performed this computer-based task equally well. The data also indicate that two groups used equally efficient search patterns or motor strategies to find the target when it was visible.

Figure 3 illustrates the search paths of the 16 participants on the second practice trial. Each of the eight participants in Group 22-29yoa found the target and remained
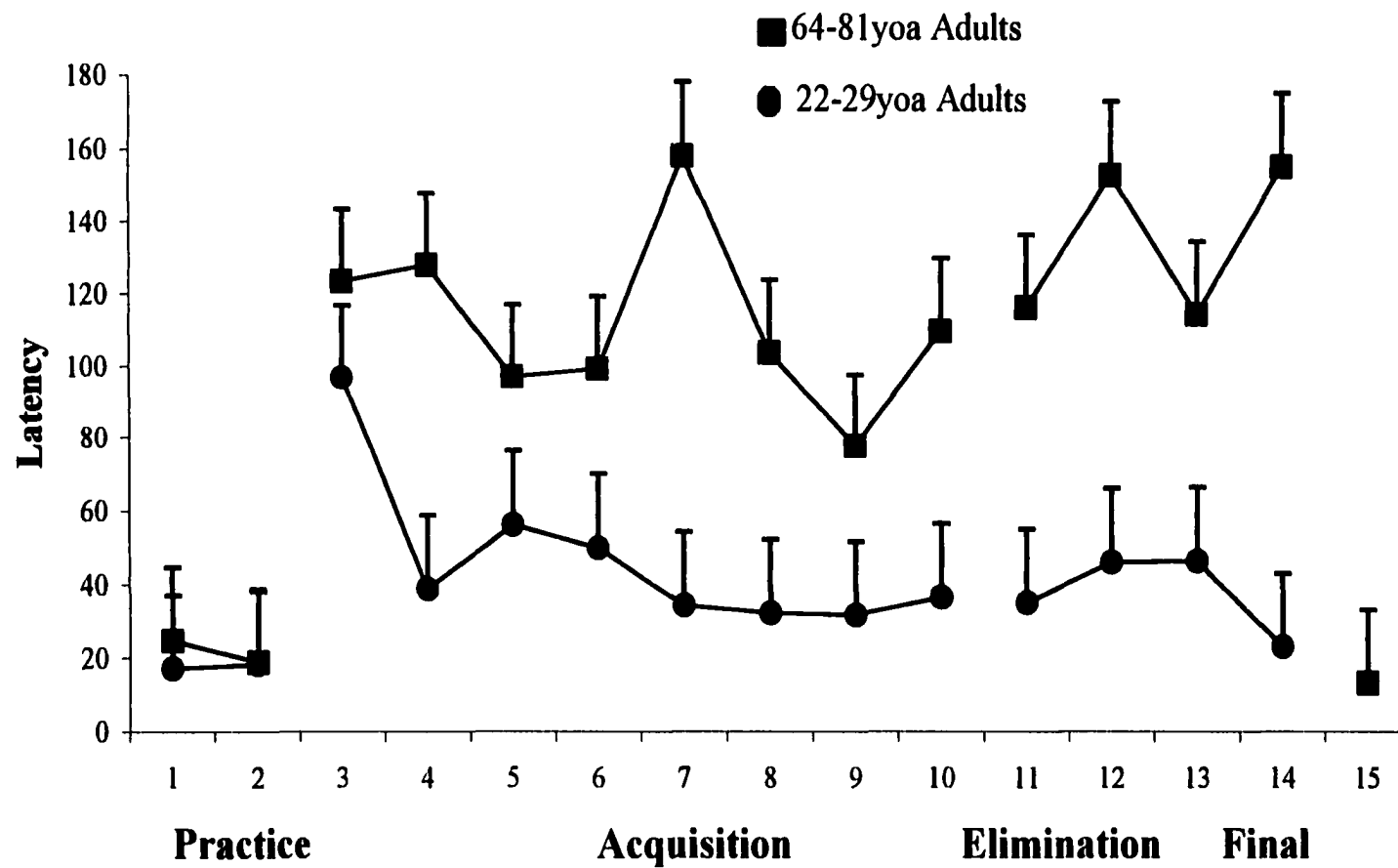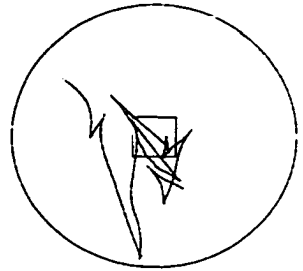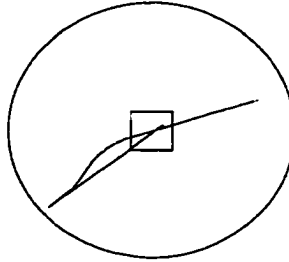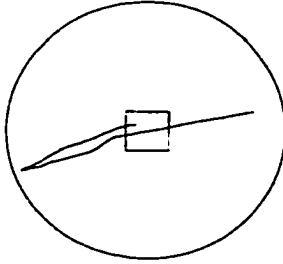
Figure 2. Mean time and SE to find the target in seconds over the Practice, Acquisition, Elimination, and Final trials.

64-81yoa
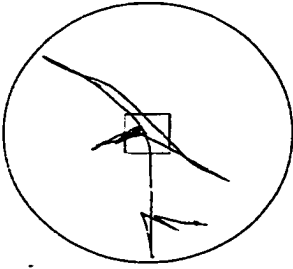
64-81yoa

22-29yoa

22-29yoa
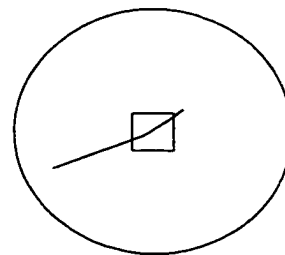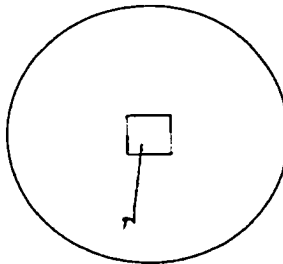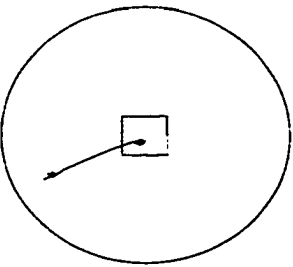
Figure 3. An aerial view of the individual search paths taken by all 16

participants during the second Practice Trial.

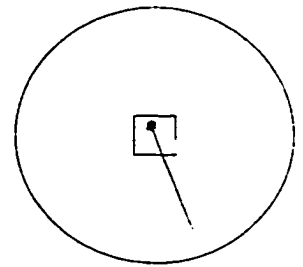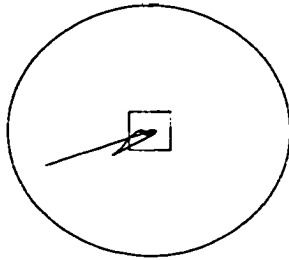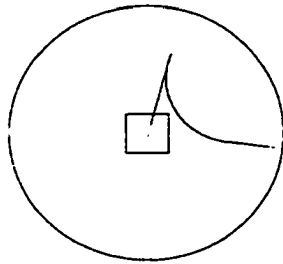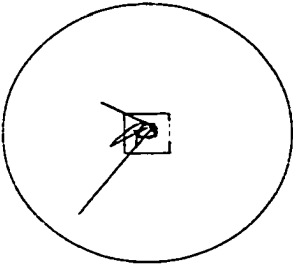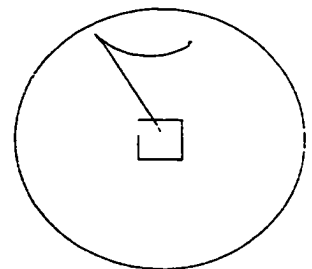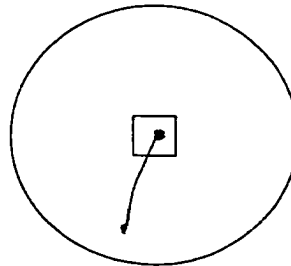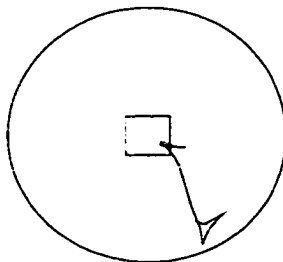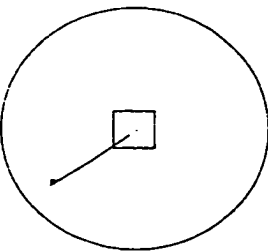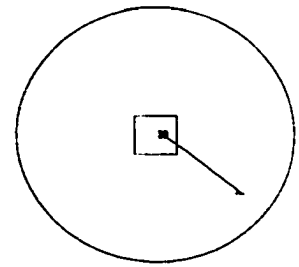upon it until striking the space bar. On that same trial, four of the participants in Group 64-81yoa found the target and remained on it until striking the space bar. In contrast, the remaining four participants crossed the target at least twice before remaining on it and striking the space bar. A sign test comparing the number of participants that stopped in the older group to the number of participants that stopped in the 22-29yoa group did not detect a significant difference between these two groups ($p = 0.54$). Although we cannot conclude that stopping behavior is greater in the 22-29yoa group than the 64-81yoa group, we must note the sign test, lacks power to detect differences between groups especially with small samples. These differences may exist, but could not be detected with this sample and using this test.

A goodness of fit chi-square test however, rejected the null hypothesis that there is no difference between the groups in terms of stopping behavior, because $X^2 = 4.00$ and $X^2_{.05}(1) = 3.84$. This result implies there is a difference in stopping behavior between the two groups. The mean age for those four participants in Group 64-81yoa who stopped was 69.5 years, whereas the mean age for the four participants who did not stop was 76.5 years.

Practice Puzzle Task

Two independent raters scored the puzzle task. Correlations on each measure yielded perfect agreement. Figure 4 illustrates the mean scores for each group on three measures (wall placement, object placement, and object accuracy) for the practice puzzle. These three measures reflect the participants' knowledge of the spatial configuration of the practice room. It appears that in the practice puzzle task, the 22-29yoa group placed
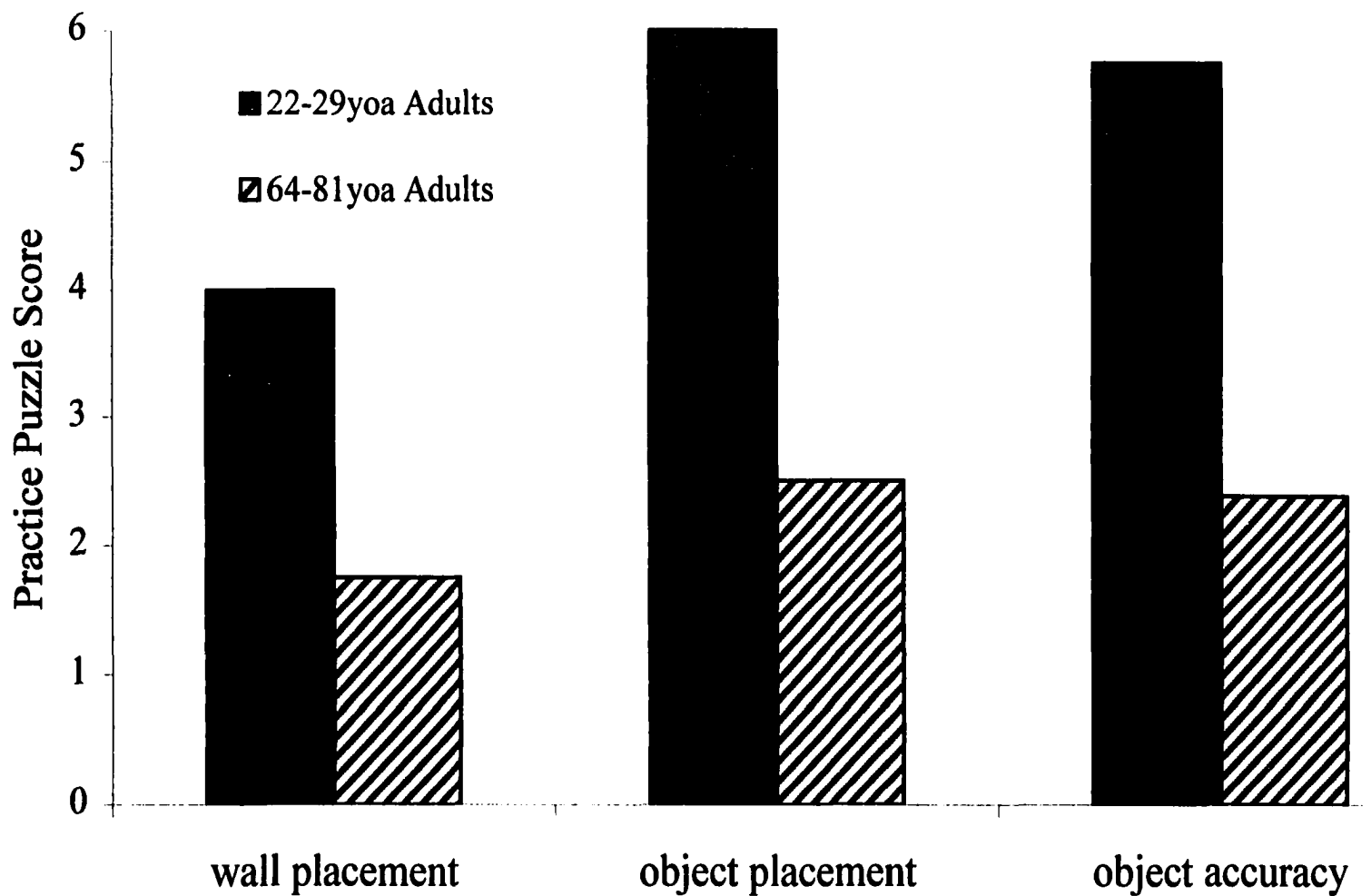
Figure 4. Distribution of practic puzzle scores on the three spatial configuration measures. A maximum score for wall placements was a 4. A maximum score for object placement and accuracy was a 6.

the walls and the objects more accurately than the individuals in the 64-81yoa group.

Independent samples Mann-Whitney tests confirmed this impression. The test detected

significant differences between the two groups performance on wall placement (p = .00),

object placement (p = .01), and object accuracy (p = .02). These analyses support the

impression that 22-29yoa adults were accurate with their spatial configuration of the

practice room, whereas 64-81yoa adults were not as accurate.

For each participant who did not complete the puzzle task perfectly, the

experimenter would construct the task for them while the participant watched. It was

noted by the experimenter that for the 64-81yoa adults, the construction by the

experimenter seemed to help them understand how the computer-generated room was

constructed. The older adults verbally confirmed this impression with statements such as

"Ah, now I get it."

Acquisition Trials

The panel labeled "Acquisition" of Figure 2 illustrates the mean time required to

find the target during the Acquisition trials for both groups. During the these trials, none

of the eight participants in Group 22-29yoa and three of the eight participants in Group

64-81yoa required help to locate the target on one of the first three acquisition trials.

Participants in Group 22-29yoa appeared to learn the location of the invisible target

immediately and performed optimally on the seven remaining acquisition trials.

Participants in Group 64-81yoa appeared to require more time to find the target for all

acquisition trials. A repeated measures split-plot ANOVA confirmed these impressions.

The analysis detected a significant Group effect, $F(1, 14) = 31.32$, no significant Trial

effects, $F(7, 98) = 1.61$, and no significant Trial x Group effect, $F(7, 98) = 1.33$. A within-subjects repeated measures ANOVA conducted on time to find the target detected significant Trials effects for Group 17-25yoa, $F(7, 49) = 2.94$. Post-hoc orthogonal contrasts conducted on the data obtained from Group 22-29yoa indicated the following pattern of acquisition: (Trial 3 is the first acquisition trial)

$$\text{Trial } 3 > 4 > 5 = 6 = 7 = 8 = 9 = 10$$

The ANOVA detected no significant Trials effect for Group 64-81yoa, $F(7, 49) = 1.05$.

Figures 5 and 6 illustrate the acquisition curves obtained from the individuals in the two groups. Visual inspection of the curves in Figure 5 supports the statistical interpretation. The curves indicate that seven of the individuals in Group 22-29yoa learned the location of the invisible target, but there is some variability early on as to which trial that learning occurred. Visual inspection of the curves in Figure 6 also supports the statistical interpretation. The curves indicate high variability in Group 64-81yoa across acquisition trials. Four individuals in Group 64-81yoa show some decrease in time to find the target over the last few acquisition trials. The remaining four participants showed no consistent decreases in time to find the target. Figure 7 illustrates a representative sample of search paths on acquisition trials 8, 9, and 10 obtained from four of the eight participants in Group 64-81yoa. As can be seen, there is a noticeable variability in performance of the 64-81yoa participants both in terms of locating the target and to the efficiency of their search paths. Some of these participants appear to locate the target on one trial but then do not relocate the target on the next trial. In contrast, others appear to locate and subsequently relocate the target.
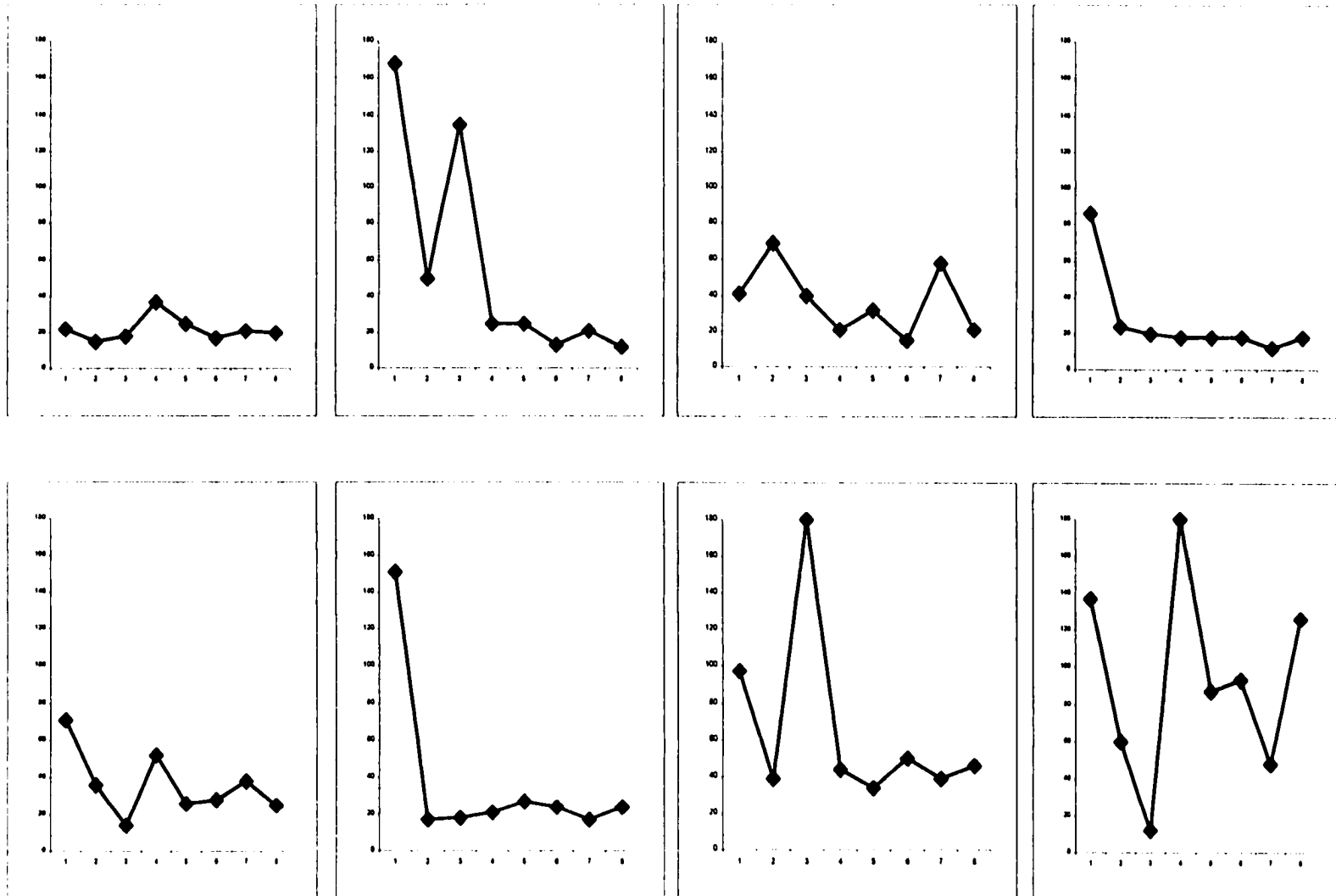
<u>Figure 5.</u> Individual acquisition curves for all 8 participants in Group 22-29yoa.
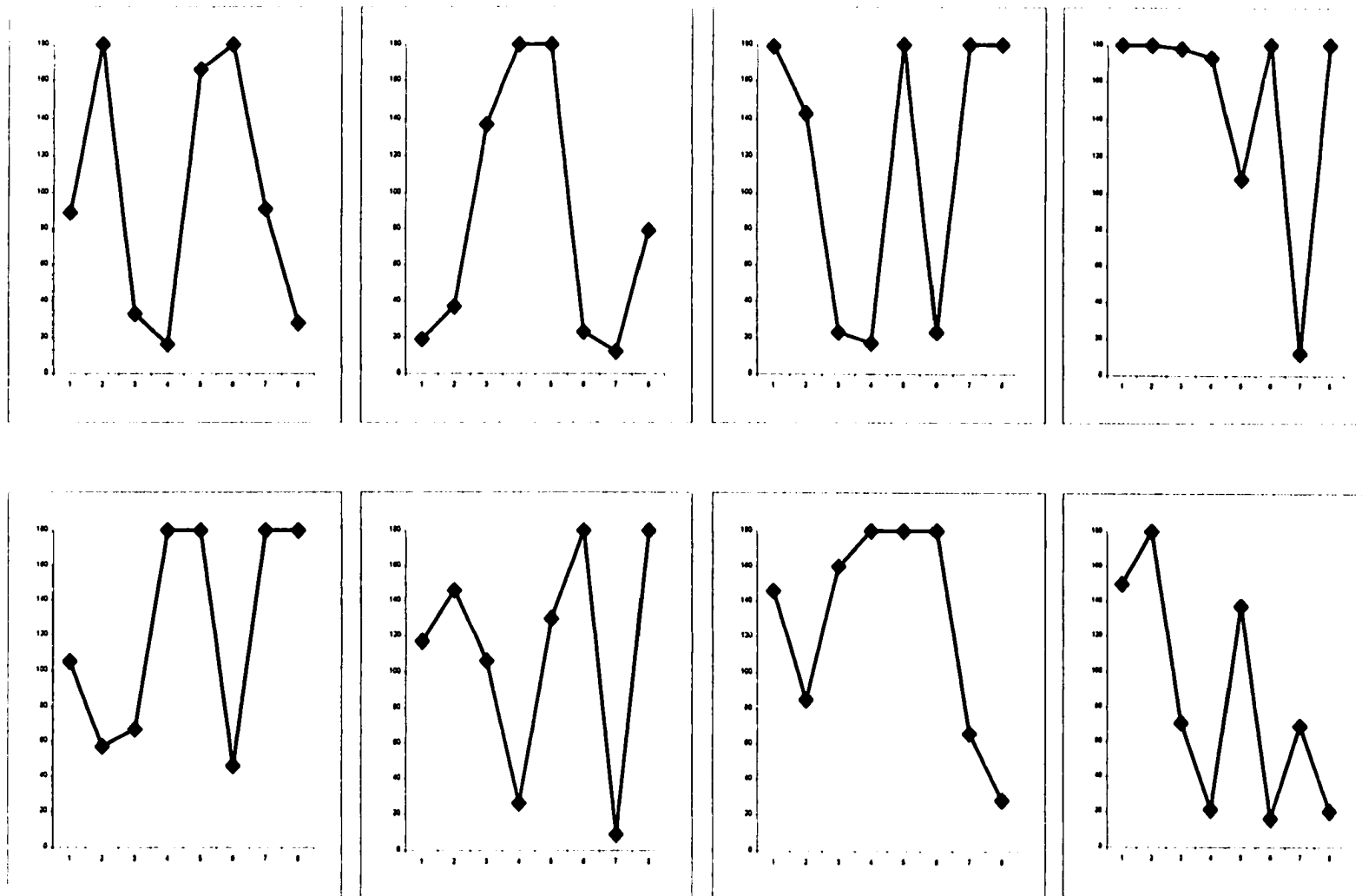
Figure 6. Individual acquisition curves for all 8 participants in Group 64-81yoa.

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Figures 7 and 8 depict a representative sample of search paths obtained from eight participants (Group 22-29yoa: P 2, P 10, P 12, P 13, Group 64-81yoa: P 1, P 6, P 8, P 11) on the last three acquisition trials (trials 8, 9, and 10). Inspection of these data suggests that the 22-29yoa adults and 64-81yoa adults used somewhat different motor strategies while searching for the invisible target. Of interest is the performance of participant 1 (Group 64-81yoa) in Figure 7. This is the only person who did not immediately stop after locating the target. This participant is also one of the four participants who did not stop on the visible target in the practice trials.

Elimination Trials

Figure 9 represents the mean time required to find the target in the baseline and elimination trials. The first bar in Figure 9 illustrates the time required to find the invisible target over the mean of acquisition trials 8-10. This bar established as the baseline to compare the elimination trials. The next four bars represent the mean time required to find the invisible target for each elimination trial. As can be seen, eliminating all of the distal cues on any two walls did not appear to affect the place performance of the 22-29yoa adults. The mean time required to find the target for the four elimination trials remained stable across trials. In contrast, eliminating all of the distal cues on any two walls appeared to affect the place performance of the 64-81yoa adults. The mean time required by the 64-81yoa adults to find that target on all four trials was greater than on the acquisition trials.

A repeated measures split-plot ANOVA confirmed these impressions. The analysis detected a significant Group effect, $\underline{F}(1, 14) = 40.20$, a significant Trial effect,

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Figure 7. An aerial view of the individual search paths taken by four participants in Group 22-29yoa (P2, P10, P12, and P13) during the last three Acquisition trials.
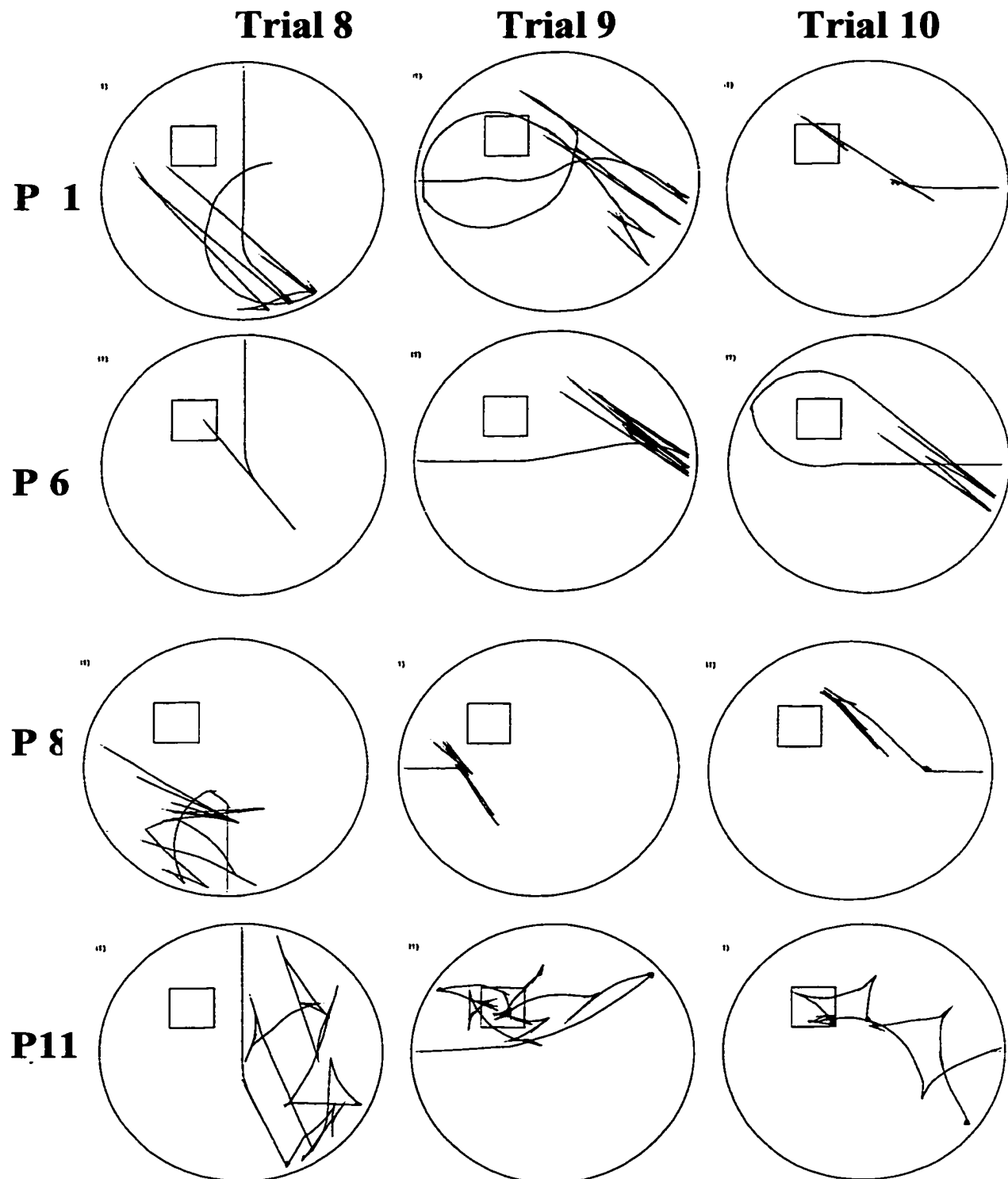
Figure 8. An aerial view of the individual search paths taken by four participants in Group 64-81yoa (P1, P6, P8, and P11) during the last three Acquisition trials.
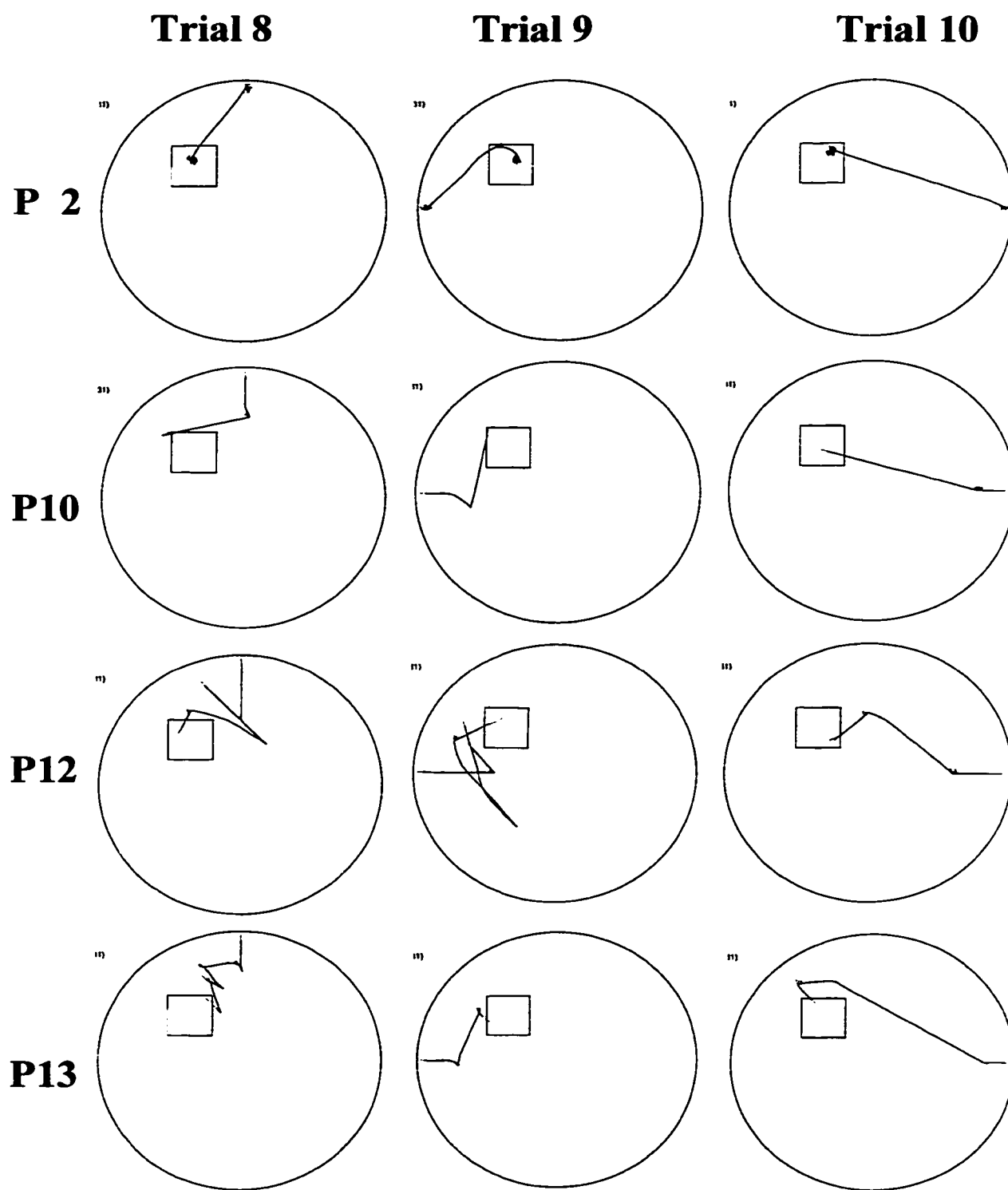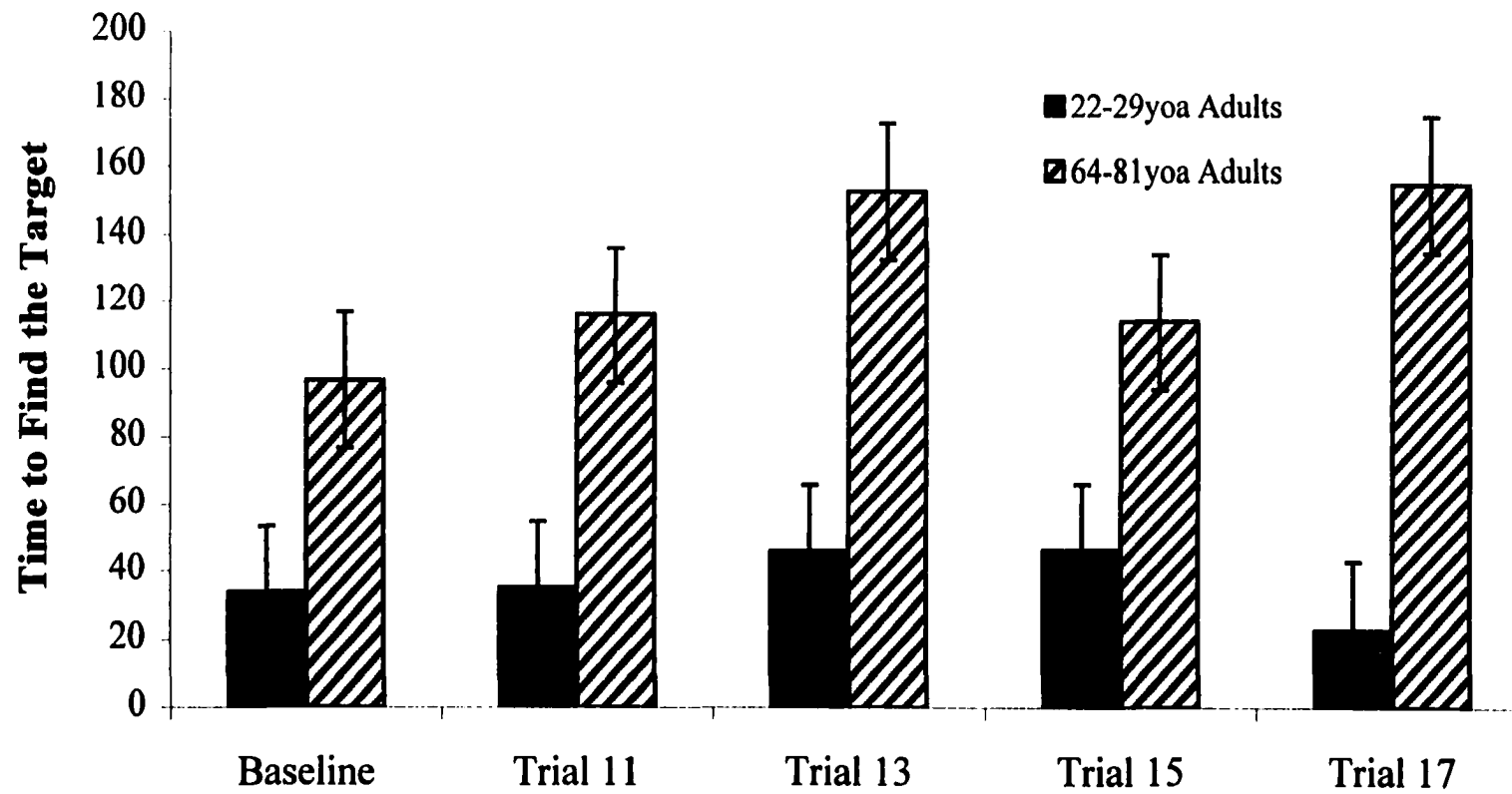
Figure 9. Mean time and SE to find the target in seconds for the baseline (mean Acquisition trials 8-10) and mean time and SE to find the target in seconds for all 4 Elimination trials.

$\underline{F}(4, 56) = 2.42$, and a significant Trial x Group interaction, $\underline{F}(4, 56) = 2.97$. Separate within-subject repeated measures ANOVAs detected no significant effects across Trials for Group 22-29yoa, $\underline{F}(4, 28) = 1.15$, but significant effects across Trials for Group 64-81yoa, $\underline{F}(4, 28) = 3.35$. Post-hoc comparisons on the data obtained from Group 64-81yoa detected the following: (a) no significant differences between the time to find the target on the first elimination trial and the third elimination trial, $\underline{F}(1, 7) < 1$, (b) no significant difference in time to find the target between the second elimination trial and fourth elimination trial, $\underline{F}(1, 7) < 1$, (c) a significant difference between time to find the target on the first and third elimination trials taken together and compared against time to find the target on the second and fourth elimination trials, $\underline{F}(1, 7) = 8.66$, and (d) a significant difference between time to find the target on the four elimination trials taken together and compared against time to find the target on baseline trials, $\underline{F}(1, 7) = 6.06$. The participants in Group 64-81yoa thus seem to have difficulty locating the target when distal stimuli are removed from two of the arena walls. It was noted by the experimenter that the older adults verbosely commented when walls were eliminated. They seemed somewhat taken aback and disrupted when this occurred. The 22-29yoa adults showed no such reactions to the elimination trials.

Probe Trial

Figure 10 presents the mean time the participants searched the quadrants on the probe trial for each group. It appears the participants in Group 22-29yoa searched the target quadrant (NW) more than any of the other three quadrants. In contrast, the participants in Group 64-81yoa equally distributed their search over the four quadrants.
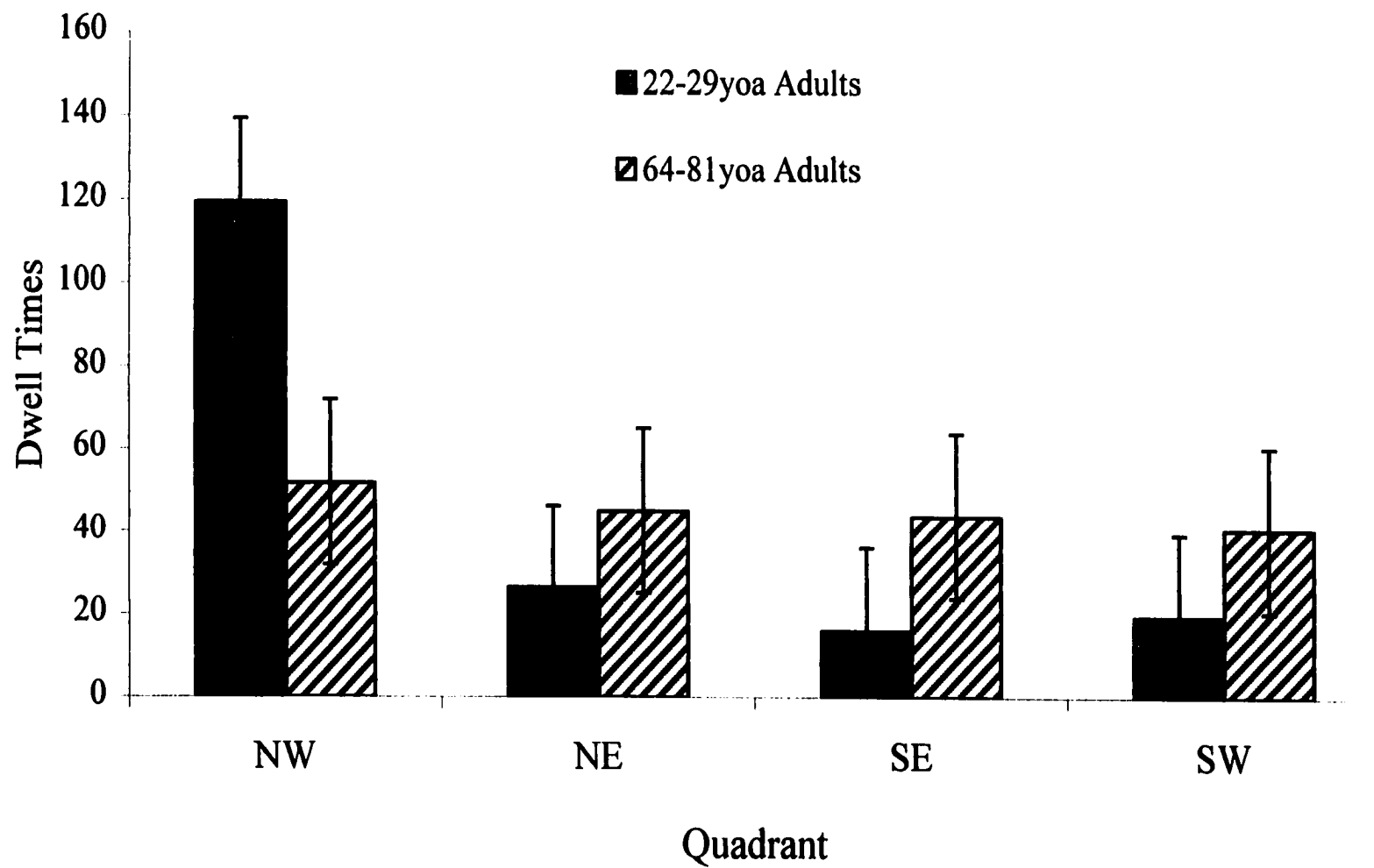
Figure 10. The mean duration of time in seconds and SE spent in each quadrant during the Probe trial for both groups. The NW quadrant was the target quadrant.

Separate within-subject repeated measures ANOVAs conducted on the data obtained from each group detected a significant Quadrant effect in Group 22-29yoa, $F(3, 21) = 13.55$, but no significant Quadrant effect in Group 64-81yoa, $F(3, 21) < 1$. Post-hoc contrasts conducted on the data obtained from Group 22-29yoa detected the following: (a) no significant difference between the mean time spent searching the NE and SW quadrants, $F(1, 7) < 1$, (b) no significant differences in mean search time between the NE and SW quadrants taken together and compared to the mean search time in the SE quadrant, $F(1, 7) < 1$, and (c) a significant difference in mean search time between the NE, SW, and SE quadrants taken together and compared to the time spent searching the NW quadrant $F(1, 7) = 17.62$.

Experimental Puzzle Task

The same two independent raters scored the experimental puzzle task. Correlations on each measure yielded perfect agreement except on wall ($\kappa = .49$) and target placement ($\kappa = .70$) in the experimental task. Nonetheless, the scores between the two raters on each of these two measures were significantly correlated at the .05 level. The raters disagreed on 5 of the 128 scores rated. For those five items, the statistical analyses used an average of the two rater's scores.

Figure 11 illustrates the mean scores for each group on three measures (wall placement, object placement, and object accuracy) for the experimental puzzle. As before, these three measures were meant to reflect the participant's knowledge of the spatial configuration of the experimental room. It appears there were no differences between the two groups on any measure. Also, these scores appear relatively high,
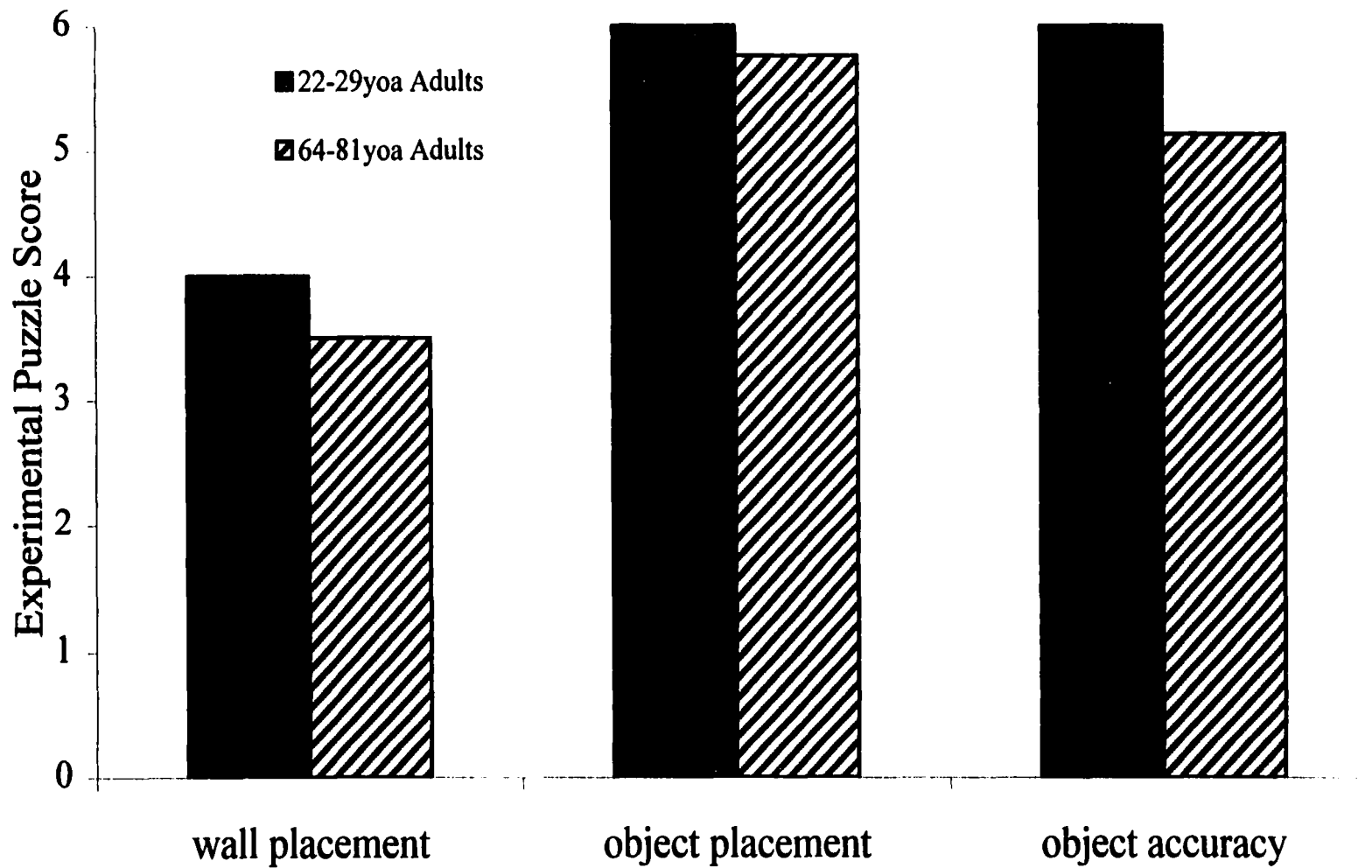
Figure 11. Distribution of puzzle scores for both groups on the three spatial configuration measures. A maximum score for wall placement was a 4. A maximum score for object placement and accuracy was a 6.

suggesting accurate reconstruction of the experimental puzzle task. Independent samples Mann-Whitney tests found no differences between the two groups performance on the experimental room puzzle task on wall placement ($p = .23$), on object placement ($p = .44$), and on object accuracy ($p = .11$). The analysis supports the impression that the participants in both groups knew the spatial configuration of the experimental room equally well.

It appears that for 22-29yoa adults, accurate spatial configurations occur as evidenced by high scores after only three trials (one demonstration, two practice) in the practice arena. In contrast, 64-81yoa adults accurate spatial configurations of the arena occurs (a) after practice and understanding of the task, and (b) after seventeen trials in the experimental arena.

Figure 12 shows the mean score for each group on target placement. It appears that 22-29yoa adults accurately placed a representation of the target in the correct quadrant. Surprisingly, it appears that 64-81yoa adults did not. An independent samples Mann-Whitney test detected a significant difference between the two groups ($p < .00$). All eight participants in Group 22-29yoa received a perfect score in target placement; six of the eight participants in Group 64-81yoa received scores of 1; the remaining two participants in Group 64-81yoa received scores of 0. 22-29yoa adults consistently place the target in the correct quadrant, but 64-81yoa adults did not.

Actual Space versus Computer-Generated Space

Correlation analyses between the two studies were conducted on three measures taken from each study. Newman and Kaszniak (1997, study 1), used three measures to
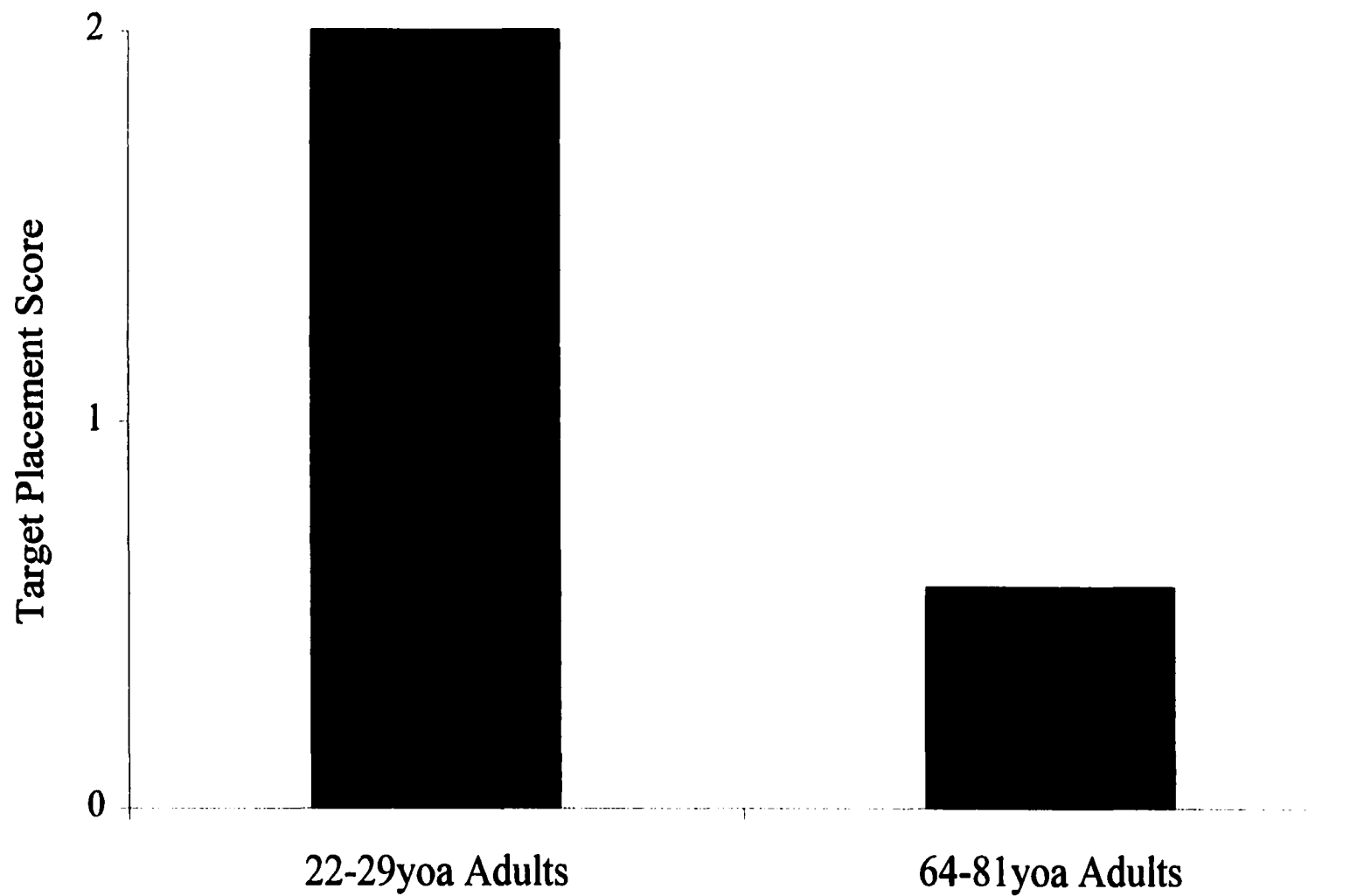
Figure 12. Distribution of experimental target placement for both groups on the puzzle task. A score of 2 indicated a correct quadrant placement.

evaluate performance: learn error, rotation error, and probe error. Error is a mean score of how inaccurate in degrees the placement of the pole was relative to the correct spatial position. Learn trials were the first three trials of testing in which the pole was placed in the correct spatial position. Rotation trials were the other nine acquisition trials where participants were started from novel locations. Probe trials consisted of four trials in which distal cues were removed. For analyses, data were grouped from the C-G Arena (study 2) from comparable trials. For each measure the mean time required to find the target across specified trials was taken. To compare against learn error, the latency data from the first three acquisition trials were used. The reasoning for this is that the experimenter helped the participants find the target on those first three acquisition trials if they could not find it within a time limit. For rotation error, the latency data from the remaining five acquisition trials were used. The reasoning is that no help was given and each participant started from several locations. For probe error the latency data from the four elimination trials were used. The reasoning is that the same cue elimination occurred.

Correlation analyses indicated positive correlations between the two studies on all three measures: (a) learn scores, $r = 0.76$, $p < .00$ (b) acquisition scores, $r = 0.59$, $p < .00$ (c) elimination scores, $r = .58$, $p < .00$. Thus, one could argue that similar patterns existed between the two studies on learning, acquisition, and elimination trials.

There are more possible analyses that can be conducted between the two studies. Those analyses are ongoing and will be left for future studies.

Discussion

The present study demonstrated: (a) 22-29yoa adults and 64-81yoa adults take the same amount of time to locate a visible target, (b) 64-81yoa adults show different stopping behaviors on visible target trials, (c) 22-29yoa adults perform better than 64-81yoa adults on acquisition trials, elimination trials, and the probe trial, (d) some 64-81yoa adults seem to place learn, but elimination of sets of distal cues disrupts performance as measured by time to find the target, (e) 22-29yoa adults accurately reconstruct the practice puzzle task; in contrast, 64-81yoa adults do not accurately reconstruct the practice puzzle task, (f) 22-29yoa adults and 64-81yoa adults both accurately reconstruct the walls and objects on the experimental puzzle task, and (g) 22-29yoa adults accurately placed the target on the experimental puzzle task, whereas 64-81yoa adults reconstructed the experimental room but they did not accurately place the target in that room.

Practice Trials

The data suggested that when the target was visible, 64-81yoa and 22-29yoa adults participants used equally efficient search patterns or motor strategies to locate it. Thus, it appears both 22-29yoa adults and 64-81yoa adults understood and performed this part of the computer-based task equally well. This similarity may be due to the fact that finding the visible target does not require knowledge of distal cues or their relationships.

Stopping behaviors

Participants' stopping behavior on the practice trials is also of theoretical interest. Four of eight 64-81yoa adults crossed the target before stopping on it and exiting the

arena. In contrast, all 22-29yoa adults and the four remaining 64-81yoa adults stopped on the target and remained on it until they exited the arena. One possible explanation for this difference in stopping behaviors could be that some 64-81yoa adults did not understand the task procedures or had difficulty controlling the joystick. But all participants, with the exception of one, remained on the invisible target after locating it. The important difference between practice and experimental trials may be that the platform was visible in the practice trials and invisible in the experimental trials. Another important difference may be that they had more practice with the joystick. The important difference between the individuals who did not stop and those individuals that did stop on the target may be functional changes associated with age. As mentioned previously, the mean age of those individuals who did not stop was 76.5 years. The mean age of those individuals who did stop was 69.5 years. An interpretation of this finding could be related to behavioral problems associated with perseveration (Lezak, 1996).

Perseveration, or behavioral rigidity, is a difficulty in making mental or behavioral shifts. Not stopping on the visible target could be an example of the behavioral inflexibility of individuals as they get older. Another example would be an increase in the time it takes to find a target from a novel start location. To adopt different perspectives to carry out the operations necessary for task completion, one must be able to change and modify behavior, responses, and point of view flexibly.

To test whether these 64-81yoa adults are exhibiting behavioral inflexibilty, neuropsychological tests such as the Trail Making Test and the Wisconsin Card Sort could be given to participants (Lezak, 1996). If, according to these types of tests, the 64-

81yoa adults who do not stop on the target also exhibit behavioral and cognitive deficits associated with pre-frontal damage according to the tests, then this would support the notion that stopping behavior in the C-G Arena might be used as one part of a battery of neuropsychological tests.

Acquisition and Probe Trials

The time 22-29yoa adults, but not 64-81yoa adults, required to find an invisible target decreased significantly across acquisition trials. If we assume a direct correspondence between time to find the target and knowledge of its location, decreasing latencies to find the invisible target indicate 22-29yoa adults learned the location of the invisible target. Yet, there is noticeable variability in performance of the 64-81yoa participants in terms of locating the target. Some of these participants located the target on one trial but did not locate it on the next trial. In contrast, others located the target successfully for the last several trials. The argument could be made that four of eight 64-81yoa adults began to acquire the location of the target over the last few acquisition trials.

The 22-29yoa adults did not find the invisible target using proximal cues, since none were programmed into the arena. These participants could also not have used motor strategies to locate the target because they entered the arena at random start points and were therefore required to generate unique routes to find the target from each start point. Thus, it appears the 22-29yoa participants used distal cues and relations among them to learn and remember the location of the invisible target. If no such learning of distal cues occurred, then successful and rapid location of the target across trials would not occur.

Additionally, the time 22-29yoa adults spent searching any given quadrant in the arena during the probe trial was greater for the target quadrant than any other. In contrast, 64-81yoa adults showed no preference for any one quadrant; rather, they searched all four quadrants equally. Given these data, we can conclude that place learning based on the relationship between distal cues occurred in 22-29yoa adults, but not in 64-81yoa adults.

Elimination Trials

Across the elimination trials, removing any set of distal cues did not disrupt performance of 22-29yoa adults. The 22-29yoa adults consistently and rapidly located the target independent of which sets of stimuli were removed (see Jacobs, et al., in press, for similar findings). In contrast, the 64-81yoa adults took more time to find the target when sets of distal cues were removed. Therefore, it seems removing distal stimuli disrupted performance in 64-81yoa but not 22-29yoa adults.

Informally, the 64-81yoa adults visibly reacted to the elimination trials. Every 64-81yoa adult commented to the experimenter and expressed frustration during the elimination trials. 22-29yoa adults gave no such response.

As mentioned earlier, four of eight 64-81yoa adults appeared to give evidence of some memory for the location of the target toward the end of the acquisition trials. If this was true, then why would their performance on elimination trials be disrupted? Even though the 64-81yoa adults might not have successfully acquired the location of the invisible target by the end of the acquisition phase, removing any set of distal cues disrupted their ability to locate the target. Reasons for this might include: (a) 64-81yoa adults form cognitive maps so fragile that any change of cues in the environment disrupts

the entire map, (b) 64-81yoa adults are not given enough acquisition trials to place learn, or (c) 64-81yoa adults are using single cues or single sets of cues rather than relationships among cues to guide their search.

The argument that 64-81yoa adults are not exposed or given enough acquisition trials to learn the location of the target rests on the assumption that 64-81yoa adults could place learn, but require more practice than 22-29yoa adults. Whether 64-81yoa individuals would exhibit greater learning with more practice cannot be determined by the results from this study. A study that might disconfirm this reasoning would involve increasing the number of acquisition trials to which 64-81yoa adults are exposed thus determining if and at what point 64-81yoa adults place learn.

The argument that 64-81yoa adults do not use relationships among cues but single cues is compatible with S-R theory of place learning. This theory argues that organisms use single cues to search for a particular place within space. According to this model, movement is guided by the position of individual cues, not the relation among sets of cues. This view predicts that removing sets of cues will disrupt performance in the arena task because a crucial cue could be removed, thereby disallowing successful movement. On the other hand, cognitive mapping theory argues that spatial relations among distal cues guide place learning. Therefore, searching based on single cues does not count as place learning. Cognitive mapping theory predicts that removal of distal cues would not affect performance, because no single cue guides the search process; rather, the whole environment contributes to the construction of a cognitive map.

In the present study, 22-29yoa adults performed optimally on all four elimination trials. This is consistent with a prediction made by cognitive mapping theory. In contrast, 64-81yoa adults did not perform optimally on the four elimination trials. The elimination of any set of distal cues disrupted their performance. It is thus possible that 64-81yoa adults are guided by the position of individual cues rather than relations among sets of cues. Such a notion may explain why efficient place learning does not occur in the C-G Arena for 64-81yoa adults.

If one could devise a study in which 64-81yoa adults could at some point place learn, then one test these two theories against one another. If 64-81yoa adults place learn based on S-R theory, then their performance would be disrupted on elimination trials subsequent to their acquiring the location of the target consistently. If, on the other hand, 64-81yoa adults place learn based on a cognitive map, then their performance would not be disrupted on elimination trials.

Also, one could propose a study to determine if the inflexibility of cognitive maps disrupts acquisition of target location. The study would involve having 64-81yoa adults enter from one start location and determining if the time it takes them to find the target decreases across several trials. If it does decrease, then 64-81yoa adults could be transferred to novel start locations and tested to see whether their performance is disrupted. If 64-81yoa adults show no difference in time required to locate the target from the novel start location, then this suggests (a) they are using the relationships between distal cues to guide behavior rather then motor strategies, and (b) their cognitive maps are flexible enough to allow transfer of learning.

Puzzle Task

There was a large difference between the accuracy of 22-29yoa and 64-81yoa adults on the practice puzzle task. It appears that for 22-29yoa adults, accurate spatial configurations occur as evidenced by high scores after only three trials (one demonstration, two practice) in the practice arena. In contrast, 64-81yoa adults do not perform accurately on the practice puzzle task.

There are two possible reasons for the difference in accuracy of practice puzzle task configurations. First, three trials may not be enough exposure to the practice room for 64-81yoa adults to learn the spatial configuration of the walls and objects in that room. The 64-81yoa adults were able to perform accurately on the experimental puzzle task only after extensive exposure (17 trials) to the experimental room. Thus, we can speculate that if 64-81yoa adults are given enough trials, or exposure, to a room, they might be able to accurately reconstruct that room.

Second, overshadowing (see Kamin, 1969; Pavlov, 1927) of distal cues might have occurred on the practice trials due to a strongly salient proximal cue, the visible target. Therefore, 64-81yoa adults perform less accurately on puzzle scores due to attending to the visible platform and to the task procedures. In contrast, the 64-81yoa adults accurately reconstruct the experimental room because there are no salient proximal stimuli in that room; the target is invisible. Therefore, the 64-81yoa adults are able to learn the spatial configuration of that room. Moreover, 64-81yoa adults might have been attending to the task procedures. This argument assumes (a) 64-81yoa adults had no prior exposure to computers, and (b) 22-29yoa adults have had prior exposure to working

on computers. If these assumptions are valid, then the following support for this argument could be made. After the experimenter reconstructed the puzzle, the 64-81yoa adults stated they now understood the task and its relation to the construction of the computer-generated room. 22-29yoa adults had no such reaction. Additionally, the 64-81yoa adults may have been attending to the unfamiliar computer and joystick. Moreover, the 64-81yoa participants had accurate scores later in the experimental puzzle task, after being shown the task requirements and having had exposure to both the computer and the joystick for several invisible target trials.

It follows from the discussion above that reasons why the two groups performed comparably on experimental puzzle task scores might be because: (a) the 64-81yoa adults were used to the task and knew what to attend to, (b) the 64-81yoa adults had enough exposure after seventeen trials to learn the spatial configurations, and (c) the target was invisible so no overshadowing of distal cues could occur.

The opposing reasons suggested for the puzzle task differences are speculative at this time. Future studies need to be conducted to investigate these speculations. One such study could involve running two groups of 64-81yoa adults through 20 acquisition trials in the same experimental room. One group would have a visible target for all 20 trials, the other group would have an invisible target for all 20 trials. Immediately after the acquisition trials, each participant would be given a puzzle task.

An important theoretical question is why 64-81yoa adults can accurately reconstruct the experimental room on the puzzle task, but did not accurately place the target on the puzzle task. One reason for this difficulty in target placement might be that

spatial mapping occurs but place learning does not. More specifically, while the individual wanders through the C-G Arena, he constructs a spatial map of the environment (latent learning). Place learning, on the other hand, occurs only once the target has been located. The individual cannot add the location of the target to the constructed spatial map if he has never been on the target, or been on the target for a few times. Thus, it could be suggested that accurate spatial maps of the entire environment including the target will only occur in adults after they have acquired the target.

Conclusion

In sum, four measures of spatial knowledge (time to find the invisible target on acquisition and elimination trials, quadrant search time during a probe trial, and puzzle task accuracy) converge on the suggestion that 22-29yoa adults learn and remember the location of an invisible target in computer-generated space on the basis of distal cues. These data suggest that place learning based on distal cues alone occurs in 22-29yoa adults. In contrast, the same four measures converge on the suggestion that 64-81yoa adults do not learn and remember the location of an invisible target in computer-generated space on the basis of distal cues. The 64-81yoa adults are able to construct the experimental puzzle room but are not able to accurately place the target within that room.

Thus, all four measures suggest that learning of spatial configurations occurs in 64-81yoa adults. Therefore, the main difference between 22-29yoa adults and 64-81yoa adults is that 22-29yoa adults appear to locate the target based on relationships between distal cues and 64-81yoa adults do not appear to locate the target based on relationships

among distal cues. Cognitive maps or representations of the room itself do not differ significantly between groups of 22-29yoa adults and 64-81yoa adults. The difference lies in the fact that 64-81yoa adults do not accurately place the target within a representation of that room.

Future studies might examine the ease with which place learning occurs as a function of age. Of the eight 64-81yoa adults, four appeared to place learn toward the end of the eight acquisition trials. It is interesting to note that the mean age of those who may have place learned is 68.75 years, whereas the four remaining 64-81yoa adults who showed no evidence of place learning had a mean age of 77.25 years. It is pure speculation at this point whether this age-related phenomenon concerning place learning would hold true with a larger sample.

There is a clear need for future studies explaining the theoretical implications of the findings reported here. These results need to be replicated with a larger sample in a more controlled study. Using a larger sample size with more age groupings could more accurately pinpoint the age at which changes in spatial cognition and place learning occur. Moreover, the question of whether the computer-generated world reliably and validly measures performance in the real world needs to be explored. A possible study could involve running participants concurrently through a real world arena such as that described by Newman and Kaszniak (1997) and through the computer-generated arena. This procedure would allow for more direct comparisons between the two tasks.

Appendix A
C-G Arena Instructions

Demonstration Phase:

Pay close attention to these instructions and to what I will demonstrate. I am going to show you how to complete a computer task. When I am done, you will do the same task. If at any time you begin to feel dizzy or upset in any way please let me know.

First, I will describe what you will see on the computer screen and what you will need to do later. If you have any questions about these instructions or your task, ask them as we go through the demonstration and later while you are practicing.

I will enter two different imaginary rooms, a waiting room and a demonstration room. Both rooms contain large circular arenas inside large square rooms.

I will start in a bare room, the waiting room. There I will practice moving and looking around. When I am ready, I will transport myself to the second room, the demonstration room. There I will search for, find, and stand on a large blue target. The target will be visible on the floor of the arena. Once I move onto the target, the computer will beep each time I turn or move.

I will then take a good look around so I know what the room looks like and so that I know where the target is located. When I am ready, I press the space bar and the computer screen will go blank. It will then be your turn to go into the same room I was in and find the same visible target. You will do this twice to become familiar with the task and the joystick. Do you have any questions?

Practice Phase:

It is now your turn to practice the same computer task in the same room. Like me, you will start in a bare room, the waiting room. Use the joystick to practice moving and looking around.

Moving and looking:
        To go forward, push the joystick forward.
        To go backward, pull the joystick backward.
        To turn to the right, push the joystick to the right.
        To turn to the left, push the joystick to the left.
        When you turn to the right or left, it will be as if you were standing in one place and turning.

When you have mastered moving and looking, press the space bar on the keyboard. You will then be transported into the practice room. In the practice room, your task will be to search for, find, and stand on the same large blue target as I did. As you saw, the target

will be visible. Once you move onto the target the computer will beep each time you turn or move. Once you are on the target, take a look around. Be sure not to move off the target once you find it. If you do not hear the computer beep that means you are no longer on the target. When you are ready press the space bar and you will be transported back to the waiting room.

You can practice or rest there. When you are ready, press the space bar and you will be transported back to the practice room where you will find and stand on the same target. When you are ready, press the space bar and the screen will go blank. You will then be ready for the testing phase.

Do you have any questions?

Testing Phase:

Now we are going to do something a little bit different. You will complete the same task you just practiced, but this time you will be in a completely different room. Also, the target will not be visible until you find it. You won't be able to see the target at all until you are standing on it and the computer starts beeping. Once you find the target and hear the beeps, take a good look around the room and see where you are. This is important because the target will be in the exact same place every time. After you find the target and take a look around, you can press the space bar and go back to the waiting room. You need to be on the target to do this.

Once you are in the waiting room you can rest or practice there. When you are ready, press the space bar to go back to the experimental room. You will repeat this cycle: waiting room – experimental room – find and stand on the target – waiting room- for several trials.

You do have a limited amount of time to find the target. If you go over this time you will be automatically transported back to the waiting room. If this happens, press the space bar when you are ready to go back to the experimental room.

It is important to know the location of the target and the room. Remember the target will be in the exact same place each time. For some trials, certain walls of the room may be removed. You are still in the exact same room as before, but some things may be missing. This is why it is important to know where the target is located and what the room looks like.

Finally, we have designed one trial to be really challenging. On that trial, we have made the target really hard to find. If you think you are in such a trial, please keep searching until you find the target or until the trial ends.

The last trial will be very easy. In this trial the target will be visible just like it was in the practice trials. When you come to this trial, you will know that you are finished.

Do you have any questions?

Important Reminder:
   The target will always be in exactly the same place.

Appendix B

Puzzle Task Instructions

These pieces represent everything that was in the room. Place these pieces on the paper in the same way that they were arranged in the room. The blue square is the target. Be as exact as possible when placing the target. Do you understand what you are supposed to do?

Appendix C
Medical History Questionnaire

1. Do you have hypertension or hypo-tension that is not controlled by medication? If yes, please describe.

2. Have you had any cardiac arrests? If yes, when?

3. Do you have any systemic illnesses that you are not taking medication for? If yes, please describe.

4. List each medication you are taking and why that medication was prescribed.

5. Do you have difficulties with vision or motor skills? If yes, please describe.

6. Have you ever had periods of unconsciousnous or other neurological problems? If yes, when? Please describe.

7. Are you right or left handed?

Are any of the answers to the above questions different then how you would have answered these questions when you went through the previous task with Mary Newman and Al Kaszniak? If yes, which ones.

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