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Aging and Biases in Spatial Memory: A Dynamic Field Approach

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by

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Spatial cognition encompasses a wide variety of abilities and requires the interaction of several regions of the brain, including the hippocampus, striatum, and pre-frontal cortex (PFC). (Packard & McGaugh, 1996; Reuter-Lorenz et al., 2000). Given that these areas atrophy in later adulthood (Golomb et al., 1993; Raz et al., 2003; Aizenstein et al., 2006), it raises the question of how spatial cognition changes with age. It has been found that increased task complexity leads to an age-related decline in performance (Nagel et al., 2009). Other factors that lead to a decline in memory performance in older adults include whether the memory task involves allocentric or egocentric memory (Desrocher & Smith, 1998). This study developed a computational model of spatial working memory recall and recognition abilities for young adulthood to late adulthood using a type of neural network—dynamic field theory. This model was used to generate hypotheses of how spatial working memory recall and recognition abilities change from young adulthood to late adulthood. This model also influenced the development of hypotheses of how long-term memory performance changes with age, and how working memory abilities predict long-term memory abilities. Some of the hypotheses were supported, such as performance declined as task complexity increased, and, compared to younger adults, older adults had a greater level of error on the long-term memory task. Other models and hypotheses, such as the prediction that there would

not be a significant difference in performance between the two age groups on a spatial working memory recall task, were not supported.

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CHAPTER I: INFLUENCE OF AGING ON THE BRAIN AND MEMORY

From 1946 through the early 1960s, there was rapid rise in the birth rate of the United States, leading to what has been dubbed as the Baby Boomer Generation (U.S. Census Bureau, 1997). Today, in 2018, the members of the Baby Boomer generation are either older adults (at least 60 years old) or quickly approaching late adulthood. According to the U.S. Census Bureau, older adults made up almost a fifth (18.5%) of the United States population in 2011 (U.S. Census Bureau, 2011). Because of this increase in the older adult population, population demographics are shifting from the historically pyramidal-shaped distribution in which there were very few older adults to one that is more equally distributed across the age range. Several factors have influenced this change in demographics including improved medical technology that has increased the longevity of the human lifespan, and the largest generation in U.S. history entering late adulthood. With an increasingly aging population, both in the United States and around the globe, it is becoming more important to study changes that occur due to advanced age. The purpose of this thesis is to examine how memory (with a primary focus on visuo-spatial memory) is influenced by age-related behavioral and neurological changes.

Spatial cognition is a complex, interdisciplinary area that has connections to other forms of cognition. There are many forms of spatial cognition (Klencklen, Despres, & Dufour, 2012) and many ways that people use spatial cognition in their daily lives. People use spatial cognition to assess their surroundings, reach for an object on their desk (which may or may not be in their line of sight), look for car keys, move from room to another, navigate to work or home, and learn how to traverse a new city. This specific study focuses on different types of location memory and errors in remembering an object's location. The long-term goal of this line of research is to develop a framework for better understanding how people form mental maps and navigate around layout. Klencklen, Despres, and Dufour (2012) discuss how spatial memory is necessary for navigation and that a key part of spatial memory is a person's ability to remember the location of objects. Therefore, in order to understand navigation, it is important to have a better understanding location memory. Furthermore, it is important to examine factors that influence spatial memory. One factor of particular interest to the present study is how spatial cognition changes over the lifespan. While the literature discusses how various types of spatial cognition change across the lifespan, one area that has some gaps is the development of location memory. Several studies have examined the development of location memory in children (e.g. Newcombe, Huttenlocher, & Sandberg, 1994; Schutte & Spencer, 2002; Spencer & Hund, 2002; Schutte & Spencer, 2009), there is noticeably less research examining location memory abilities in late adulthood (Evans, Brennan, Skorpanich, & Held, 1984; Moffat & Resnick, 2002; Yamamoto & DeGirolamo, 2012).

In the context of the present study, cognitive development is operationalized as any age-related change in cognition. These changes can either be improvements in cognitive ability or a decline in cognitive ability. As the following sections will demonstrate, spatial cognition is not a static ability; it develops across childhood, (e.g. Schutte & Spencer, 2002; Spencer & Hund, 2002), and it changes yet again in late adulthood (e.g. Moffat & Resnick, 2002). The research reviewed in the following paragraphs discusses how some forms of spatial cognition decline while other parts remain unchanged. It is important to understand factors related to cognitive decline in order to better understand what can be done to either prevent or slow down hindrances to our memory. This area of research is particularly important for the questions of how to prevent or treat memory loss due to dementia. The present study only focuses on healthy cognitive aging and does not test a clinical population, such as people with dementia. The study of healthy aging is just as important as the research involving a clinical population because in order to understand what factors cause dementia and how this disease impairs cognition, it is necessary to first understand healthy aging. The study of healthy aging requires an interdisciplinary approach and the present study seeks to meet this need by using developmental and cognitive theories to behaviorally test changes in cognition. This study also takes an interdisciplinary approach by using the neurocognitive literature to create neural network models of cognitive development.

Traditionally, behavioral, neurological, and developmental theories have focused on developmental changes either during childhood or during adulthood. In the past, developmental psychology tended to focus primarily on the cognitive development of infants, children and adolescents. For example, Piaget's (1963) last stage of cognitive development, formal operations, begins during the teenage years. His theory does not address cognitive changes in late adulthood. Other theories, such as the Reduced Processing Resources theory and Gerodynamics only focus on development in adulthood (see Schroots (1996) for a review).

Dynamic field theory (DFT) has been used to address cognitive changes in childhood (e.g. Samuelson, Schutte, & Horst, 2009; Schutte & Spencer, 2002; Schutte, Spencer, & Schöner 2003; Schutte & Spencer, 2009; Schöner & Thelen, 2006; Simmering, Schutte, & Spencer, 2008). DFT is a developmental theory that is based on the neuroscience of neural interaction. An advantage of DFT is that it can be used to address changes that occur from infancy through late adulthood.

The purpose of the current study was to fill the aforementioned gaps in the cognitive development literature in two ways: (a) behaviorally through investigations involving spatial memory tasks and (b) through computational models using DFT. This study tested younger adults between the ages of 18-22 years of age and older adults who were between the ages of 60-80 years of age and did not show any signs of clinical impairment (e.g. mild cognitive impairment, Alzheimer's disease or another form of dementia, Parkinson's disease, or Korsokoff's syndrome). Three tasks measured the differences between young adults' spatial memory abilities and older adults' spatial memory abilities.   One task tested for groups differences in geometric biases on a spatial working memory recall task in which participants had to recall the location of one target. Only one target was used for this task in order to directly study the influence of the midline axis on memory for a location. Prior research has found that the presence of multiple items in the tasks space could bias spatial working memory (e.g. Johnson & Spencer, 2016), and the current study is only interested in the influence of the midline on spatial memory biases. Therefore, the author did not want to add another factor that could potentially confound the midline's influence location memory. A second task was a spatial working memory recognition task in which participants viewed layouts of varying numbers of targets and had to determine whether a probe matched one of the previously seen locations. The term "working memory" is applied to the first two tasks because prior research has found that both visuospatial short-term memory tasks and visuospatial working memory tasks involve an executive function component (e.g. Miyake et al., 2001). Miyake et al. (2001) also found that these two types of visuospatial memory are correlated with each other. The third task tested participants' long-term recall memory in which participants had to learn a variety of layouts that contained three targets during a study phase, then do a distractor task for 10 minutes, and then try to recall the different locations that targets had appeared at for each layout.

The second goal of the study, which is expanding the use of DFT to computationally model neurocognitive changes in late adulthood, was accomplished by creating models to generate predictions about differences between the spatial memory performance of younger and older adults as they completed the behavioral tasks in this study. DeGirolamo and Schutte (2014) demonstrated that dynamic neural field models could capture cognitive changes in late adulthood. They accomplished this by modeling the results of a spatial working memory task used by Nagel et al. (2009) that studied differences between younger adults and older adults on a spatial working memory recognition task. DeGirolamo and Schutte (2014)'s models are similar to some of the models used in this paper and both sets of models have tested the role of task complexity. Another set of models tested the geometric biases of younger adults and older adults. Geometric biases are biases toward or away from the midline symmetry axis of a task space (e.g. Spencer and Hund, 2002; 2003). Specifically, a bias away from the midline is when an individual "remembers" a target as being further from the midline axis than it actually was and a bias toward the midline is when the person "remembers" the target as being closer to the midline than it actually was. The parameters for the computational models were based off the neurological and behavioral results of studies that examined executive functioning and memory in late adulthood.

The next sections describe various factors that influence the development of spatial cognition. The first section elaborates on age-related changes in behavior. Specifically, section 1.1.1 will discuss how spatial encoding changes with age, followed by section 1.1.2, which provides an elaboration of how spatial memory changes across the lifespan. Section 1.2.1 discusses neurological changes that occur with age. Finally, section 1.2.2 covers a discussion of how the brain compensates for age-relate changes.

1.1 *Influence of cognitive aging on spatial memory*

While it is important to examine what changes occur in the brain as we age, it is equally important to examine how these neurological changes translate into cognitive behavior. For example, how does compensatory activation in the brain affect behavior? Does it maintain certain behaviors at the expense of others? The purpose of this section is to provide a discussion of how cognitive aging impacts different aspects of spatial memory, including the influences of task complexity, how sequence influences spatial memory, and how spatial memory is encoded. The ensuing discussion will address the aging process's influence on different components of spatial cognition within the framework of Atkinson & Shiffrin's (1968) Information Processing Model. It is important to note is that these components are not mutually exclusive and issues with how information is encoded will influence both working memory and long-term memory.

1.1.1 *Factors influencing age-related changes in spatial encoding*

There are several factors that influence how spatial locations are encoded. These factors included accuracy of perception, ability to maintain and scan a mental image, and whether the person uses a coordinate strategy or categorical strategy. Other factors include executive functioning and perceptual processing speed. Spatial memory is dependent on how accurately people perceive and encode information from their sensory store. Klencklen, Despres, and Dufour (2012) define visuo-spatial perception as the process through which we analyze how objects are placed within a space. It also serves as a basis for the ability to accurately complete the following tasks: orient oneself within an environment, reach for a visible item, and shift one's gaze (visual attention) to different locations. Visuo-spatial perception can be further divided into categorical representations (which are abstract and schematic) or coordinate representations (measurement-based organization based on object locations). As discussed in the prior section, it was found that younger adults use a coordinate strategy to encode visuo-spatial information while older adults use a categorical strategy to encode information (Antonova et al., 2009). Furthermore, younger adults tend to have a more accurate performance than older adults when using a coordinate information processing (Bruyer, Scailquin, and Coibion, 1997).

As information moves from the sensory store to the short-term memory store and long-term memory store, the person forms a mental image of the visuo-spatial information that he or she encoded. Individual differ in their abilities to perform different mental imagery tasks (e.g., Cui, Jeter, Yang, Montague, & Eagleman, 2007; Kosslyn, Brunn, Cave, & Wallach, 1984). However, Klencklen, Despres, & Dufour’s (2012) review focuses on differences between age groups, which collapses individual differences into a higher-order level. Their review describes four sub-components of mental imagery: image generation, image maintenance, image scanning, and image rotation. Only two of these types of mental imagery are relevant to the current study: item maintenance and mental scanning. Item maintenance involves the ability to hold the generated image within a person's mind. This particular component, specifically the participants’ ability to maintain the locations of targets in their memory, is the primary interest of the current study. Specifically, this study sought to examine how location maintenance was impacted by the shorter maintenance timeframe of working memory, the longer maintenance timeframe of long-term memory, and how a person's age impacted their ability to maintain a location over these periods of time. Finally, this study examined how the type of task (recall or recognition) impacted working memory performance. For the spatial working memory recall task, participants only needed to maintain the location of one object in their memory. For the spatial working memory recognition task and the long term memory task, participants needed to maintain the locations of multiple targets that appeared simultaneously.

Image scanning involves the ability to mentally access the measurement features of an object, such as size, shape, and distance between objects (Klencklen, Despres, & Dufour, 2012), and the ability move attention from one object to another (Denis & Kosslyn, 1999). Certain parts of image scanning can be impacted by a person's age. For example, Iachini, Poderico, Ruggiero, and Iavarone (2005) examined the ability to learn a perimeter of colored points and recall certain details about the layout by mentally scanning the memory of the perimeter. The researchers found that both younger adults and older adults performed with equal levels of accuracy on recalling the order of colors that were presented; however, the older adults were significantly less accurate at recalling the distances between each of the items (Iachini et al., 2005). In the current study, the spatial working memory recognition task and the long term memory task both entailed shifting attention from one object to another. The target locations were counterbalanced across the quadrants of the computer screen. Additionally, the researchers used an H-trace screener to ensure that the participants in the current study had the oculomotor ability to scan the entire computer screen.

Additionally, Iachini et al. (2005) found differences between the younger adults and older adults in the amount of time spent scanning the different layouts. For the spatial layouts that had smaller distances between the landmarks, younger adults and older adults spent the same amount of time scanning the layout. However, the younger adults spent more time scanning the layouts that had a larger distance between the landmarks, while the amount of time the older adults spent scanning the layout remained relatively unchanged as a function of layout. Iachini et al. (2005) point out that mental scanning tasks only become harder for people as they age if there is a large distance between landmarks. One potential implication that can be taken from their results is that older adults have trouble adjusting their cognitive processing strategy in order to complete the task at hand. While Iachini et al. propose this claim for their study, this idea is more speculative for location memory and needs to be further researched. Iachini et al.'s study is relevant for the spatial recognition task. Participants scanned layouts that contained multiple targets. The distances between targets varied. Additionally, there were three levels of complexity (presence of either 3, 5, or 7 targets). The inability to adjust one's scanning strategy to account for one of these factors could influence a person's performance. Additionally, Iachini et al.'s study is relevant for the long-term memory task, because this task entailed scanning layouts with three targets that were varying distances from each other.

One method of assessing changes in strategy and its impact on performance was having participants complete tasks that required using categorical information and tasks that required using coordinate information. In the current study, categorical information was defined as spatial categories within a homogenous space. Prior research has found that young adult and older children divide a homogenous space into equal-sized categories and are biased away from the midline symmetry axis and toward the center of the spatial category (Spencer and Hund, 2002; Spencer and Hund, 2003; Schutte and Spencer, 2009; Huttenlocher, Newcombe, & Sandberg, 1991). The shape and size of the categories are based on the homogenous space. For example, Huttenlocher, Newcombe, and Sandberg (1991) found that people were biased toward the center of a quadrant if the stimuli were presented in a circular homogenous space. Spencer and Hund (2002) found that people were biased toward the center of the right side or left side of a rectangular homogenous space. Coordinate information is the amount of error in the participants' responses: specifically the distance between their responses and the target location. However, other researchers use slightly different definition for categorical and coordinate information. For example, Meadmore, Dror, and Bucks (2009)'s definition for categorical information is related to the current study's definition, with one difference. While the current study and their study look at categorical information with regards to direction, they focus more on where a target is relative to another target (Target A is to the right of Target B) while the current study looks at categorical information in the context of the environmental categories.

Using the definition of category as where one target was located relative to other targets, Antonova and colleagues compared the performance of younger adults and older adults on a virtual allocentric memory task. Allocentric memory involves remembering where objects are located in relation to each other (as opposed to egocentric memory, which is remembering where objects are in relationship to oneself). Typically, this paradigm is commonly used to examine spatial memory performance. However, the authors applied their results to how the strategy use when processing visuo-spatial information changes with age. Antonova et al. found that not only were younger adults significantly more accurate than the older adults on the allocentric memory task These researchers suggest that younger adults tend to process spatial information using a coordinate strategy while older adults tend to process spatial information using a categorical strategy. These results are not surprising given that Bruyer, Scailquin, and Coibion (1997) found that older adults were significantly less accurate than younger adults on a coordinate visuo-spatial processing task.

In addition to testing people on the visuo-spatial memory task, Iachini et al. (2005) also administered a series of psychometric tests to the participants. They found that while some spatial cognitive abilities were preserved with age—such as the ability to perceive and recall line lengths—other abilities declined—such as the capacity of attention, visuo-spatial working memory, and visuo-spatial reasoning. The decline in these abilities could lead to a decline in accuracy when remembering the locations of different objects. Other studies have found that inhibition declines with age. For example, Tipper (1991) found that the introduction of a distracting picture has a much greater effect on the processing abilities of older adults than younger adults. Additionally, Christ, White, Madernach, and Keys (2001) found that it takes older adults a longer amount of time to inhibit a response.

Another factor that influences the memory abilities of older adults is processing speed. Park et al. (1996) looked at how working memory (measured by a Backward Digit

Span, reading span task, and a computation span task) and processing speed influenced three types of long-term memory. The types of long-term memory included a verbal free recall task, a verbal cued recall task, and a spatial recall task that entailed remembering which quadrant a word appeared in. Park et al. found that while working memory and speed influenced free recall abilities and cued recall abilities, the only factor that influenced performance on their long-term memory task was processing speed. While Park et al.'s spatial long-term memory task has a verbal component to it, the present study's long-term memory task uses symbols instead of words to avoid potentially accessing verbal memories instead of spatial memories.

1.1.2. *Factors influencing age-related changes in spatial memory*

There are several factors that influence the development spatial memory abilities from young adulthood to late adulthood. These factors include task complexity (Nagel et al., 2009), visual distinctiveness of the environment and landmarks (Cherry & Park, 1993; Sharps & Gollins, 1988), and the type of memory task (recall vs. recognition) (Sharps & Gollins, 1988). One influence is task complexity. Nagel et al. provided an example of how task complexity influences spatial working memory across the lifespan. Their study compared younger adults to older adults on a spatial working memory task in which participants were shown a layout with one, three, or seven targets. After the targets disappeared from the screen for two seconds, participants were shown a pro be and asked if the probe either matched or did not match the location of one of the targets. For the one-target and three-target tasks, there was not a significant difference between the younger adults and the older adults. On the most complex task—the seven-target task—the older adults were significantly less accurate than the younger adults. They also used fMRI to measure BOLD responses in the prefrontal cortex, premotor cortex, the posterior parietal cortex, and temporal lobe. Nagel et al. were examining differences between performance level (low vs high) and age (younger adults vs older adults). They found that brain activation in the older adults that had higher performance levels on the behavioral tasks was similar to the younger adults that had a lower performance on the tasks. Specifically, as task complexity increased, high-performing older adults and low-performing younger adults showed a small increase in BOLD response in the prefrontal cortex, premotor cortex, and the posterior parietal cortex. The spatial working memory recognition task in the current study uses a similar design. However, it is anticipated that there was a ceiling effect for the 1-target trials in the study conducted by Nagel and colleagues. The current study dropped the 1-target condition and used a 5-target condition instead. The advantage of this change is that it tests an intermediate level of complexity.

Besides task complexity, a second factor that influences memory differences between younger adults and older adults is the visual distinctiveness of the environment (Klencklen, Despres, and Dufour, 2012). There are a few studies that examine how the level of visual detail in the environment influences a person's spatial memory ability. Cherry and Park (1993) compared the performance of college students, older adults with higher levels of education and older adults with lower levels of education on a task involving learning object locations. Participants learned the spatial locations of different objects either from a plain, black-and-white map or from a colorful 3D model. Additionally, all of the objects in the map/model were either categorically related or categorically unrelated.

The critical results were that the younger adults did significantly better than the older adults with lower education levels on both tasks while the performance of the younger adults and the higher-educated older adults on the spatial recall task using the 3D model did not differ. Conversely, younger adults did significantly better than both groups of older adults on spatial recall when learning the layout from the plain, black-and-white map. Sharps and Gollins (1988) used a similar paradigm and noted that either color or having a 3D model lead to a statistically similar recall performance between younger adults and older adults. Additionally, Sharps and Gollins (1988) noted that among the older adults, there was not a significant difference in performance when the layout was presented in a colorful 3D model compared to conditions where a layout was presented as either as a black and white 3D model or as a colorful map. Their study suggests that adding an extra level of detail, regardless of whether it is color or an extra dimension, helps older adults perform better on certain spatial cognition tasks.

The type of memory task also plays a role in how performance changes across the lifespan. Interestingly, both Sharps and Gollins (1988) and Cherry and Park (1993) find that while the level of detail in an environment influences the performance of older adults on a spatial memory recall task, the level of detail present in an environment does not influence older adults' performance on spatial memory recognition tasks (see Sharps & Gollins, 1988, for a review). Specifically, older adults do just as well as the younger adults on both a detailed environment and a simple one. Sharps and Gollins (1988) speculate that the reason for this is that recall memory is more susceptible to the influences of aging. A potential reason for this susceptibility is that recall memory is a more cognitively and neurologically taxing than recognition memory, because recognition involves hints or cues and recall entails attempting to remember information without external cues.

In the present study, tasks were structured so that were visually unique from each other and minimize the likelihood of participants remembering locations from a different task while avoiding introducing a confounding variable. In alignment with these findings, the spatial working memory recognition task used white circles on a black background while the spatial working memory recall task and the long term memory recall task used colorful shapes.

1.1.3 *Summary of changes in spatial cognition*

The cognitive aging literature clearly demonstrates that there is not a simplistic answer to how memory changes as people age. While there is an age-related decline in performance on some tasks, performance on other tasks does not change. Task complexity (Nagel et al., 2009), level of detail about the layout (Cherry & Park, 1993; Sharps & Gollins, 1988) and the metric distance between objects (Iachini et al., 2005) are all factors influences whether or not there is an age-related change in task performance.

While behavioral tasks demonstrate how memory changes across the lifespan and the use of neuroimaging techniques is beneficial in detecting neurological differences between younger adults and older adults, there is one set of questions that the psychological literature does not do a good job of answering. Specifically, there has been little focus on lifespan changes in cognition. Sander, Lindenberger, and Werkle-Bergner (2012) discuss how working memory changes over the lifespan and that while it improves over childhood and declines in later adulthood, this pattern of improvement and decline does not necessarily mean that an older adult's cognition is similar to a child's cognition. As cognitive performance declines with age, one issue that has yet to be addressed is how that decline looks compared to earlier stages of the human lifespan. For example, is the performance of older adults is similar to young adults, but with a higher level of error or variability, or if the older adults' performance is more similar to a child or adolescent's performance?

One well-established paradigm to test this question is the spatial working memory recall task used in this study. This task looks at how well an individual can maintain a target's location in memory and how geometric biases influence the recall of target locations. This particular task requires the ability to maintain a location in memory without the memory becoming distorted and causing inaccuracies in recalling the location. Several studies have examined geometric biases in memory during early childhood and young adulthood (e.g., Schutte, Spencer, & Schöner, 2003; Schutte & Spencer, 2009) When remembering a location in a homogeneous space, such as on a monitor or on an otherwise empty table top, the memory responses of 3-year-olds tend to be biased toward the center of the space when asked to recall a location. In contrast, the responses of 5-year-olds, 11-year-olds, and younger adults are biased away from the center of the space and toward the center of each half of the space (Spencer & Hund, 2002; Spencer & Hund, 2003; Schutte & Spencer, 2009). These changes in memory biases have been termed a change in geometric categorization. Other researchers have found that although younger adults are biased away from midline on a working memory recall task, they can recognize the unbiased target location when completing a working memory recognition task (e.g. Sampaio & Wang, 2009; Holden, Newcombe, & Shipley, 2015). However, there are two major gaps in this area of the literature: 1. There has not been work examining geometric biases in late adulthood, and 2. How geometric biases in working memory are related to long term memory performance has not been examined. One aim of this study is to answer these open questions. A second aim is to examine differences in location memory performance on a working memory recall task and a working memory recognition task change from young adulthood to late adulthood.

The third aim of this study was to use a developmental theory to discuss cognitive changes that occur in late adulthood. There is a wide range of factors that influence cognitive development. For example, Kramer and colleagues (2007) point out that cognitive aging is influenced by (a) genetic inheritance, (b) changes in the release and uptake of neurotransmitters, and (c) changes in a person's endocrinology, and (d) physiological changes in brain size and makeup (e.g. amount of gray matter and amount of white matter). This review will focus on the neurological changes associated with cognitive aging. The review of neurological changes will focus on the two brain regions most associated with memory: the medial temporal lobe (MTL) (e.g. Kramer et al., 2007) and the prefrontal cortex (e.g. Giovanello & Schaeter, 2011). The following sections will also examine the neurological changes associated with cognitive aging of these regions. The author will discuss how this information is useful in developing neural network models to describe changes in spatial cognition in late adulthood.

1.2.1 *Neurological changes across the lifespan*

There are several areas of the brain that are involved in learning and memory. The primary functions of the MTL are to help convert working memory and short-term memory into long-term memory, in addition to the recognition and recall of information. A person's age can have a significant impact on both the anatomical and neurological functioning of his or her hippocampus, which is the part of the MTL that plays the largest role in memory formation. For example, Golomb et al. (1993) used a MRI to examine how the volume of the human hippocampus changes with age. They tested adults between 55 and 88 years of age. Overall, just under a third of their participants (32.5%) showed signs of hippocampal atrophy. They also found that increasing age was linked to an increasing prevalence of hippocampal atrophy, which suggests that while age plays a role in neural atrophy. Golomb et al. pointed out that changes in the brain are generally not solely due to one variable and that in addition to age, there are other factors that influence changes in the volume of the brain. One such example is that the authors also noted a gender effect: males were more likely to experience atrophy and this gender difference was greater in the older age groups.

Golomb et al. (1993) found that this decrease in hippocampal volume impacted certain types of memory, but not others. Older adults with hippocampal atrophy tended to perform more poorly on a verbal short-term memory and a nonverbal short-term memory test that are a part of the Guild Memory Scale. These results imply that hippocampal volume plays a role in recalling information from memory. Conversely, there was not a significant difference between those with hippocampal atrophy and those without atrophy on a forward digit span task, which was used to test the participants immediate recall abilities. This signifies that the decrease in hippocampal volume does not directly impact performance on a task that is traditionally used to test a person's immediate memory capabilities.

Kramer et al. (2007)’s longitudinal study supported the findings of Golomb et al. (1993). Kramer et al. administered a battery of memory scales that tested older adults' immediate recall, delayed free recall, and delayed cued recall and found that declining levels of hippocampal volume were associated with declining memory abilities. Additionally, Kramer et al. (2007) found that declines in executive functioning were related to lower levels of cortical grey matter and higher levels of white matter signal hyperintensities, an MRI marker of cerebrovascular disease.

Overall, the neurological literature demonstrates that the MTL undergoes several changes as people age, including hippocampal atrophy, an increase in prevalence among the general population as they age, and a greater magnitude of atrophy as age increases (Golomb et al. 1993). Hippocampal atrophy becomes greater and more prevalent in the population as people age, and is related to a decline in performance on certain cognitive tasks (Golomb et al. 1993). These results occurred in a cross-sectional design (Golomb et al. 1993) and in a longitudinal design (Kramer et al., 2007). These neurological changes are related to changes in cognition and behavior. Adults with greater levels of hippocampal atrophy demonstrated greater cognitive deficits (e.g. Golomb et al. 1993, Jack et al. 1997).

There is also a significant decline in the volume of the frontal lobe, especially in the prefrontal cortex region (Aizenstein et al., 2006). Specifically, the gray matter in the frontal lobe atrophies at a quicker rate than the gray matter in the other three lobes (Dennis and Cabeza, 2008) and the prefrontal has the greatest risk of atrophy (see Juraska and Lowry, 2012, for a review).

Chapter Two of this thesis attempts to computationally model how this age-related atrophy of the brain impacts cognition through the use of simulated neurons. Due to the fact that the older adults experience significant levels of atrophy in several areas of the brain, it is speculated that neural connections are weaker for older adults than for younger adults. Therefore, the researcher used weaker parameters for the simulated neural connections in the computational models for older adults than the parameters for the simulated neural connections for the younger adult models. Before this thesis delves into more specific details about the development of these computational models, it is necessary to discuss how the brain attempts to compensate for these neural changes and how memory changes with age. The discussion of these two areas will highlight why this study used certain paradigms to model cognition and then behaviorally test these models.

1.2.2 *Neurological and behavioral compensation*

While hippocampal atrophy can lead to cognitive deficits, other areas of the brain become more active in an attempt to compensate and preserve some cognitive functioning (e.g. Gutchess et al., 2005; Dennis & Cabeza). While Gutchess and colleagues (2005) found an age-related decline in hippocampal activation, they also proposed that older adults compensated by activating other regions of the brain. Gutchess et al. (2005) used a scene recognition task to examine changes in neural activation and how the brain compensates. They examined brain activation for remembered items and found that as people age, there is decreased activation in the parahippocampal region of both hemispheres and increased activation in the prefrontal cortex. They also found a negative association between the activation in the parahippocampus and prefrontal cortex. These results imply that the increased activation in the prefrontal cortex compensates for the declining MTL functioning.

This shift in activation has been replicated in a number of studies (e.g. Giovanello & Schacter, 2011) and is commonly known as "posterior-to-anterior shift in aging" or

"PASA" and the evidence in the literature suggests that this shift may be compensatory (see Dennis & Cabeza, 2008, for a review). Specifically, the occipital lobe in older adults has a lower level of activation and their prefrontal cortex has a higher level of activation. This shift is seen in a number of cognitive functions. For example, Dennis and Cabeza (2008) note that the PASA pattern appears when older adults complete a visuo-spatial cued attention task. The specific task that Dennis and Cabeza's review refers to can be found in Corbetta, Miezin, Shulman, and Petersen (1993). Participants see a target appear in a location directly to the left or the right of center of the screen. The participant would then press a button and the stimulus would disappear. After a delay, the target would reappear in a new location. On 80% of the trials, the target moved further away from the center (e.g. if the initial target appeared just right of center, it would re-appear further to the right of the center). For the other 20% of the trials, the target would move in the opposite direction. Participants were supposed to press button when they saw the target. The PASA pattern also occurs in tasks that require prolonged attention and tasks involving episodic memory recognition (see Dennis & Cabeza, 2008). While some research attributes the increase in activation in PFC to compensation, other research has found similar changes as task complexity increases. Nagel et al. (2009) compared the BOLD response within the dorsolateral pre-frontal cortex, premotor cortex, and parietal cortex as task complexity increased. They found that the BOLD response increased from the 1-target to the 3-target condition for both high-performing and low-performing groups of older adults. High-performing adults, however, did not show a change in in BOLD response from the 3-target condition to 7-target condition while low-performing adults showed a decrease in BOLD response within the right dorsolateral prefrontal cortex. As task complexity increased, the high-performing younger adults had higher activation in both the right and left dorsolateral prefrontal cortex, right premotor cortex, and left posterior parietal cortex. The low-performing younger adults only showed a small increase in activation in the left pre-motor cortex. This finding suggests that the level of activation is related to performance. However, it is difficult to attribute how much of the activation is related to task complexity, how much is related to compensation for another area of the brain, and how much is related to age-related changes.

Based on the findings that hippocampal activation is related to encoding spatial information (see Burgess, Maguire, & O'Keefe, 2002, for a review) and long-term memory (e.g. Graham and Hodges, 1997) while activation in the prefrontal cortex is related to working memory (e.g. Reuter-Lorenz et al., 2000), it is important to determine how the PASA pattern influences behavior. Specifically, this study is interested the issue of how PASA influences the relationship between working memory and long-term memory changes with age. To examine this relationship, two distinct spatial memory recall tasks were used: one working memory task and one long-term memory task. The spatial working memory (SWM) task has been used previously to capture developmental changes in spatial working memory in childhood (e.g. Schutte & Spencer, 2002; Schutte, Keiser, & Beattie, 2017; Schutte, Torquati, & Beattie, 2015). The long-term memory (LTM) task was developed specifically for this study. The advantage of LTM task is that similar to the SWM recall task, it captures where the participants responded relative to the actual target location. Furthermore, the LTM task is distinct enough from the SWM recall task to prevent carry-over effects from one task to the other task. A third advantage of the design of the LTM task is that it allows the researchers to not only examine the relationship between the SWM recall task and the LTM test phase, it also allows for the examination of how the encoding during the study phases contributes to long-term memory.

Giovanello and Schacter (2011) examined the interaction between prefrontal cortex and MTL during a relational memory task. To study how aging impacted relational memory and neurological functioning, Giovanello and Schacter (2011) used a word pairing task in which participants were exposed to either intact pairs (those words previously paired together), rearranged pairs (words seen before but in different pairings) or new pairs, and had to state whether or not they had seen that specific word pair before. In addition to the relational recognition task, participants also completed an item recognition task. After equating performance between groups, both groups showed activity in the left dorsolateral PFC in both tasks. Furthermore, while younger adults showed activity in the left posterior ventrolateral PFC and right hippocampus during the relational recognition task, older adults showed activity in these two brain regions for both the relational task and the item recognition task. These results are summarized in Table 1.

Table 1.
Groups showing neural Region x Task activation (Giovanello & Schacter, 2011)

Brain Area	Relational Memory	Item Recognition
Left dorsolateral PFC	Both groups	Both groups
Left ventrolateral PFC	Both groups	Only older adults
Right hippocampus	Both groups	Only older adults

While this supports Gutchess et al. ‘s (2005) findings of reduced specialization in the brain, Giovanello and Schacter (2011) point out that their results demonstrate that this reduced specialization is limited only to contexts that require the use of item recognition.

For the current study, each layout presentation used the same type of item: (a) the recognition task used white circles for each layout and for each level of complexity (e.g. 3-target, 5-target, and 7-target); (b). the SWM recall task used a blue triangle; and (c). each layout for the LTM task had the same three stimuli (e.g. three hearts for one layout, three stars for another layout, etc.). Both the SWM recognition task and the LTM task entail multiple targets, participants will need to factor the relationship between the target locations as they study the layouts.

With regards to the use of relational memory in spatial cognition, people use relational memory to group landmarks together. This grouping aids in place learning by allowing people to learn where objects are in relation to one another. The SWM recognition task and the related DFT models attempt to capture how spatial relational memory changes with age. Within the computational models of the SWM recognition task and the behavioral task, the researchers paired two of the targets closer to each other by placing them close to each other in order to accentuate a spatial relationship between the two targets. The purpose of computational models is to provide a neural network model of the mental representations from the behavioral task.

The next section unites the neurological and cognitive literature surrounding changes that occur during late adulthood by discussing how mental representations change with age. It discusses different theories that attempt to describe the aging process and argues that the best way to address the issues surrounding neurocognitive aging is by applying the developmental psychology theory of dynamic systems and DFT, which is a sub-theory of dynamic systems theory, to cognitive changes that occur in late adulthood. While DFT has traditionally modeled cognitive changes in children and young adults (e.g. Schutte and Spencer, 2009; Schutte, Spencer, & Schöner, 2003), the current thesis builds off the work of DeGirolamo and Schutte (2014) in using DFT to model spatial cognition in older adults.

CHAPTER II: A DYNAMIC FIELD APPROACH TO NEUROCOGNITVE AGING

2.1 *Current theories on age-related cognitive changes*

The literature presented thus far leads to the question: How does neural change relate to cognitive change and how do these two areas interact to influence behavior? Schroots (1996) reviews several classical and modern theories that attempt to explain neurocognitive changes and are summarized in Table 3.

Table 3.
Theories on Aging (Schroots, 1996)

Classical Theories

Theory	Description
Developmental Tasks/Activity Theory	Success in tasks leads to happiness and makes future tasks easier. Task failures lead to sadness and more difficulty in future tasks
Psychosocial Theory of Personality Development	Person attempts to resolve conflict between two opposing characteristics by balancing individual needs with societal needs
Counterpart Theory	Behavioral characteristics (cognition, emotion, and motivation) gained from prior experiences, influence decisions made in current environment
Disengagement/ Activity Theory	People become more introverted with age and starting in middle age, pull away from previous activities and more emotionally withdrawn
Personality Theory of Age and Aging	Transitional events impact development. Certain unexpected events (such as injury) and age-normative events occurring earlier/later than normal can have negative impact on development
Cognitive Theory of Age and Aging	Combines biological, sociological, and interactionist perspectives to examine psychodynamic of aging. Argues that it is perceived change, not objective change, that leads to behavioral change

Modern Theories

Theory	Description
Lifespan Development and Aging	Proposes that because abilities decline, a person's adaptability declines and he/she select and optimize behaviors that enhance quality of life and compensate for behaviors as they decline
Reduced Processing Resources	Cognitive declines are caused by age-related declines in processing abilities, such as attention, processing speed, and working memory capacity
Personality and Aging	Argues that personality characteristics influence cognition and that changes in cognition reflect changes in personality
Behavioral genetics	Genes play a role in how cognition changes with age. Additionally,

and Aging	examines how age-related changes in cognition varies in similar environments and differing environments

New Theories	
Theory	Description
Gerotranscendance	People have changes in perception of perception of world, themselves, and relationships with others (increasingly desire meaningful relationships over superficial ones)
Gerodynamics / Branching Theory	Dynamic systems theory applied to aging. Theorizes that internal and external systems become increasingly chaotic with age, which will eventually lead to death of these systems and that once the system passes a critical point, the individual will experience a biological, psychological, and/or social change. Each change leads to either improved functioning or a decline in functioning.

Each of these theories has their advantages and disadvantages and attempts to address at least some portions of development. While the focus of some of these theories is narrower, Gerodynamics/Branching Theory attempts to capture the vast majority of factors that influence cognitive and neurological changes. The main reason for this claim is that each of the other theories focuses on only a single niche area of development (such as only focusing on cognitive changes, social changes, or balancing individual needs with society's needs) instead of looking at all of these factors together. On the other hand gerodynamics seeks to encompass all of these niches and seeks to model potential future behavior and changes. Table 4 describes the tenets of gerodynamics

Table 4.
Propositions regarding gerodynamics (Schroots 1995, pg. 77).

#	Proposition	Summary
1	"Living Systems conform to constraints of the Second Law of Thermodynamics"	Matter becomes more disordered over time, which means people move toward death. Because humans are an open system, they can increase their level of order (as opposed to a closed system, which can only become more disorganized over time).
2	"Order can arise out of disorder in living systems by way of self-organization"	Supports 1st proposition's implication that a human's systems (e.g., biological system, psychological system) can increase in their orderliness and disorderliness. Stabilization occurs through self-organization. This occurs through autocatalytic reactions (at

		least 1 item is part of both the input and the product) in which new structures or behaviors evolve into something new and the excess energy is released. Specifically, there is a positive association between entropy and organization. When disorder enters a system, the system re-organizes in order to compensate for this disorder and to remove the disorder from the system.
3	"The dynamics of living systems is represented in nonlinear series of transformations into higher and/or lower order structures (or processes), showing a progressive trend toward more disorder than order over the lifespan".	Encompasses both Proposition 1 and Proposition 2. Can be looked at from one of two types of approaches. The first approach looks at influence of age on the biological, psychological, and social systems. The second approach looks at how there are different patterns of aging: primary aging patterns, secondary aging patterns, and tertiary aging patterns. Primary aging patterns involve the idea that the type and quantity of transformations a person goes through will determine his/her internal age. Secondary aging refers to the idea that as people grow older, people are more likely to develop illnesses and infirmities related to the changes in the environment. Tertiary aging deals with self-organization eventually leads to the declines in functioning and death

While Gerodynamics Theory is a dynamic systems theory that provides a stronger, more detailed description of the processes involved with age, there is two major drawbacks to it: it does not have any direct application to how cognition and behavior are represented and it does not directly address in any detail how either of these items change over time. In order to account for how these changes in behavior occur, the next section will propose a new idea: how the Dynamic Field Theory (DFT) can be applied to Gerodynamics and neurocognitive aging. While both DFT and Gerodynamics both attempt to cover several factors that influence neurocognitive aging, DFT is better able to model changes in cognition than Gerodynamics. One particular aspect of cognition that DFT is better at capturing is the changes in mental representation of spatial locations.

2.2 *Dynamic Field Theory*

Dynamic systems theory argues that change occurs through the destabilization of a particular system of behaviors and the re-stabilization of the system with a new set of behaviors (referred to as attractor states). This process is time-dependent and context-dependent (Thelen, 1992). DFT builds upon dynamic systems by allowing researchers to computationally model behavior in a neural network that uses neurophysiological principals. By simulating neural activation fields, researchers are able model how the brain mentally represents information across different timespans and contexts (Van Geert & Steenbeek, 2005), and develop predictions about how behavior changes in real-time and across development (Schutte, Spencer, & Schöner, 2003).

Buss and Spencer (2014) define dynamic neural fields as simulated group, or field, of neurons that process a particular set of cognitive representations. A field models a continuous, quantitative aspect of cognition, such as spatial location, color hue, or item salience. Each individual neuron codes for a specific location within the field. Since this thesis focuses on spatial memory, the neurons represent locations in a continuous space. Neurons that code for a specific location share overlapping activation fields with the neurons that code for nearby locations (Schutte & Spencer, 2009; see Buss & Spencer, 2014 for a review). Neurons that code for locations that are further away from each other do not share overlapping neural fields. Input to the field at a location excites neurons that codes for that location. Stimuli that are more salient have higher input values, The stronger the stimulus input is, the larger the peak of activation will be and the more likely it is that the item's location will be remembered over the course of time. The stimulus input is analogous to a target appearing on a computer screen during a behavioral task. Stronger stimulus inputs are analogous to targets that are more salient or noticeable. The stimulus input being turned off is the same concept as the target disappearing from a computer screen during a behavioral task.

There are two types of interactions between neurons in the fields. The first type of interaction is an excitatory interaction that is recurrent. A "neuron" at a specific location that is activated above a threshold (usually 0) sends excitation to itself and neurons that code for nearby locations. The second type of connection that exists between the neurons is inhibitory. The function of inhibitory connections is to prevent activation of neurons that code for locations further from the activated neurons. The inhibitory connections effectively help keep the memory for a specific location precise and prevent the peak of activation from drifting to another location in the field. These two types of connections interact to form a bell-shaped interaction kernel in which a stimulus input activates neurons that code for that specific location and nearby locations inhibits neurons that are further away.

The goal of this next section is twofold. The first goal is to replicate the model presented in DeGirolamo and Schutte (2014), which used DFT to model changes in spatial memory that occurred within the Nagel et al. (2009) study. The second goal of this section is to extend the application of DFT models to make predictions about how geometric biases in location recall change over the lifespan.

2.3 *DFT Models of Spatial Working Memory*

2.3.1 *Methods across models*

Each dynamic field model has three layers, or fields. Figure 1 provides an example of a DFT model. For each layer the X-axis represents the location of the target (with zero centered at the middle of the axis). The Y-axis represents the level of activation at a particular point in the field. The Z-axis represents time (in ms). The first layer (top layer in Figure 1) is the perceptual layer. This layer, also known as the "input layer,” is the neural field that “perceives” the targets. This layer is captures the process of a person seeing a stimulus appear during a behavioral task. The stimulus is presented for two seconds and is represented in this field by a peak of activation. When there are stimuli present in this field, excitatory activation is sent down to the inhibitory layer and to the spatial working memory layer. The next layer that is presented in the model is the inhibitory layer, which receives excitation from both the perceptual field and from the spatial working memory field. It sends inhibition to the perceptual field (represented by the “troughs”) and the spatial working memory field. The third layer is the spatial working memory (SWM) layer, which represents the maintenance of target locations in the model’s spatial working memory. This layer receives excitatory activation from the perceptual field and inhibitory activation from the inhibitory field.

The SWM layer receives excitation from the perceptual field for as long as the stimuli are presented to the model. When the stimuli “disappear” from the perceptual field (represented by the disappearance of the peaks at two seconds), the perceptual field no longer sends excitatory activation to the spatial working memory field. Memory for a particular location is represented by the maintenance of the peak of activation after the perceptual field’s activation is no longer present. A particular location is forgotten if the level of activation for the target returns to zero in the SWM field. The precision of the memory for the location of the target is represented by how much the peak of activation “drifts” (shifts to the left or right) over the course of time. If a peak does not drift or drifts very little over the course of time the memory for that specific location is more precise. The mathematical equations for the models can be found in Appendix A of Schutte and Spencer (2009).

One model represents the cognition of younger adults (18-22 years old) and one model represents the cognition of older adults (which the psychological literature commonly defines as being at least 60 year of age). The only difference in parameters between the two models is the strength of the excitatory connections and the inhibitory connections. The young adult model used the same excitatory and inhibitory parameters as the adult model in Schutte and Spencer (2009). For the older adult model, the strength of the excitatory and inhibitory connections was lower than the young adult model. The rationale for this reduction stems from the previously discussed neurocognitive decline that occurs with advanced age. Because different regions of the brain atrophy with age, there are fewer neurons in the brains of older adults. What this theoretically implies is that the neurological connections in older adults may be weaker than the younger adults, and this lack of connections may have an adverse effect on the communication between neurons. So computationally, the way to best model this neuronal loss with DFT would be to weaken the strength of the excitatory connections within the fields and lower the strength of the inhibition from the inhibitory field. While prior research discusses how age-related changes in dopamine system and the brain influence excitatory and inhibitory connections (e.g. see Braver et al., 2001), it does not specify whether the excitatory and inhibitory connections decline at an equal rate. The present study reduced these parameters in order to fit the results of Nagel et al. (2009). Additionally, “noise” was included in all of the models. This “noise” allows for slight deviations in the model to occur each time the model is run and is meant to account for within-participant deviations that occur from trial to trial.

These parameters were used to compare 18 different sets of simulations. These simulations, displayed in Table 5, examined how age interacts with different factors that the behavioral literature has shown to influence spatial memory. The first set of simulations was meant to model the spatial recognition task, in which participants have to remember 3, 5, or 7 target locations and remember whether or not a probe matches one of the target locations they see in a layout. These were simulations of task complexity, which this study operationalized as the number of targets that the individual needs to remember. This set of simulations generated predictions about the influence of task complexity across the lifespan and demonstrated that DFT can model cognitive changes across the lifespan by replicating Nagel et al. (2009)'s results. The second set of simulations built upon the first set of simulations by grouping some of the targets. The purpose of this set of simulations was to examine how the distance between two targets influences a person's memory of them. Sets of simulations were run for 3-targets, 5-targets, and 7-targets with two of the targets grouped closed together in order to test the influence of distance between targets on memory. The final set of simulations examined whether the presence of a salient midline creates a difference in geometric biases using the younger adult and older adult parameters. There has not been a behavioral study that has tested the effect of geometric biases on the memory of older adults, so these simulations generated predictions about geometric biases in older adults. The parameters are approximated based on the cognitive aging literature.

Table 5
Simulations discussing interaction between age and factors influencing spatial memory

		Young Adult	**Older Adult**
Task Complexity	**3 Targets**	Simulation 1a	Simulation 1b
	5 Targets	Simulation 2a	Simulation 2b
	7 Targets	Simulation 3a	Simulation 3b

Grouping Targets	**3 Targets**	Simulation 4a	Simulation 4b
	5 Targets	Simulation 5a	Simulation 5b
	7 Targets	Simulation 6a	Simulation 6b
Midline bias w 1 target	**10º from Midline**	Simulation 7a	Simulation 7b
	20º from Midline	Simulation 8a	Simulation 8b
	30º from Midline	Simulation 9a	Simulation 9b

2.3.2 *Interaction between task complexity and age*

The first set of simulations examined how task complexity influences the spatial memory of young adults and older adults. A secondary goal of these simulations is to see if DFT can accurately replicate the results of Nagel et al.'s (2009) behavioral paradigm. Nagel et al. (2009) tested the participants' spatial working memory recognition ability by having participants encode one, five, or seven targets while fixating a stationary point on the monitor. After 500 ms, the target(s) appeared on the screen for one second, then disappeared and a mask appeared on the screen for 300 ms. Next, the mask disappeared and the fixation point re-appeared for 3000 ms. Finally a probe appeared for 2700 ms and participants had to respond as to whether it matched one of the previous target locations or not. For the current study, the simulations were re-run using a code similar to the code used by Schutte and Spencer (2009). There was an equal distance (65º) between targets. Additionally, the stimulus inputs were presented for 2000 ms. If the peaks of activation in the SWM field were maintained after the stimulus input was turned off, then the target location was remembered.).

With regards to the 3-target simulation, there was not a significant difference between the young adult DFT model, which "recalled" all 3 targets on all 100 simulations, and the older adult DFT model, which recalled an all 3 targets across the 100 simulations (*SD* = 0). Figure 1 provides an example of the young adult model's performance for the 3-target task. The older adult's model is presented below in Figure 2. The x-axis represents the target location, the y-axis represents the level of activation, and the z-axis represents the passage of time (in ms). As these two figures demonstrate, for both groups the peak of activation for all three targets was maintained after the stimulus inputs were turned off.

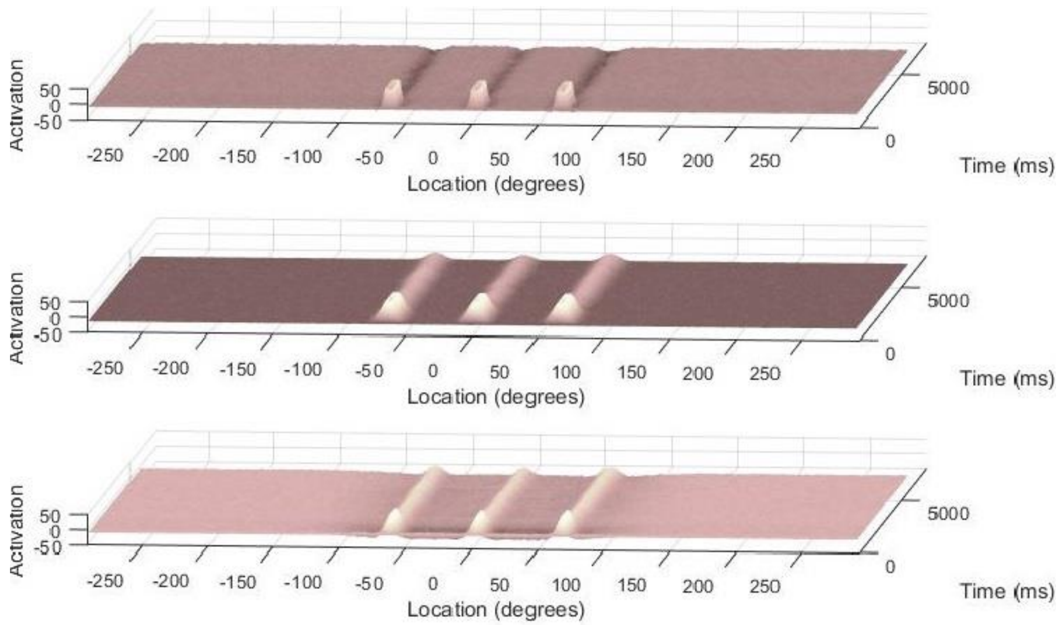

Figure 1 Model 1a Young adult performance on 3-target task

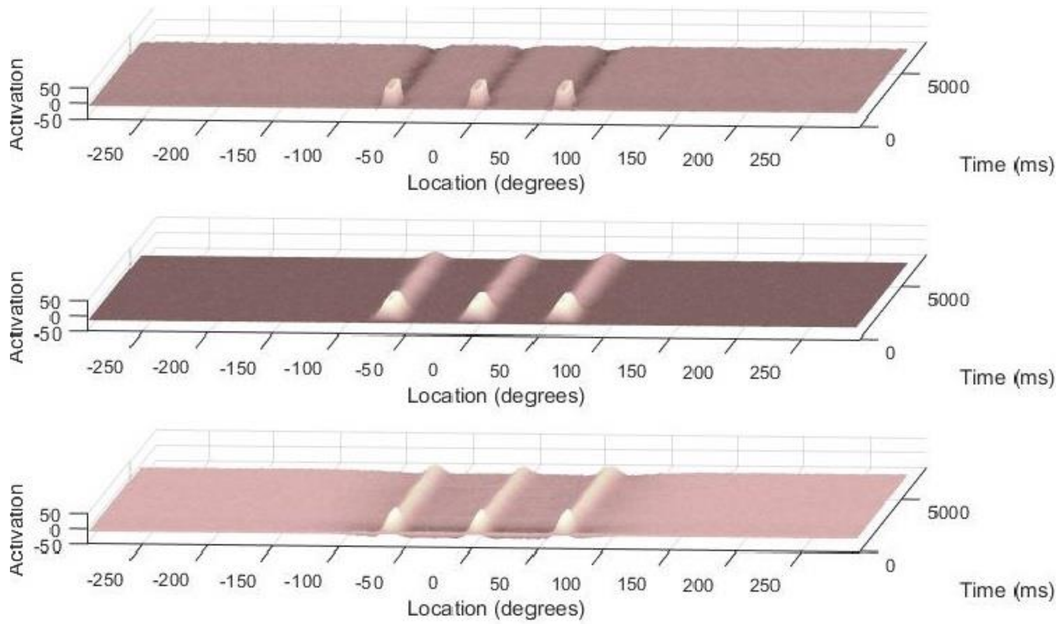

Figure 2 Simulation 1b Older adult performance on 3-target task

In order to fully replicate the results from Nagel et al. and demonstrate that DFT can capture neurocognitive changes that occur with age, 100 simulations were run for the 5-target simulation. Figures 3 and 4 provide an example of the 5-target simulation. Across 100 simulations, the younger adult model recalled significantly more targets (*M* = 4.95, *SD* = .2190) than the older adult model (*M* = 4.67, *SD* = .4726), t(139.661) = 5.376, *p*<.001.The implication of this set of simulations is that even a small difference in task complexity can alter performance. However, this does not tell us what type of relationship exists between task complexity and between-group differences in performance (e.g. linear or logarithmic).

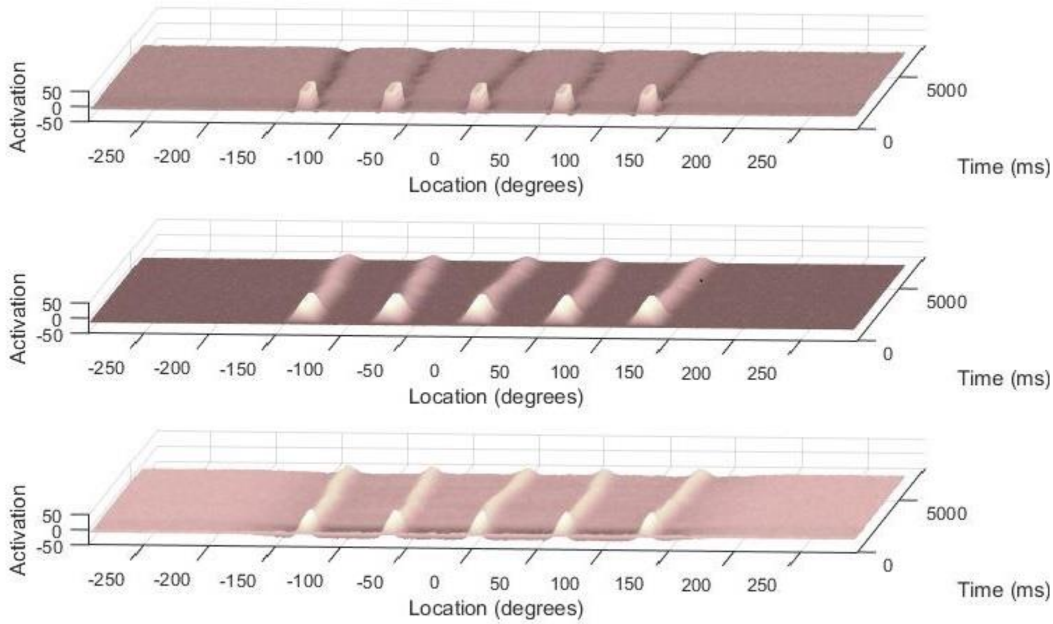

Figure 3 Simulation 2a Younger adult performance on 5-target task

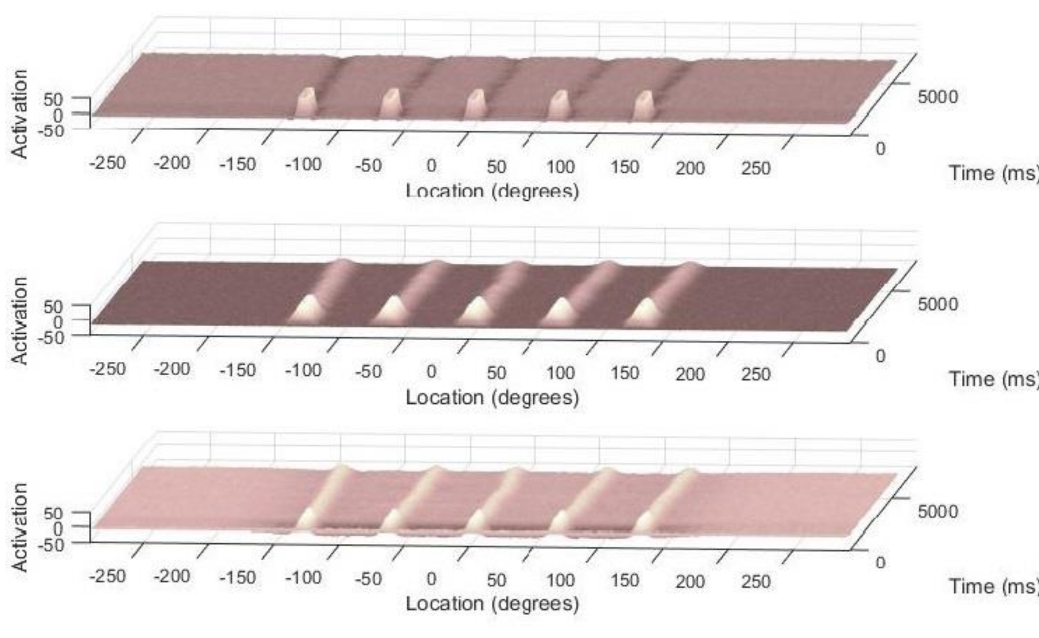

Figure 4 Simulation 2b Older adult performance on 5-target task

For the 7-target task, the simulation matched Nagel et al.'s results. The younger adult model remembered significantly more targets than the older adult model, $t(198) = 13.963$, $p < .001$ (younger adult model: $M = 6.07$, $SD = .7143$; older adult model: $M =$

4.66, *SD* = .7138). Figures 5 and 6 show simulations of the younger and older adult simulations with 7 target locations. As can be seen in the figures, in the young adult simulation six of the locations sustained their peaks in the SWM field after the stimulus inputs were turned off while the older adult model only “remembered” five of the landmarks after the stimulus inputs were turned off. One interesting phenomena to note about Figure 6 is that the memory of the target at location 130 was briefly maintained after the stimulus input was turned off, but the target was forgotten after one second. One common theme across iterations of the 7-target simulation is that it tends to forget the middle targets. The theoretical reason why this pattern occurs across age groups and simulations is that those targets that are in the center of the field tend to be exposed to higher levels of inhibition due to more neighboring targets than those targets that are toward the edge of the field. This increased exposure to inhibition could cause the peak to die out quickly.

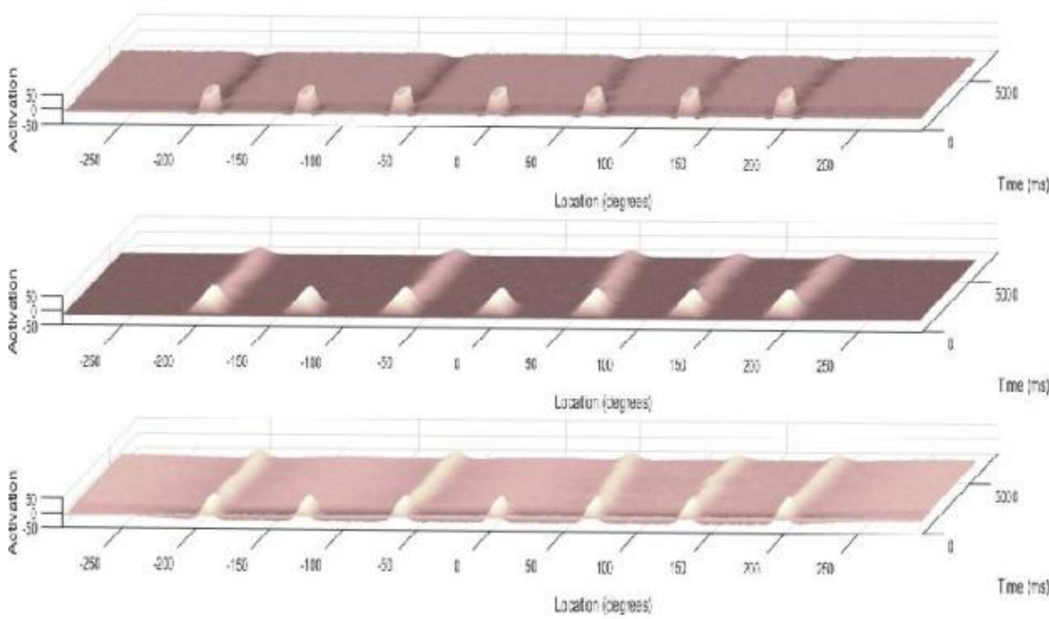

Figure 5 Simulation 3b Young adult performance on 7-target task

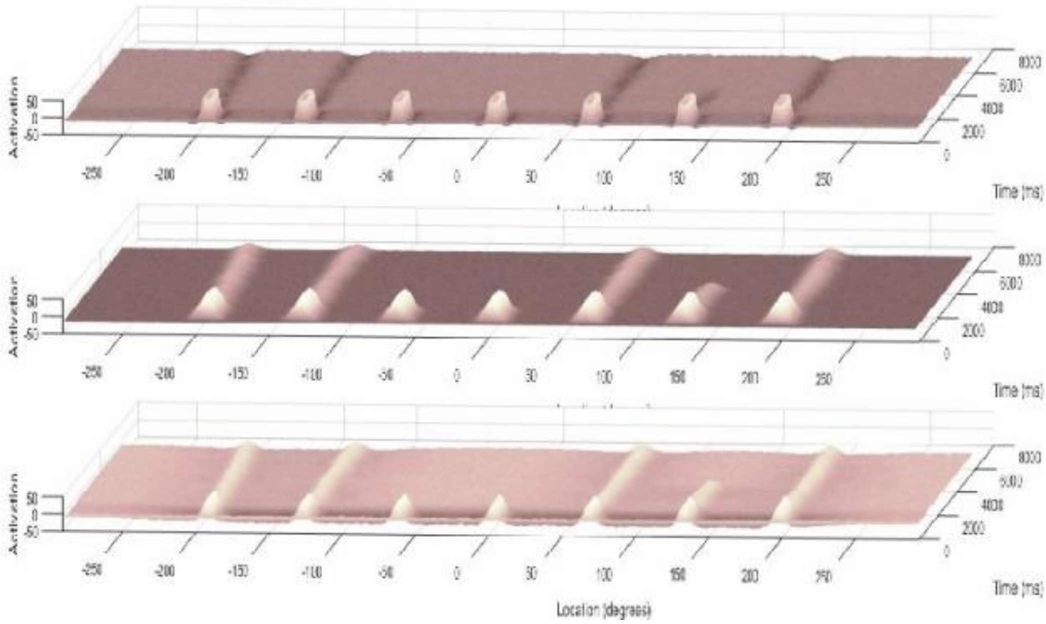

Figure 6 Simulation 3b Older adult performance on 7-target task

A follow-up analysis was run to see how performance declined for each model as task complexity increased. For both the younger adult model and the older adult model, the percent of targets "remembered" decreased in a linear fashion. For the 3-target simulation, the younger adult model, all of the targets were remembered, $M = 1.000$, $S.D. = .000$ and the model remembered significantly higher percent of targets than the 5-target simulation, $M = .990$, $S.D. = .044$, $t(99) = 2.283$, $p = .025$, and the 7-target simulation $M = .8671$, $S.D. = .102$, $t(99) = 13.02$, $p < .001$. The younger adult 5-target simulation also remembered a higher percent of targets than the 7-target simulation, $t(99) = 11.155$, $p < .001$. The same pattern held true for the older adult model. The 3-target simulation, $M = 1.00$, $S.D. = .000$, remembered a higher percent of the targets than the 5-target simulation, $M = .934$, $S.D. = .095$, $t(99) = 6.983$, $p < .001$, and the 7-target simulation $M = .6657$, $S.D. = .102$, $t(99) = 32.783$, $p < .001$. The older adult 5-target simulation remembered more locations than the 7-target simulation, $t(99) = 19.830$, $p < .001$.

2.3.3 *Interaction between task complexity, target grouping, and age*

The one major weakness with the last set of simulations is that when remembering locations there is usually not an equidistant amount of space between targets. For the majority of spatial layouts that exist in the world, some objects are grouped closer together while other objects are located further from the rest of the other targets. This weakness highlights the issue of how the distance between targets could influence the ability to remember their locations. The intent of this next set of simulations addresses this question.

The method used to model variable groupings was that two of the targets were placed close together while the other targets were further away from each other and the pairing. For the 3-target simulations, the target that had been in the middle for the last set of simulations was moved 32.5º closer to the target that was on the right-hand side. The position of the left and right targets remained unchanged from the last set of simulations (at the -65º location and the 65º location). It was predicted that grouping two of the landmarks together would influence one of the activation peaks in the pairing because the two close targets would share some excitatory and inhibitory connections. Additionally, it was predicted that the effect of grouping the variables would be even more pronounced in the older adult group given that behaviorally, the older adults tend to have more trouble at recalling precise metric information than younger adults (Bruyer, Scailquin, and Coibion, 1997).

Examples of simulations of the 3-target DFT models with 2 targets grouped together can be found below in Figure 7 (younger adult model) and Figure 8 (older adult model). As Figure 7 shows, grouping two targets together has a negative influence on maintenance of target peaks in the young adult model. Across 100 simulations, the young adult model remembered an average of 1.45 targets (*SD* = .8333). Given the previous discussion about overlapping inhibitory connections potentially causing some of the activation peaks to die out, it is not surprising that one or both of the targets grouped close together died out. For the current young adult model, inhibition is the likely cause for at least of the grouped target's activation dying out. In the first set of simulations, each target received approximately the same amount of inhibition, with the middle target receiving inhibition from the two outside targets. In Figure 7, however, the excitatory activation for the grouped targets is overwhelmed in the SWM layer by the combination of a small influence of inhibition from Target 1 and a very large amount of inhibition from the other target that is nearby. In the older adult model in Figure 8, this close proximity between Targets 2 and 3 also causes the peak of activation for both of these targets to die out in the SWM layer. So overall, what these simulations show us is that grouping targets together causes location recall to decline for the targets that are close together, and it is predicted that for behavioral studies, this decline in ability will be greater in older adults. Furthermore, Matushima and Tanaka (2014) found that monkeys had a lower level of activation in the prefrontal cortex when targets appeared in the same hemifield than when they appeared in different hemifields.

After running 100 simulations, it was found that the young adult model remembered a significantly greater number of targets *SD* than the older adult model, *SD* $t(167.168) = 2.942$, p=.004 (younger adult model: M = 1.45, *SD*= .8333; older adult model: M = 1.16, *SD* = .5265).

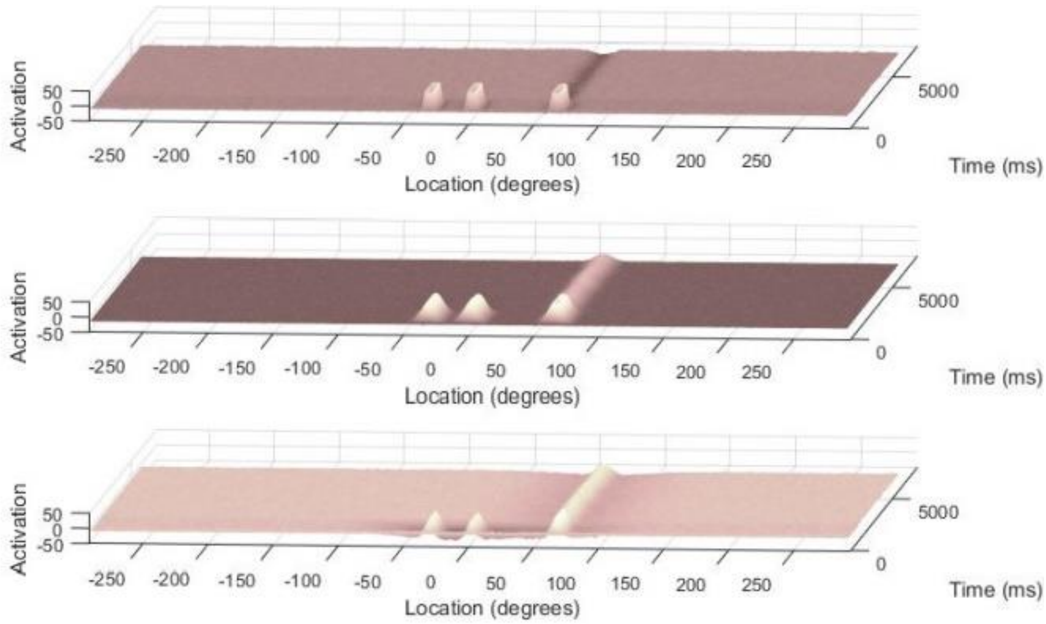

Figure 7 Simulation 4a Younger adult model performance on 3-target task with 2 targets grouped together

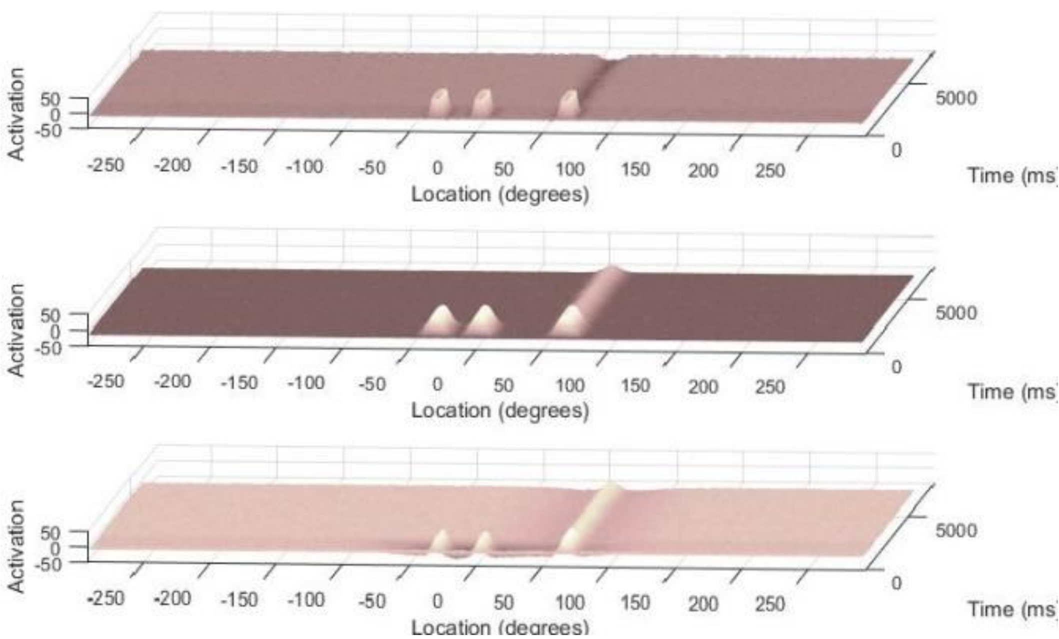

Figure 8 Simulation 4b Older adult performance on 3-target task with 2 targets grouped together

An example of each group's 5-target simulation with two targets grouped together can be found in Figures 9 and 10. As the two figures show, younger adult model and the older adult model performed similarly. Across 100 simulations, each groups remembered an average of 3 targets.

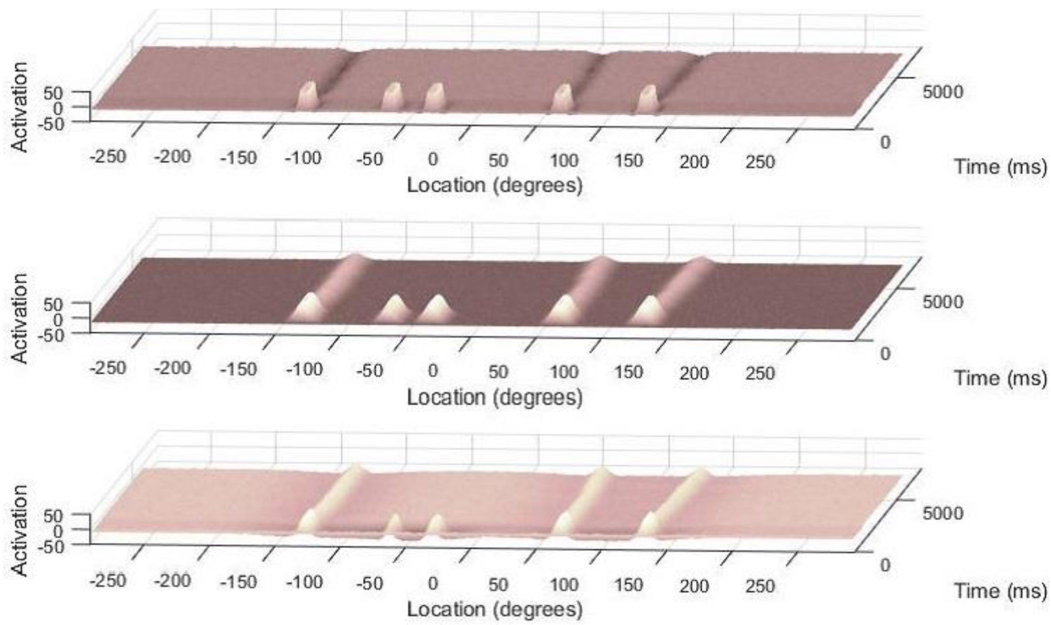

Figure 9 Simulation 5a Young adult performance on 5-target task with 2 targets grouped together

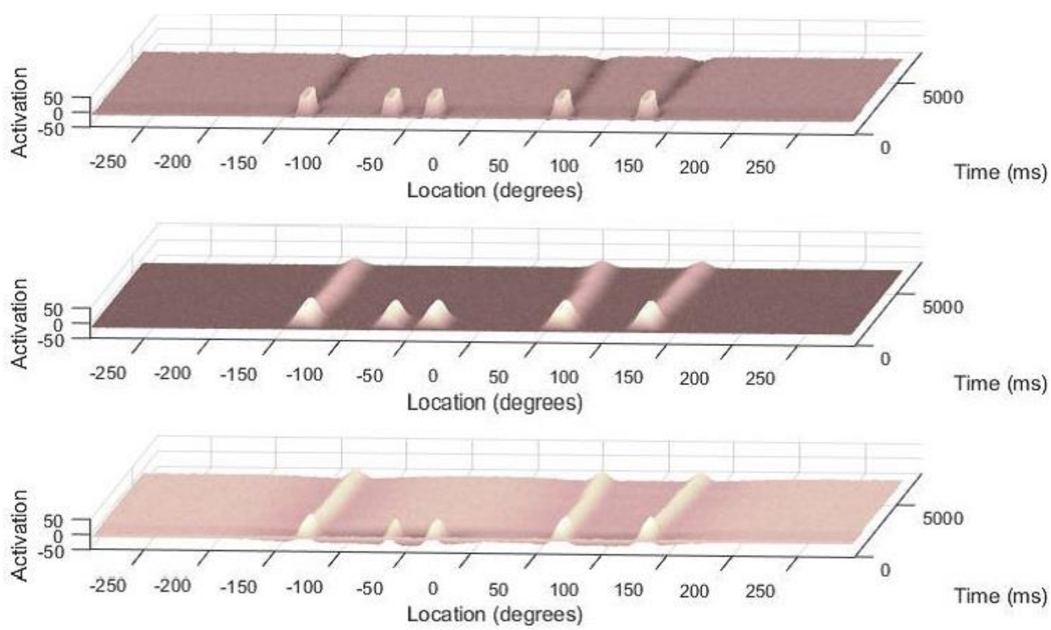

Figure 10 Simulation 5b Older adult performance on 5-target task with 2 targets grouped together

Figures 11 and 12 show the DFT simulations for younger adults and older adults respectively on the 7-target task when two of the targets are grouped together. As these simulations demonstrate, grouping two of the seven targets cause the models of both groups to show a decline in spatial memory when compared back to the original 7-target task. When we compare the no-grouping simulation to the grouping simulation for the 7-target task, the magnitude of the decline in performance is the same for both age groups (each group forgot 1 additional target). Additionally, both age groups forgot both of the targets that were paired together. Overall, it was found that the younger adult model recalled significantly more targets (M = 4.76, SD = .4292) than the older adult model (M = 4.13, SD = .6614), $t(169.826) = 7.99$, p <.001.

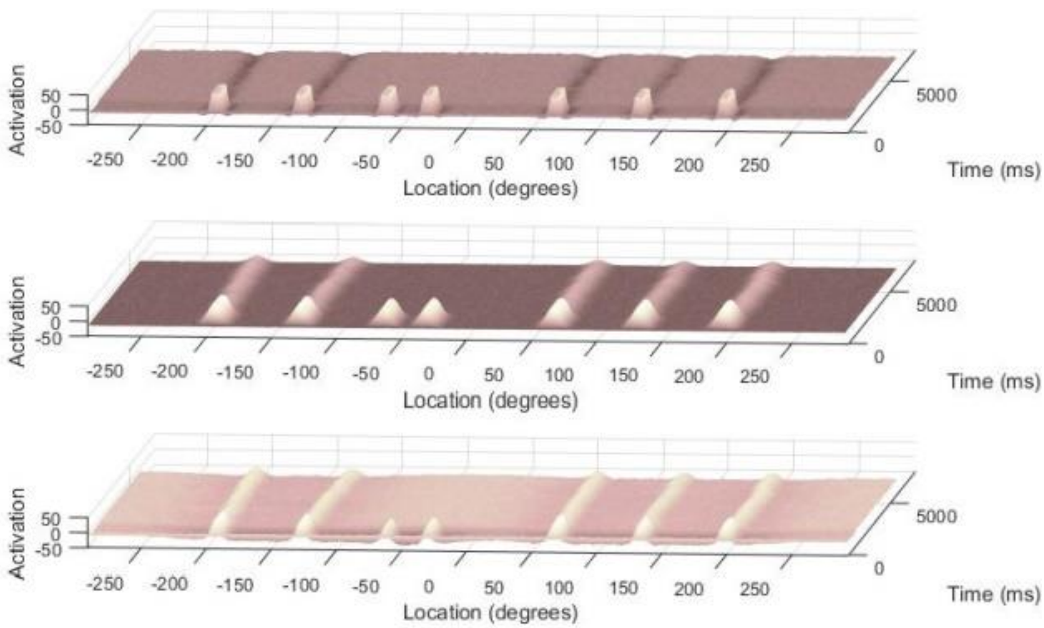

Figure 11 Simulation 6a Young adult performance on 7-target task with 2 targets grouped together

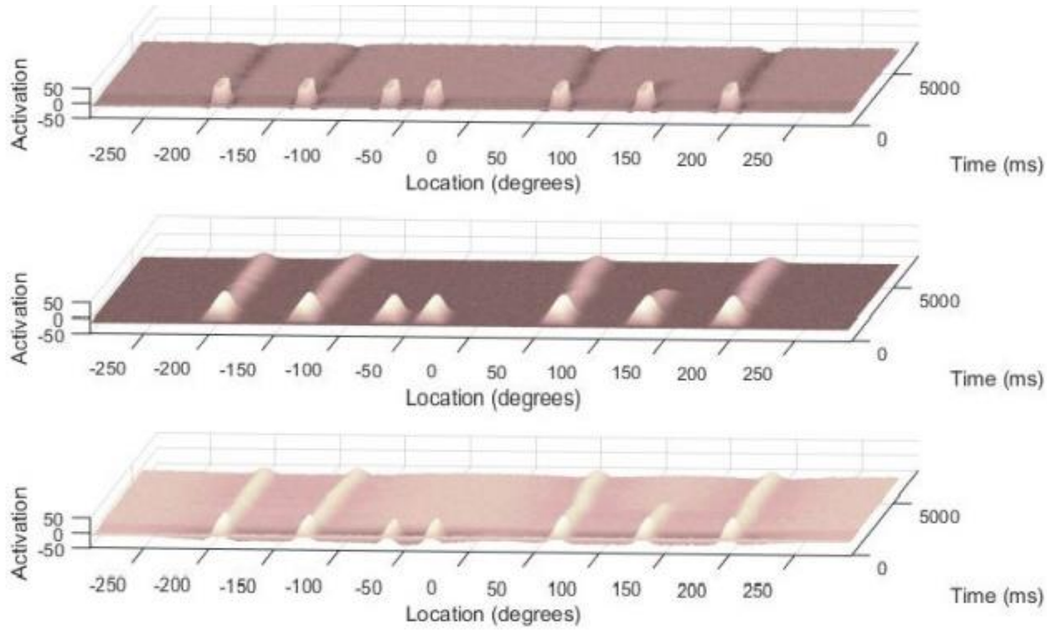

Figure 12 Simulation 6b Older adult performance on 7-target task with 2 targets grouped together

2.3.4 *Influence of cognitive aging on geometric biases*

One way that spatial memory can be biased is the presence of a salient border or boundaries, such as the presence of a visible midline. As discussed in the previous section, the recall of children 6 years of age and younger is biased toward the midline symmetry axis while children 10 years of age and older are biased away from the midline (Huttenlocher, Newcombe, & Sandberg, 1994; Spencer & Hund, 2002). Additionally, the memory of adults is biased away from the midline (Huttenlocher, Hedges, & Duncan, 1991; Spencer & Hund, 2003).

Schutte and Spencer (2009) demonstrated that it is possible to use DFT to simulate geometric biases in children and adults. However, there is not a behavioral study or DFT model that looks at whether location memory of older adults tends to be biased toward midline or away from midline. It is unknown whether the memory of older adults is similar to younger adults, if it has greater bias from the midline, or if it is similar to kids and biased toward the midline. The goal of this next section is to fill this gap in the literature. Based on the neurocognitive changes discussed in the first half of this review, two potential arguments are that either 1) older adults will show a greater bias away from midline than younger adults or 2) on average, older adults will not show a significantly greater bias away from the midline, but would instead have more variability across the 100 simulations. The argument that older adults would be biased away from the midline is contingent on the studies demonstrating that starting after 6 years of age, location memory is biased away from the midline (Spencer & Hund, 2002; Spencer & Hund, 2003). Based on these results, it is hypothesized that the older adults should be biased away from the midline, given that mentally healthy older adults have cognitive abilities that are more similar to younger adults than to young children or toddlers. Given that older adults tend to show more memory deficits than younger adults, that the memory responses of older adults may be more biased away from the midline than younger adults. It is also hypothesized that if older adults do not have a significantly different bias than younger adults, then they would have greater variability in performance, as demonstrated by a greater standard deviation from the mean. One example of greater variability is that on some trials, the responses of older adults would be more biased than the responses of younger adults and less biased than younger adults on other trials.

Schutte and Spencer (2009)'s adult DFT model showed a bias away from the midline when a target was at the 20º location. The DFT simulations for younger adults and older adults when the target location is near the midline (at the -10º mark) are displayed in Figures 13 and 14 respectively. Both groups showed a bias toward midline. While the younger adult model did not show a greater bias toward the midline (M = 2.5439, SD = 4.2353) than the older adult model (M = 1.4592, SD= 5.0641) across the

100 simulations, *t*(190.514) =1.639, *p* =.103, the older adult model had more variability across the simulations.

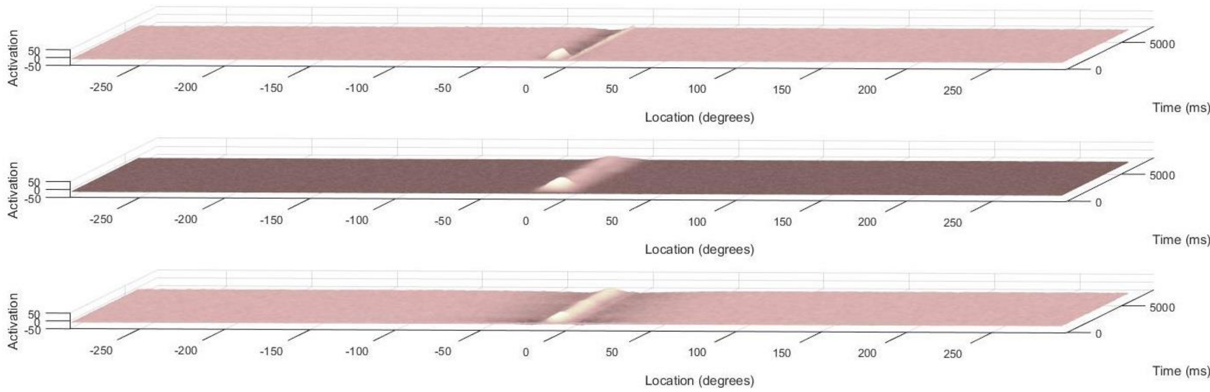

Figure 13 Simulation 7a Young adult model- 10ºs from midline

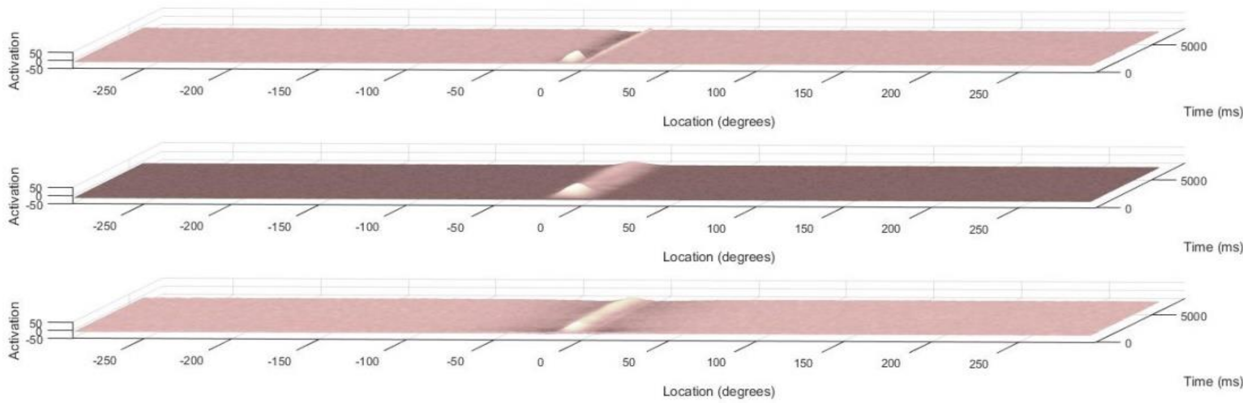

Figure 14 Simulation 7b Older adult model- 10ºs from midline

Figures 15 and 16 present simulations that use the same location (-20ºs) as Schutte and Spencer (2009). For the young adult group the simulation replicated the results of their paper, which was that the younger adult model was biased away from the midline (*M* = -3.088, *SD* = 3.2001). The older adult model was biased an average of -3.5303° (*SD* = 3.0544) away from midline across 100 simulations. However, there was not a significant difference between the younger adult model and older adult model across the 100 simulations (*t*(198) = 1.0, *p* = .319.

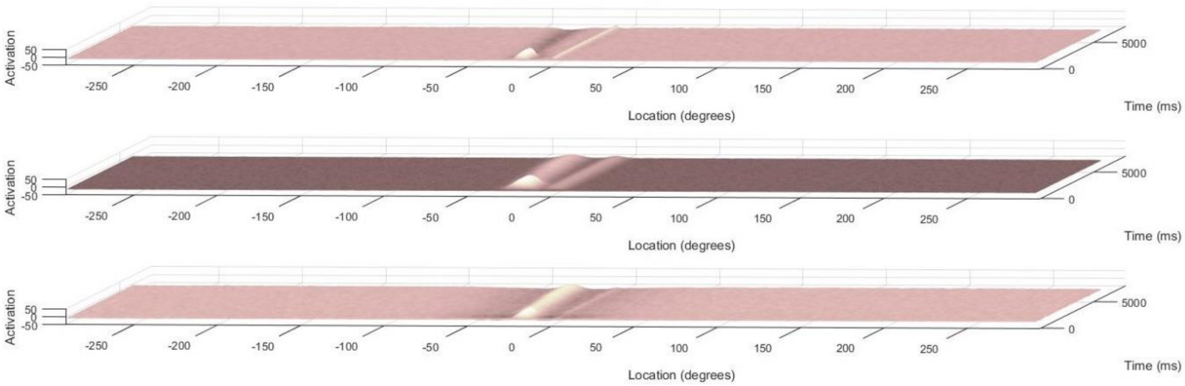

Figure 15 Simulation 8a Young adult model- 20ºs from midline

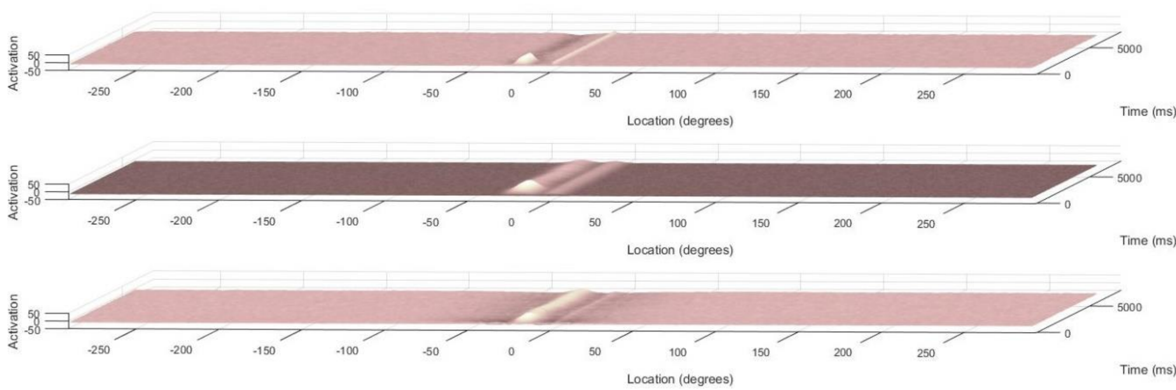

Figure 16 Simulation 8b Older adult model- 20ºs from midline

Figures 17 and 18 depict the DFT simulations for both age groups when the target is further way from the midline (at the -30º mark). At this distance, the direction of bias was away from the midline for both groups. However, there not a significant difference between younger adult model and older adult model *SD*, $t(198) = -.483$, $p = .629$ (younger adult model: $M = -2.1412$, $SD = 1.205$; older adult model: $M = -2.0414$, $SD = 1.677$). Additionally, the magnitude of the bias was lower for both groups when the target was at the -30° mark compared to when it was at the -20º mark. This suggests that there is a curvilinear relationship between target distance from the midline and the magnitude of the bias. When the target is very close to the midline, the amount of bias is small. Then as the distance from the midline approaches 20ºs, the magnitude of the bias peaks. As the target gets further and further from the midline, the midline has less of an influence on a person's recall of the location, which leads to a decrease in the magnitude of midline bias.

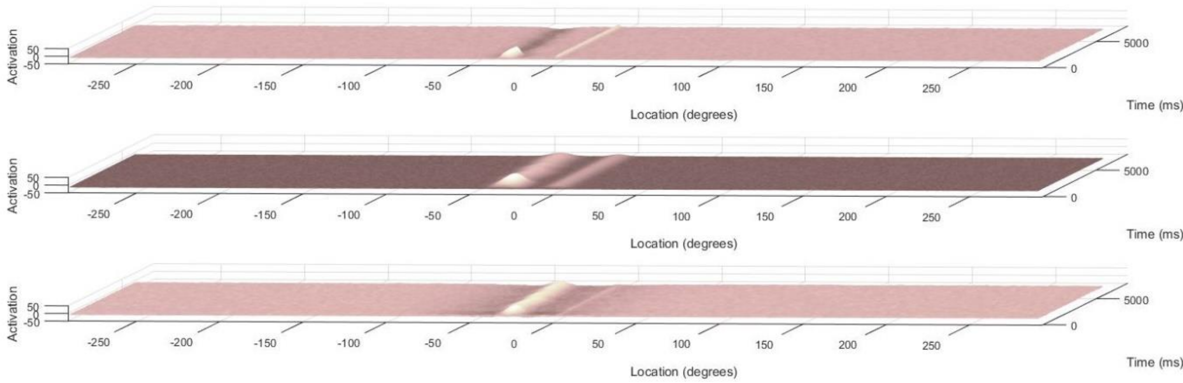

Figure 17 Simulation 9a Young adult model- 30ºs from midline

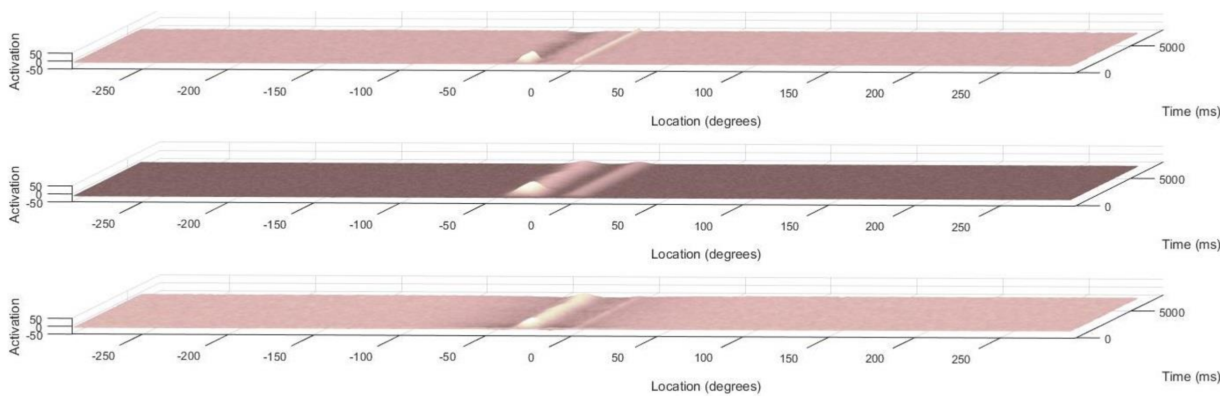

Figure 18 Simulation 9b Older adult model- 30ºs from midline

2.4 *Summary*

Overall, it has been demonstrated DFT can successfully simulate cognitive changes that occur from young adulthood to later adulthood (Simulations 1-3). Therefore, Simulations 4-9 were developed in order to generate predictions about the spatial working memory tasks that will be used in this study. The empirical hypotheses generated from these simulations are listed in the methods section, as are the hypotheses for the related behavioral tasks.

CHAPTER III: HYPOTHESES AND METHODS

3.1 Hypotheses

The following empirical hypotheses were tested in this study:

1. It was hypothesized that the results of the recognition memory task will replicate the results of Nagel et al. (2009). Specifically, the hypothesis was that the performance of the older adults on the spatial working memory recognition task would decline at a greater magnitude than the younger adults as task complexity increases. The computational models also supported this prediction.
2. Based on simulations of the DFT model, it was predicted that the participants would be more likely to forget the locations of targets that were located close together in the spatial memory recognition task.
3. Based on Simulations 7-10, the older adult model did not have a greater bias away from the midline than the younger adult model on a 1-target recall task. However, there was greater variability in the older adult model across simulations. Therefore, it was hypothesized that on the two groups would not be a significantly different in mean constant distance or directional error. It was hypothesized, however, that the memory responses of older adults would be more variable.
4. The peaks of activation in the long-term memory layers of the DFT are created by input from the peaks of activation in the working memory layer. Simulations 9 and 10 demonstrate that the older adult models have more variability in working memory, which could potentially result in

weaker, more diffuse memory traces in certain long-term memory tasks. Based on this weaker long-term memory, it is hypothesized that older adults will be less accurate than younger adults on the long-term memory task.

5. The next hypothesis stems from the empirical models and relates to the long-term memory task that participants will perform. It was predicted that the stability of an individual's spatial working memory abilities, as measured by the spatial memory recall task, would be related to the accuracy of the long-term memory task.

3.2 *Participants*

The first age group consisted of young adults 18-23 years of age. These participants were recruited through the undergraduate research pool at UNL, and the received course credit as compensation. The data from three undergraduate participants were not included in any analyses. One participant was excluded because this individual was outside of the age range. A second participant was excluded because the participant did not complete all of the tasks, and a third participant's data were excluded due to a computer malfunction. In total, data from 37 young adults were included in the dataset. The average age was 20.51 years (*SD*=1.3 years). There were 20 males (54.1%) and 17 females (45.9%).

The second age group consisted of older adults between 60-80 years of age. This is the age range most commonly used in the cognitive aging research (e.g. Moffat & Resnick, 2002; Lamar, Yousem, & Resnick, 2004; Yamamoto & DeGirolamo, 2012; Iachini et al., 2005). The average age was 68.05 years (*SD* = 5.71 years). The older adults were recruited from the University of Nebraska- Lincoln's Osher Lifelong Learning Institute (OLLI), the Center for Brain, Biology, and Behavior database of older adults interested in participating in research, and from the community. The older adults received $20 as compensation. There were 18 females (72%) and 7 males (28%). The researcher made every effort to collect an equal number of males and females; however, there are some potential factors that could have contributed to the unequal groups. First, the average life expectancy for women is longer than for men (U.S. Census Bureau, 2011), which means that there are more women in the population. Second, there also could be a cohort influence for this age bracket that could exacerbate the gender gap in the older adult group. Specifically, the older adults that were being recruited were born between 1937 and the first half of 1957. The U.S Census (2011) estimated that 54.91% of those older adults who are at least 60 years of age are female. While an equal gender distribution provides more control over the ability to examine gender effects, the demographics of the current dataset are arguably more representative of the gender distribution in the actual population.

A set of three screeners determined whether or not a person qualified for the study. Participants were first asked if they had normal or corrected-to-normal vision and if they had been diagnosed with either Parkinson's disease of Korsokoff's Syndrome. The second screener they completed was the MMSE, which tested for signs of dementia or mild cognitive impairment. A. The third screener was an H-pattern extra-ocular screener in which the participant followed the researcher's finger with their eyes while the researcher traced the letter "H" in mid-air. Participants were not asked about current medications. All participants were ultimately deemed eligible for the study

3.3 *Materials*

All of the paradigms used a Dell computer running Windows, and all of the tasks were created using E-Prime. For the working memory recall task, participants viewed the stimuli on a large 32 inch x 18 inch (82.16 cm x 46.28 cm) touchscreen LCD monitor (Sharps, Inc.) that registered the location that the participant touched. The monitor was placed 15° up from horizontal. The participants completed the working memory recognition task and the long-term memory recall task in a different room on a desktop computer. For the working memory recognition task, participants used a keyboard to make responses. The participants used a mouse to respond in the long-term memory recall task.

3.4 *Procedure*

After giving informed consent, participants completed all of the screeners. They then completed three spatial memory tasks. The order in which the participants completed the tasks was randomly assigned using Latin Squares.

3.4.1 *Spatial working memory recall task.*

In the recall task, participants viewed one target on a touchscreen. The target was triangular shaped and was illuminated for 1500 milliseconds. The target appeared in one of two locations: either 20° to the left of the center of the screen or 40° to the right of the center of the screen (see Figure 19 for a diagram of the screen). Following a delay of 10 seconds, the participants were prompted to touch the location of the target. After each trial participants received feedback about whether they were accurate, close to the target location, or inaccurate. Participants completed 50 trials for each condition, with an inter-trial delay of 2000 ms. The computer computed the directional and distance error (see

Figure 19). Constant directional error was calculated as toward- or away from the midline symmetry axis, relative to the target. It is measured in degrees (as opposed to X and Y coordinates).

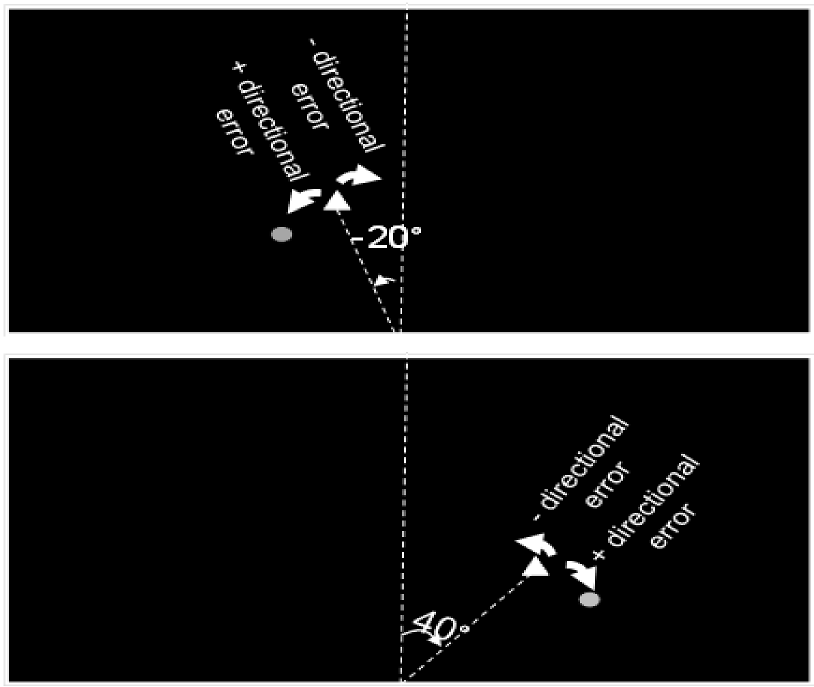

Figure 19. Diagram of target and distractor locations for working memory recall task

3.4.2 *Spatial working memory recognition task.*

Participants completed a spatial working memory recognition task in which they viewed different sized sets of visual targets (3, 5 or 7 stimuli) in different locations on a computer screen. The increasing memory load tested whether increasing task complexity influenced spatial recognition. Participants completed 50 trials of each condition. The inter-trial interval was 2000 ms. Figure 20 displays a sample of what the participants saw on the screen.

The targets appeared on the screen for 2000 ms. After a delay of 3000 ms, a probe stimulus appeared on the screen, and the participants indicated whether the location of the probe matched one of the locations in the previously presented set by pressing one of two keys on a keyboard. The researcher had all participants use the “F” and “J” keys and counterbalanced across participants which of the two keys coded for “match” and which key coded for “mismatch.” Participants did not receive feedback on this task.

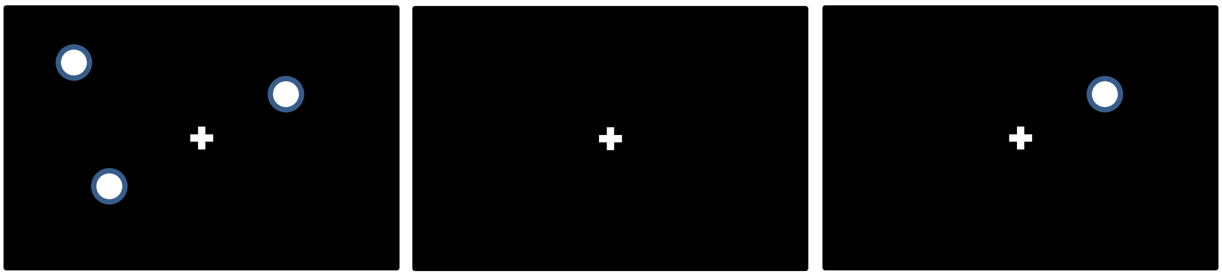

Figure 20 Example of SWM Recognition Task

3.4.3 *Spatial long-term memory task.*

In the long-term memory recall task participants viewed seven different spatial layouts that included three targets each. In each layout, the same image was used for all three targets (e.g. three pictures of a circle, three pictures of the same heart, etc.) The viewing angle for each of the targets was between 3-5º from the center of the screen. Participants viewed a specific layout for 2000 ms before the screen went blank. Once the mouse cursor appeared, participants used the mouse to click on the three locations where they had seen the object. Before the task started, the researcher instructed the participants that they had 5 seconds to make all three mouse clicks. Figure 21 provides an example of what participants saw on the screen. The inter-trial interval was a random amount of time between 1.6 and 2.2 seconds. After making the responses for the seventh layout, participants followed the same procedure four more times. The computer computed the distance between the target location and the response. Next participants completed a 10 minute a cued go-no go task as a distractor task. For each trial in this task, the participants saw either a green triangle or a blue triangle. They had to press the space bar any time they saw a green rectangle.

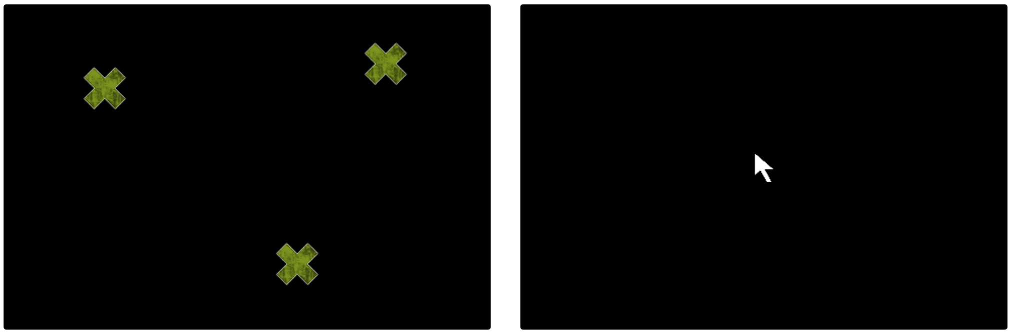

Figure 21 Example of Study Phase of LTM Task

After the distractor task, participants completed the test portion of the long-term memory task. For this portion of the task, participants recalled the locations of all three targets within each layout. Figure 22 displays an example of what participants saw. First, participants saw a prompt screen requesting that they "Please use the mouse to choose the three locations on the screen in which the following object appeared" and a picture of the object on the instruction screen. After the screen went blank and the mouse appeared at the center of the screen, the participant clicked on the three locations on the screen in which the objects had appeared. The participants could select the locations in any order. The computer recorded the three locations. Participants did not receive any feedback and the objects did not reappear on the screen after the participant responded.

Figure 22 Example Screen Display from LTM Test Phase

As previously discussed, this design is similar to the SWM recall task in that it records where participants responded relative to the actual target location. Yet, it has some differences from the SWM recall task that helps to avoid any carry-over effect between the two tasks. Furthermore, the similar dependent variables allow for the examination of how the SWM recall task contributes to the LTM test phase.

3.5 Data Analysis

3.5.1 *SWM Recognition Task*

This task assessed the accuracy of recognition memory for multiple targets by using proportion of correct trials. The data from one of the layouts in the 3-target condition was excluded due to a programming error for that layout, which meant that there were only 48 trials for this condition (instead of the 50 trials that were analyzed in the other two conditions)

Before the data were analyzed, trials were excluded if the participant did not make a response on that trial. Between the two age groups, there were 209 trials excluded in the 3-target condition (7.3%), 169 trials excluded in the 5-target condition (2.7%), and 201 trials excluded in the 7-target condition (3.3%). If the number of trials a participant did not answer was more than 2.5 standard deviations below the average number of trials, then that participant's data were excluded. The data from one younger adult and two older adults were excluded from the three-target condition. In the five-target condition, one young adult and one older adult were excluded. In the seven-target condition, the data from one younger adult and one older adult were excluded. Next, the researcher calculated the participant's percent correct for each of the three conditions. For each condition, if a person's accuracy was more than 2.5 standard deviations below the mean, then they were excluded from the analysis. In the five-target condition, one young adult was excluded. For within-subjects analyses, SPSS automatically excludes a participant's data from the analysis if the person is missing data from one of the conditions. Therefore, if a person's data was excluded from one condition, it was automatically excluded from all three conditions.

In order to test the second hypothesis, each layout in the 7-target condition had two targets paired together. Targets were considered "near" each other if they were in the same quadrant. The 7-target set size had three quadrants that contained a pairing and one quadrant that had an individual target. The quadrants that had a pair of targets were counterbalanced for each condition. Within each of the 7-target layouts, the target pair with the least amount of distance between the two targets was operationalized as the "near" pair while the other two target pairings were operationalized as "far pairing" and the target in the quadrant by itself was the "far" target.

3.5.2 *SWM Recall Task*

The average error was computed for each age group. Errors that were more than 2.5 standard deviations from the mean error for each age group were excluded from the analyses (Younger adults: 16 trials, 1.4%; Older adults: 10 trials, 1.3%).

Two separate general linear models were used to analyze this task: one with constant directional error as the dependent variable and the other with constant distance error as the dependent variable. Categorical age (younger adults and older adult) and gender (males and females) were simultaneously entered into the model as independent variables. A follow-up analysis looked at how categorical age, gender, and distance from the midline impacted the average variability of performance. This model tested the part of

Hypothesis 4, which predicted that there would be more variation in the older adult population than in the younger adult population. Because there is a wide distribution of ages in the older adult population and the brain atrophies significantly between 60-80 years of age (Golumb et al., 1993), these analyses examined whether age in late adulthood contributed to this variation in performance.

3.5.3 *LTM Recall Task*

For each trial, the computer calculated the distances between the three targets and each response. The computer assigned responses to targets that were closest to the response and that minimized the overall error in the trial. In the instances where the participant clicked in the same location twice, one of the responses was retained and assigned to a target and the other response was thrown out. If the participant clicked in the same location all three times, then all three responses were thrown out. The researcher operationalized outliers as being more than 2.5 *SD* above the mean. The mean and *SD* for the distance between the targets and responses included all responses from every trial and was calculated separately for each age group. For the study phase, 81 younger adult responses (2.1%) and 71 older adults' responses (.8%) were excluded. For the test phase, 29 younger adult responses (3.7%) and 10 older adult responses (1.9%) were excluded.

CHAPTER IV: RESULTS

4.1 Spatial Working Memory Recognition Task

The first repeated measures general linear model tested the hypothesis that the results of Nagel et al. (2009) would be replicated, specifically that participants' accuracy would decline as the task complexity increased and that performance of older adults on this task would show a greater rate of decline in accuracy relative to younger adults. There was a main effect of task complexity on accuracy, $F(2,104) = 20.55$, $p <.001$, $MSE = .008$. While there was not a significant difference in accuracy between the 3-target condition, $M =.618$, $SD =.07$, and the 5-target condition, $M = .613$, $SD=.07$, $t(55) = .415$ $p = .680$, participants did significantly better in the 3- and 5-target conditions than the 7-target condition, $M = .539$, $SD = .07$, $t(55) = 6.093$ and $t(55) = 6.097$, respectively, $p's < .001$).

There was not a significant interaction between age group and task complexity, $F(2,104) = 1.125$, $p = .328$, $MSE = .008$, which means that the results of Nagel et al. (2009) were not replicated. Additionally, there was not a main effect of age group, $F(1,52) = 1.234$, $p = .272$, $MSE = .014$, or gender, $F(1,52) = .681$, $p = .413$ $MSE = .014$. Nagel et al. did not include trial type in their analyses, so a follow-up model collapsed performance across trial type to see if Nagel et al.'s results were replicated if we did not distinguish between match trials and nonmatch trials. There still was not a significant interaction between age group and task complexity, $F(2, 104) = .329$, $p = .721$. Because the results of the follow-up model are the same as the initial model, we decided to stay with the first model that included trial type as a predictor.

Accuracy differed between the match and non-match trials, $F(1,52) = 16.996$, $p < .001$, $MSE = 1.32$. Participants were significantly more accurate on the Match trials, $M =$

.656, *SE* = .017, than the Non-match trials, *M* = .517, *SE* = .019, $p < .001$. There was a significant interaction between age group and trial type, $F(1,52) = 6.206$, $p = .016$, *MSE* = .482. Figure 23 displays each group's average accuracy on match and non-match trials. Younger adults were significantly less accurate than older adults on the match trials, $t(54) = -2.379$, $p = .021$, and they were more accurate than the older adults on the nonmatch trials, $t(54) = 2.817$ $p = .007$. When comparing accuracy on match trials and nonmatch trials within each group, there was not a significant difference in the younger adults' performance between the two trial types, $t(34) = 1.663$, $p = .108$. Older adults were significantly more accurate on match trials than nonmatch trials, $t(20) = 3.999$, $p = .001$, suggesting that they were more likely to respond "match" on nonmatch trials.

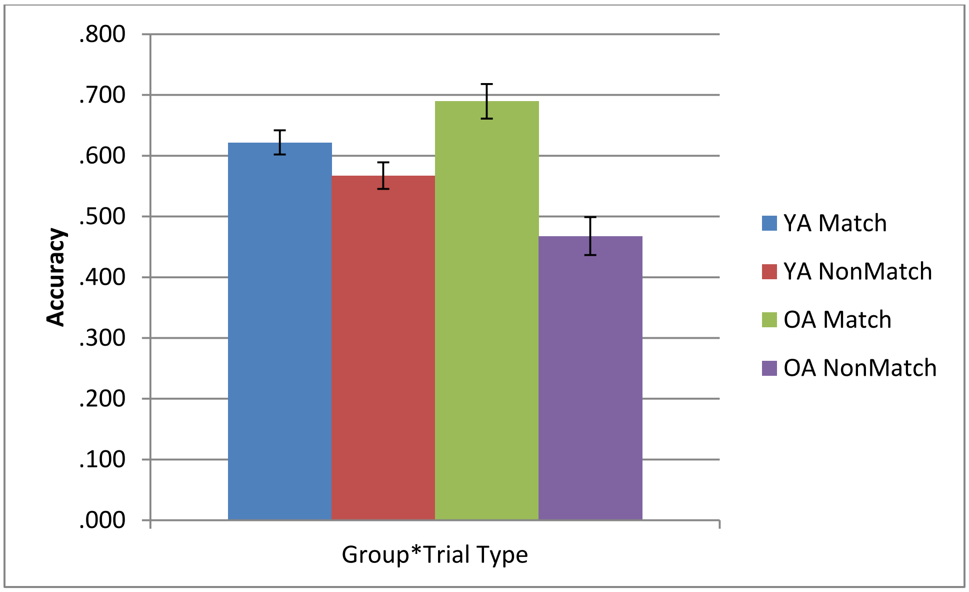

Figure 23. Group accuracy on match and nonmatch trials in the SWM recognition memory task.

Finally, there was an interaction between task complexity and trial type, $F(2,104) = 37.985$, $p <.001$, *MSE* = .619. Figure 24 displays the mean and standard deviation for each term of the interaction. Participants did significantly worse on the 3-target match trials than the 5-target match trials $t(56) = -6.144$, $p < .001$ and the 7-target match trials $t(56) = -2.375$, $p = .021$. Conversely, they did significantly better on the 3-target non-match trials than they did on the 5-target non-match trials, $t(56) = 6.159$, $p < .001$, and on the 7-target non-match trials, $t(56) = 8.610$, $p < .001$. Participants did significantly better on the 5-target match trials than on the 7-target match trials, $t(57) = 3.098$, $p = .003$. They also did significantly better on the 5-target nonmatch trials than they did on the 7 target nonmatch trials, $t(57) = 4.432$, $p < .001$.

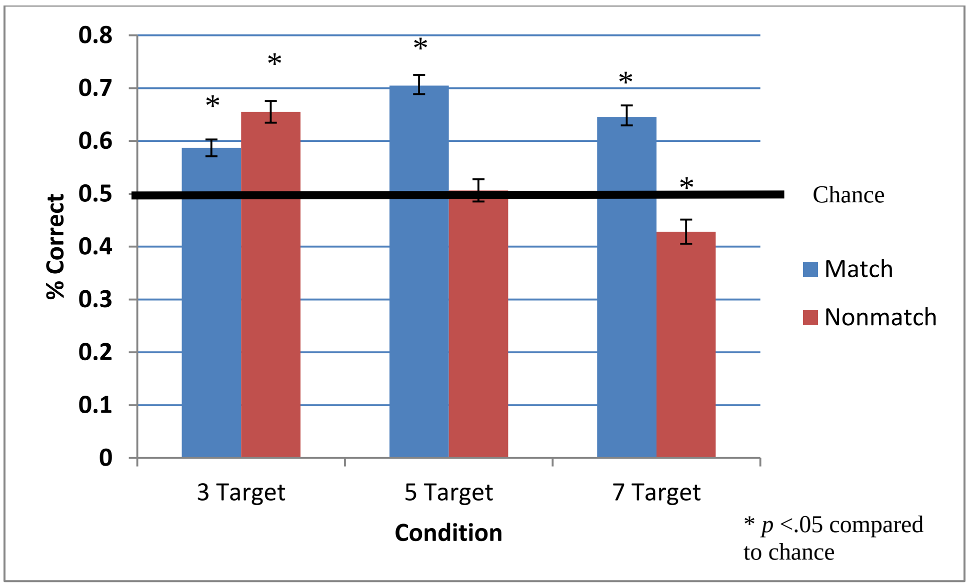

Figure 24. Interaction between task complexity and trial type in the SWM recognition task. Error bars represent standard deviations.

A second set of repeated measures general linear models were run to test the second hypothesis, which proposed that participants would be more likely to forget those objects that were closer together. As mentioned above, the distance between targets was classified as a categorical variable and only the data from the 7-target condition were used in this analysis. There were 3 distance categories: (a) the tested target was in the same quadrant as another target and the distance between the these two targets was smaller than any other pairing, (b) the tested target was in the same quadrant as another target, but another target pairing had a smaller distance between the targets, and (c) the tested target was in a quadrant by itself. There was a main effect of distance between targets, $F(2,112) = 12.293$, $p < .001$, $MSE = .023$. Figure 25 displays the mean comparisons. The results demonstrate the opposite effect of what had been anticipated. Participants were more accurate when targets were very close to each other in the same quadrant compared to when they were in the same quadrant, but further apart, $p < .001$, or if the targets were far apart, $p < .001$. There was no significant mean difference between those tested targets that were in the same quadrant as another target, but further apart, and when the tested target was in a quadrant of its own, $p = .829$. There was not a significant interaction between trial type (match vs. non-match) and distance between targets, $F(2,112) = 1.123$, $p = .329$.

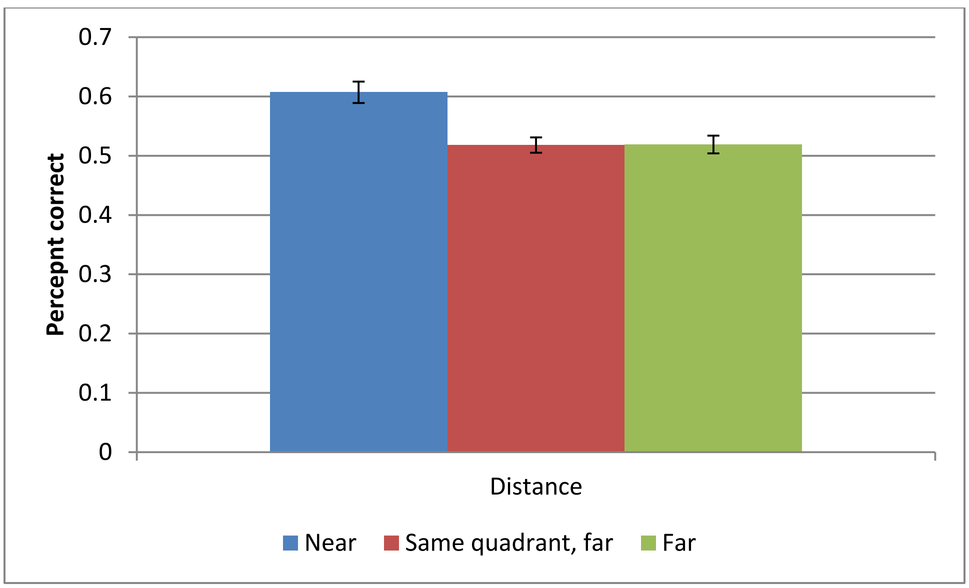

Figure 25 Average accuracy when distance between targets varies. Error bars represent standard error.

4.2 Spatial Working Memory Recall Task

The third hypothesis predicted that there would not be a significant difference in constant directional error or distance error between younger or older adults on the SWM recall task, but there would be a higher degree of variability in the older adults' performance. This hypothesis was tested by running two general linear models in SAS with the Proc Mixed function. The independent variables for both models were the participants' age group, gender (males were coded as 0), and categorical distance from midline (near vs far). Targets close to the midline appeared at 20° from center and were coded as 0 while further targets 40° from the center were coded as 1.

The first model had constant directional error as the dependent variable. There was a significant main effect of age group on constant directional error $F(1,58) = 7.97$, $p = .007$. Younger adults were significantly more biased away from the midline, $M = 1.663$ mm, $SE = .27$, than older adults $M = .384$ mm, $SE = .364$. Furthermore, while the younger adults' constant directional error was significantly greater than zero, $t(58) = 6.16$, $p < .001$, the magnitude of the older adults' bias away from the center was not significantly greater than zero, $t(58) = 1.05$, $p = .296$. Therefore, the younger adults were significantly biased, but the older adults were not.

Target location had a significant main effect on constant directional error, $F(1,58) = 37.75$, $p < .001$. There was also a significant interaction between age group and target location, $F(1,58) = 10.16$ $p = .002$. The means are displayed in Figure 26. The constant directional errors that that are significantly greater than zero are marked with a "*" in the graph ($p < .05$). There was a significant difference between younger adults' and older adults' responses when the target appeared at 20°, t(58) = 3.77, $p < .001$, but not when it appeared at 40°, t(58) = 1.5, $p = .14$.

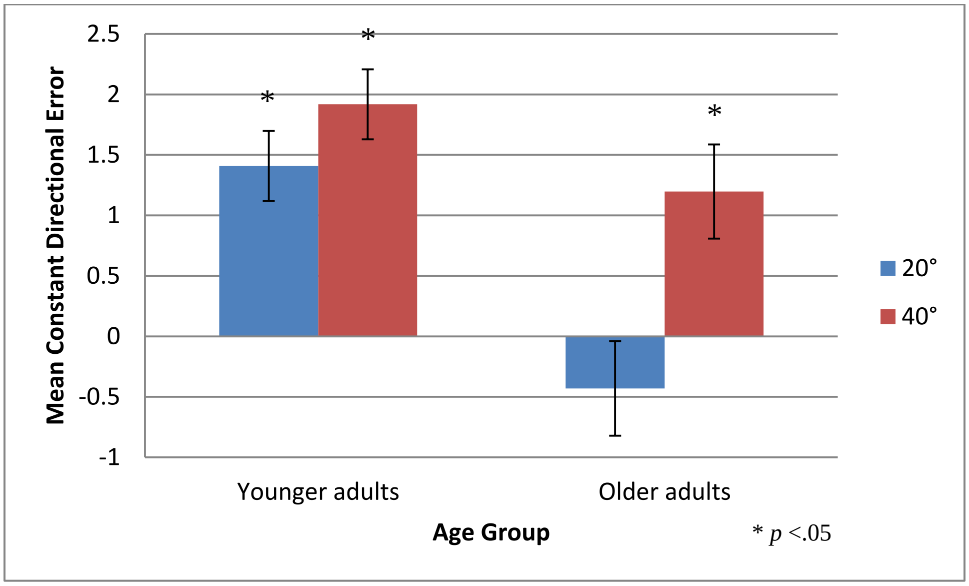

Figure 26 Average age group directional bias in the SWM recall task. Error bars represent standard error.

A second general linear model tested the hypothesis that there would be more variability in the older adults' memory than the younger adults' memory. The independent variables were age group and target location. The dependent variable was the standard deviation of each participant's constant directional error. Contrary to the hypothesis, there was not a significant difference in variability between the younger adults, M = 3.007 mm, *S.E.* = .10, and the older adults, M = 2.821 mm, *S.E.* = .13, $F(1,59) = 1.24$, $p = .270$. There was a significant main effect of target location, $F(1, 59) = 11.06$, $p = .002$. Responses were more variable when the target appeared at 40°, M = 2.967 mm, SE = .0833, than when the target appeared at 20°, M = 2.861 mm, SE = .08. Furthermore, there was a significant interaction between target location and age group, $F(1,59) = 21.34$, $p < .001$. The means and standard errors are displayed in Figure 27. The only significant difference was that younger adults had significantly more variation in their responses when the target appeared at 40º than when the target appeared at 20º, *t*(59) = -6.33, *p* <.001. There was not a significant difference in performance between younger adults and older adults when targets appeared at 20º, *t*(59) = .23, *p* = .818, or at 40º, *t*(59) = 1.96, *p* = .055.

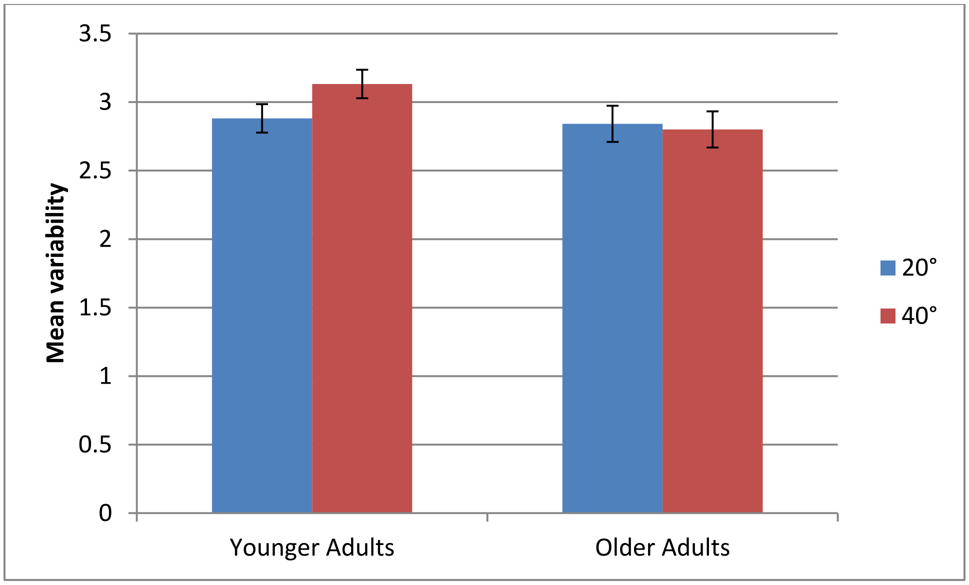

Figure 27 Mean variability (*SD*) in directional error**.** Error bars represent standard error.

The final model had constant distance error as the dependent variable. There was not a significant effect of age group, *F*(1,58) = .64, *p* = .426, or of gender, *F*(1,58) = 2.67, *p* = .108. There was a significant main effect of target location, *F*(1,58) = 53.39, *p* < .001. When the target appeared at -20°, constant distance error, *M* = 4.631 mm, *SE* = .560, was significantly greater than when the target appeared at 40°, *M* = .584mm, *S.E.* = .557, *t*(58) = 7.31, *p* < .001.

4.3 LTM Recall Task

4.3.1 Analysis of LTM Study Phase

A general linear model was run using the Proc Mixed function in SAS. The error from the three responses on a trial was averaged together (e.g. the average error of the three responses on the first trial of Layout 1). There was not a significant main effect of age group on the magnitude of response error, $F(1,59) = .17$, $p = .679$. The average response error for the younger adult group was $M = 16.393$ mm, *S.E.* = .517, and the average response error for the older adult group was M = 16.738 mm, *S.E.* = .633. There was a significant main effect of trial, $F(4,240) = 5.17$, $p = .001$. Means are displayed in Figure 28. Errors on Trial 1 were significantly larger than Trial 2, $t(240) = 2.94$, $p < .004$, Trial 3, $t(240) = 4.25$, $p < .0001$, Trial 4, $t(240) = 3.34$, $p = .001$, and Trial 5, $t(240) = 3.1$, $p = .002$. There was not a significant difference in error between the other trials, all *p*’s > .05. This result means that participants had similar performance on Trials 2, 3, 4, and 5. Layout was entered into the model as a control variable and had a significant influence on the level of error in responses, $F(6,366) = 27.87$, $p < .001$. Average error for each layout in the study phase was included in the test phase models to control for differences in how well each layout was learned during the study phase.

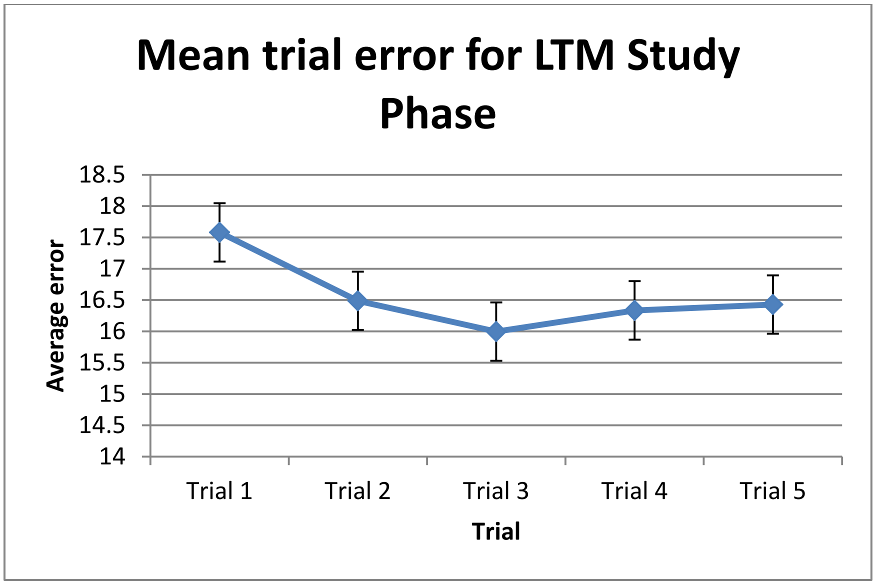

Figure 28 Main effect of trial on average error. Error bars represent standard error.

4.3.2 Analysis of Long-term Memory Test Phase

Errors were computed using the same method as the study phase. The first model examined how performance on the study phase contributed to error in the test phase. In this model, performance from the study phase consisted of the average error for each layout. The error from the study phase was included in the model to control for how well the layouts were learned during the study phase. This model also controlled for the main effects of gender, age group, and layout. The error from the study phase was related to the level of response error on the long-term memory task, $F(1,353) = 6.11$ $p = .014$. A linear regression with the same independent variables was used to follow up on this effect. The purpose of this follow-up analysis was to examine how strongly the error from the study phase contributed to participants' error in the test phase. The maxr method of entering variables accounted for the most variance, $R^2 = .055$. The final regression model was significant, $F(4,417) = 6.1$, $p < .001$, After accounting for a person's gender, age group, and layout, a person's error in the test phase increased by .894 for every 1-unit increase in the average error from the study phase, $p < .001$.

There were two hypotheses for the long-term memory task. The first hypothesis was that older adults would make larger errors than younger adults would. After controlling for test, layout, and performance on the study phase, there was a significant main effect of age group, $F(1,59) = 4.25$, $p = .044$. Younger adults made significantly smaller errors $M = 42.971$ mm, *S.E.* = 2.128 than older adults $M = 50.12$ mm, *S.E.* = 2.7.

The second hypothesis predicted that stability of performance on the spatial working memory recall task would predict performance on the long-term memory task. The standard deviation from the spatial working memory task was included in the model. The model also controlled for gender, age group, and test phase layout. This hypothesis was not supported. There was not a significant relationship between the average standard deviation from the spatial working memory task and the test phase of the long-term memory task, $F(1,355) = .34$, $p = .5603$.

A second model was run to see if overall performance on the spatial working memory recall task would be related to performance on the long-term memory task. One model was run to test this hypothesis using the participant's mean constant directional error from the SWM recall task as a measure of their working memory ability. This model controlled for gender, age group, ands test phase layout. There was not a significant relationship between performance on the SWM recall task and on the test phase of the LTM task, $F(1,354) = 1.09$, $p =.298$, which means that performance on the SWM recall task did not predict performance on the test phase of the LTM task.

CHAPTER V: DISCUSSION

There were two goals of the present study. The first goal was to examine how different types of spatial memory changed across the lifespan, how working memory abilities contributed to long-term memory, and to examine how the interaction between working memory and long-term memory changed from young adulthood to late adulthood. There are two aims behind this goal. One aim l was to examine how cognitive aging impacts working memory recall abilities and working memory recognition abilities The present study also examined how performance on a long-term memory changed across the lifespan by examining how information was initially encoded and how it was maintained in long-term memory. The second aim of first goal was that this study looked at how the interaction of spatial working memory recall abilities is related to influence long-term memory performance. The second goal of this study was to examine the ability of DFT to model cognitive development in late adulthood.

The following sections will discuss one task at a time. Each section will first summarize the findings of that task within the context of the current study, followed by a discussion of how the present results compare to previous behavioral studies and the DFT simulations. Potential future research will also be discussed within each section. Finally, the discussion of each task will summarize how that task relates to age-related changes in cognition. After the last behavioral task is reviewed, a discussion of whether DFT is the most appropriate theory to address neurocognitive aging will conclude this chapter.

5.1 Spatial Working Memory Recognition Task

Overall, participants' performance on the spatial recognition task yielded mixed support for the hypotheses. The first hypothesis predicted the replication of the findings of Nagel et al. (2009)'s findings. Specifically, the first hypothesis was that accuracy would decrease as task complexity increased and that older adults' accuracy would decrease more rapidly than younger adults' accuracy. While there was not a significant difference in accuracy between the 3-target and 5-target tasks, participants did significantly worse on the 7-target condition compared to the other two conditions. This result supports the first part of the hypothesis, and suggests that the increase in level of difficulty between the 3-target and 5-target conditions was not great enough to cause a decrease in accuracy. The second part of the hypothesis, however, that older adults' accuracy would decrease more rapidly than younger adults' accuracy as complexity increased, was not supported. Instead, the increasing task complexity had a similar influence on the performance of younger adults and older adults. The implication of this finding is that spatial working memory recognition performance, as measured by this task, did not change over adulthood.

The second hypothesis, based on DFT, was that accuracy would decrease if the tested target was close to a second target. While the distance between targets influenced location memory, the results did not support the specific hypothesis that the DFT simulations predicted. In fact, the opposite effect was observed. Specifically, participants were more accurate if the two targets were paired together compared to those trials in which the tested target was an intermediate distance from other targets (i.e., the tested target was in the same quadrant as another target but not paired with it), or far from the other targets (i.e., in a different quadrant).

In comparing these results to Nagel et al. (2009), it is clear that the present results are consistent with some of their previous findings but run counter to others. Recall that

Nagel et al. observed that while there was not a significant difference between performance on the one-target condition and three-target condition, accuracy of performance declined as the task complexity increased from three targets to seven targets. The present study found that performance was statistically equivalent between the 3-target and 5-target condition and that performance significantly declined on the 7-target condition. These findings suggest that the difference in difficulty between the 3-target task and 5-target task was not large enough to cause a significant decline in performance. However, the significant decline in accuracy on the 7-target task suggests that this condition was noticeably harder than the other two conditions. One potential explanation for the results is that the threshold of working memory capacity is greater than five objects. Alvarez and Cavanagh (2004) found that adults can retain an average of 4.7 objects in their visual short-term memory capacity. While the task from their study generally utilizes different cognitive processing than the current study's recognition task, there is some overlap between the two paradigms in terms of encoding visuo-spatial information. Perhaps the 5-target set fell within the participants' capacity for encoding visuo-spatial information while the 7-target set fell outside their ability to encode all locations. A follow-up study should test this speculation that there is a similar encoding capacity for all visuo-spatial memory tasks.

Furthermore, Nagel et al. (2009) found that performance accuracy declined at a greater rate for older adults than it did younger adults. The results of the current study did not replicate this finding, instead accuracy for both age groups declined at a statistically similar rate. A number of differences between studies could have led to these differences in results, and these are considered in turn. The first difference between this study and the study by Nagel and colleagues was that Nagel and colleagues only had participants respond on match trials. Having to choose between two responses could potentially cause a response bias or involve a different strategy in responding than only having one response option (Summerfield & Koechlin, 2008; Lamar, Yousem, & Resnick, 2004). The process of choosing between two active responses, such as in the current study and Lamar, Yousem, and Resnick's study, may impact cognition differently than Nagel et al.'s paradigm, which entailed participants deciding between an active response (pressing a button for match trials) and a passive response (not pressing anything for nonmatch trials). A drawback of Nagel et al.'s paradigm is that from a behavioral standpoint, it is difficult to detect whether the participants did not press the button because they believed it was a nonmatch trial or if they did not respond in time.

The present study found that on match trials older adults performed better than younger adults while younger adults performed better than older adults on the nonmatch trials. Performance was collapsed across match and nonmatch trials to examine if differentiating between match and nonmatch trials influenced the analyses. However, Nagel et al. (2009)'s finding regarding the interaction of age and task complexity was still not replicated in the current study. The present study did not find that as task complexity increased, older adult performance declined at a greater rate relative to younger adult's performance.

A second factor that could explain why performance of older adults in Nagel et al. (2009) declined at a greater rate as task complexity increased could be related to how long the layouts were presented on the screen. In Nagel et al.'s study, each layout was on the screen for 1000 ms while the layouts in the present study were on the screen for 2000 ms. Visuospatial processing speed is particularly sensitive to age-related declines (e.g. Jenkins et al., 2000) and speed becomes even more important as task complexity increases (Hale & Myerson, 1996). A future study should examine the interaction between processing speed and task complexity to see if the present study's extra time for processing is why the results differed from Nagel et al. (2009).

A third potential factor that may have led to this study finding a different result from Nagel et al. (2009) could be related to differences in how the instructions were given. . During the present study's consenting process, participants were informed that this study examined whether certain types of spatial memory changed with age. If the older adults made a comment about how they would not do well because they were older, they were told that not all facets of memory decline with age. Some research has found that age-related stereotype threat can enhance performance in some instances and hinder performance in other instances (Barber and Mather, 2013; Mazerolle et al., 2012), while other research has found that age-related stereotype threat only hinders memory (Chasteen et al., 2005; Hess, Hinson, & Hodges, 2009). It is possible that the exchange with the older adults in the present study may have enhanced their performance by providing extra motivation to do well and avoid confirming negative stereotypes about the memories older adults. It is unknown how many older adults in the present study or Nagel et al.'s study experienced stereotype threat. It is also unknown whether this phenomenon enhanced the performance of older adults or hindered the performance of older adults in Nagel et al.'s study. However, previously cited literature (e.g. Barber and Mather, 2013; Chasteen et al., 2005; Hess, Hinson, & Hodges, 2009; Mazerolle et al.,

2012) emphasizes the need to better control for potential stereotype threat among older adults.

In addition to the interacting with a person's age group, trial type also interacted with task complexity. Participants performed significantly better on the 5-target condition than the 7-target condition, regardless of the type of trial. Participants performed significantly worse on the 3-target match trials than the 5-target match trials and 7-target match trials. One potential explanation for this finding is that participants may have felt less confident about the probe matching one of the target locations for the 3-target condition. The 3-target condition has fewer potential match locations than the other conditions (which means more potential nonmatch locations). Because there were more potential nonmatch locations than match locations on the 3-target condition, participants may have been biased to respond "nonmatch" when they were uncertain about which response to make. For the 7-target condition, participants performed significantly better than chance on the match trials. They performed significantly worse than chance on the nonmatch trials.

One potential explanation for this difference between match and nonmatch trials is that for the nonmatch trials, the participants had misremembered one of the targets appearing in that location. Prior research has found that participants have false memories on a verbal working memory task (e.g. Roediger & McDermott, 1995). In their study, Roediger and McDermott had participants study a word list. After a delay, participants were presented a series of words and asked whether they had appeared on the previously seen word list. The authors found that participants had believed some of the previously unseen words were on the list they had memorized and were confident of their answers.

The present study could have potentially replicated the findings of Roediger and McDermott within the spatial domain in that participants may have incorrectly believe that there had been a target in the nonmatch location. However, it is difficult to detect whether the participants truly thought the probe matched one of the locations, because the current study only used behavioral measures and did not ask about confidence in answers.

One alternative explanation for the difference in performance between match trials and nonmatch trials is that these two conditions activate different regions of the brain (e.g. Sinha & Glass, 2017). Sinha and Glass (2017) used a matching task that tested verbal working memory. Participants pressed one button if a string of letters matched a previously seen string or press another button if the string did not match. Sinha and Glass found that during recognition tasks, young adults showed activation in the hippocampus during match conditions and that both the hippocampus and the caudate nucleus were activated. They discussed how the caudate nucleus is activated for serial learning tasks and that the hippocampus interacts with the caudate nucleus on the nonmatch tasks.. Overall, the implication of Sinha and Glass (2017)'s study is that people process match trials differently than nonmatch trials. Sinha and Glass's finding that there is difference in activation between match trials and nonmatch trials could imply that people use different strategies when completing match trials compared to nonmatch trials.

Another alternative explanation for misremembering a target appearing in the nonmatch location is that participants may have guessed and chose "match" when they were unsure of the correct answer. Participants may have been more likely to use this strategy in the 7-target condition than in the 3-target condition, because the amount of unoccupied space in the 7-target condition was less than the amount of unoccupied space in the 3-target condition. Participants may have believed that guessing “match” in the 7-target condition was the best approach because the number of match locations per cm was greater for this condition than for the other conditions. This explanation may be most relevant to the older adults. Prior research has found that older adults tend to rely more on a sense of having experienced the information during encoding and that older adults have similar accuracy to young adults on familiarity tasks (e.g. Ward et al., 2017). Additionally, the present study found that older adults did significantly better on the match trials than younger adults. The older adults in the present study may have relied more on how familiar the probe’s location seemed to them. However, it is difficult to assess whether the participants actually remembered if the target had appeared in that location, if they guessed because it seemed like a familiar location, or if the people randomly guessed. A follow-up study could include a measurement of the participants’ confidence in the accuracy of their answer for each trial.

The second hypothesis was that people would be more likely to forget those targets that were close to another target. This prediction was based off of DFT simulations that suggested having two targets close together would cause the memory for at least one of the target locations to fade. The model and the hypothesis were not supported by the behavioral data. Instead, participants were more accurate if the tested target was close to a second target. A modification of the DFT model may be more appropriate for this situation. Johnson and Spencer (2016) expanded the DFT model of spatial working memory to examine how shifting attention to another location influenced location memory. They accomplished this objective by adding another perceptual field, a 2-D color-space field that coded both the location and color of a stimulus. They also conducted a behavioral study to test their model. The task they modeled had a target appear in a particular location. After the target disappeared, participants completed a color discrimination task during the brief delay. This task required them to shift their attention to a colored dot that appeared in either the same or different location than the target. Participants made a response about the color they saw on the screen and then, after a short delay, had to recall the position of the initial target. The results of the DFT model and the behavioral data were that memory for the target location shifted toward the location of the colored dot.

The difference between the current study's task and Johnson and Spencer's task is that the current study displayed multiple targets simultaneously while Johnson's and Spencer's task only displayed one target at a time. In order to test the speculation that the behavioral results from the present study were related to shifts in attention, the revised model would use an approach similar to Johnson and Spencer's model to capture shifts in attention. The present study's model of the recognition task simultaneously entered all of the stimulus inputs into the model. Johnson and Spencer's model entered the stimulus inputs sequentially; thus, capturing shifts in attention through the sequential input. Sequentially entering the stimulus inputs into the model may be a more accurate approach of how people process spatial information in the SWM recognition task. This approach would capture the idea that instead of encoding all of the stimulus locations at once, people move a "spotlight of attention" around the screen resulting in sequential encoding of the locations.

The proposal that people move their attention around the screen comes from the spotlight model of attention proposed by Posner and colleagues (e.g. Posner, Snyder, &

Davidson, 1968). According to this theory, attention is focused on one particular area. However, the recognition task required participants to look at multiple areas. Despite the targets appearing on the screen simultaneously, the spotlight model of attention would argue that people encode locations serially. It is anticipated that people would scan the different locations within the spotlight, one at a time. Then the participants could shift their attention (spotlight) to another are area of the screen and scan the locations in that area by encoding one target location at a time. For this task, participants may have spent more time focused on the area of the screen that had the most targets, and found this strategy to be the most beneficial approach to the task. As described in the prior paragraph, DFT model would need to be revised to better capture how attention and spatial working memory interact when remembering multiple locations. Specifically, future models and behavioral studies should examine how people focus their attention, especially to see if they spend more time attending to a cluster of targets. The use of eye-tracking equipment can help answer this question.

Furthermore, the metric information related to a layout, such as the distances between targets, can influence how people focus their attention and how well they can encode the target locations. Recall that Iachini et al. (2005) found that older adults had trouble estimating the distance between targets. In addition to this finding, Iachini et al. also noticed that older adults tend to have a similar performance to younger adults when scanning a visual environment that has targets close together. However, while younger adults took longer to scan the layout when the items were further apart, the older adults did not adjust their scanning time. Iachini et al. states that this finding implies larger distances between landmarks make it harder for older adults to scan and learn. In other words, having targets close to each other is beneficial for older adults as they encode spatial information. In terms of Iachini et al.'s findings in relation to the results of the present study's SWM recognition task, perhaps the shorter distance between targets is just as beneficial for the younger adults as it is for older adults. The present study did not find a difference between the two age groups, regardless of the distance between the tested target and another target. However, this task tested spatial recognition memory while Iachini et al.'s paradigm tested spatial recall memory, which could explain the difference in the role that distance between two targets plays in remembering a location.

In summary, the results are mixed in terms of whether older adults have worse spatial recognition memory abilities than younger adults. As hypothesized, accuracy declined as task complexity increased. On the one hand, there was not any evidence for the hypothesis that older adults' accuracy would decline at a greater rate than younger adults' as task complexity increased. Instead, the older adults' accuracy declined at a similar rate to the younger adults' accuracy as task complexity increased. This finding suggests that recognition memory abilities are preserved. However, the significant interaction between age and trial type suggests that some parts of working memory recognition abilities decline with age while others improve. Younger adults were significantly more accurate on nonmatch trials when compared to older adults while older adults performed better than younger adults on the match trials. Finally, there was not any support for the hypothesis that accuracy would be lower on trials where the tested target was close to another target. Instead, this study found that participants were more accurate on these trials. This finding held true for both younger adults and older adults.

5.2 Spatial Working Memory Recall Task

In addition to SWM recognition abilities, this study examined how SWM recall abilities changed with age. Based on the DFT simulations, the third hypothesis predicted that older adults would be significantly biased away from midline, there would not be a significant difference in magnitude of bias younger adults and older adults, and that older adults would be more variable in their responses. Unlike the simulations, the overall memory responses of older adults were significantly less biased than younger adults. However, this finding was influenced by the target's location. The memory responses of older adults were not significantly biased away from midline or toward midline when the target appeared at the 20º location. However, the older adults' responses for targets appearing at the 40º location were biased away from the midline the same amount as the younger adults.

With regards to the difference in older adults' performance at the 20º location compared to the 40º location, one potential explanation rests on the idea that neural underpinnings of spatial memory improves during childhood, peaks during young adulthood, and declines in late adulthood. Schutte and colleagues use the framework of DFT and the spatial precision hypothesis to discuss how memory for spatial locations becomes more precise from childhood through young adulthood (e.g. Schutte & Spencer, 2009; Schutte & Spencer, 2002; Schutte, Spencer, & Schöner, 2003). The older adult model has a weaker, broader peak of activation due to the lower excitatory and inhibitory parameters. From a DFT perspective, one potential explanation for the older adults' lack of bias on the 20º location could be that the amount of inhibition from the midline was not strong enough to the memory to drift further from the midline. Johnson and Spencer

(2009) discuss how peaks of activation can be biased toward areas with high level of excitation/lower levels of inhibition. It is possible that the 20º location was close enough to midline to be influenced by this axis. Specifically, it is possible that the older adults' peak of activation at 20º overlapped with the midline's peak of activation to not be repelled by inhibitory connections and far enough way where the memory was not drawn toward the midline in a significant way. With regards to the older adults showing bias away from the midline at 40º, this target may have been far enough from midline that the target peak of activation only overlapped with inhibition from midline, causing the memory to be repelled from midline. In terms of the spatial precision hypothesis, weaker interactions also result in more variable responding in a location memory task. Although prior research has demonstrated that older adults have a decline in accuracy on certain recall tasks (e.g. Permlmutter, 1979; Craik & McDowd, 1987; Craik, 1994), the results of this study did not support the idea that the older adults were more variable than younger adults.

The current study's finding that older adults were less biased than younger adults for targets appearing at 20º is particularly interesting. The previously discussed research by Antonova et al. (2009) found that older adults relied more on categorical processing than coordinate processing. The midline symmetry axis divides the screen into spatial categories, so it was expected that midline would play a role in older adults' responses. Part of the divergence in findings between Antonova et al. and the current study may be attributed to methodological differences. In the current study, categorical biases were operationalized as biases away from the midline of the touchscreen and toward the center of the two spatial categories: the center of the left half and the right half of the screen.

The current study also used a 2D spatial layout that the participants viewed from a map-like perspective. Conversely, Antonova et al. had participants view the layout from a 1st-person perspective and navigate around 3D environment. Within their task, categorical information was defined as where target was located relative to the participant and other landmarks, such as whether the target was to the left or the right of another object. It is possible that their definition of spatial categories relies on a different cognitive process than the underlying cognitive processes that underlie the present study's definition of spatial categories. For example, Yamamoto and DeGirolamo (2012) had participants re-create maps of environments that participants learned from either a 1st-person perspective or from a map-like perspective. The 1st-person perspective is similar to how Antonova et al.'s participants viewed the layout and the map-like perspective is similar to how participants viewed the present study's layouts. Yamamoto and DeGirolamo found that the older adults' maps of the 1st-person layouts were more distorted than younger adult maps. Conversely, there was not a significant difference between the two age groups when they re-created maps of the environments that were learned from a map-like perspective.

The current study replicated previous findings in the literature. In both the current studies and prior studies (e.g. Spencer & Hund, 2002), the location memory of younger adults was biased away from the midline. The finding that older adults were not significantly influenced away from midline at 20° was contrary to the prediction of the DFT model. This finding is also contrary to Crawford, Landy, and Salthouse (2016)'s finding that the influence of category weight had a similar influence on the responses of older adults and younger adults. They also found that older adults were less precise in their responses than younger adults, which is different than the results of the present study.

A future study should compare how the interaction between the type of memory (recall vs recognition) and age influences biases in spatial working memory. Prior research found that younger adults' memories for a location were biased toward a spatial category when they completed a working memory recall task and were not biased toward a spatial category when they completed a working memory recognition task (Sampio & Wang, 2009). Sampio and Wang argue that the results demonstrate that people remember the correct location of a target and are able to demonstrate memory for that location. Their interpretation is that geometric biases are not learned when the location is being stored in memory. They argue that their results demonstrate that biases in spatial memory occur when the locations are being retrieved. While Sampio and Wang's study only focused on younger adults, one future line of research should examine whether this effect changes if older adults completed the tasks.

In summary, none of the hypotheses for this task were supported, Older adults were less biased from the midline than younger adults when the target appeared at 20º . The older adults and younger adults had a similar level of bias from the midline when the target appeared at 40º. Additionally, the performance of older adults was not more variable than the performance of younger adults. These results provide evidence that not all cognitive functioning declines with age.

5.3 LTM Recall Task

The study phase of the LTM task measured the level of accuracy in learning locations and examined how cognitive aging influenced this ability. There was not a significant difference between younger adults and older adults in the study phase of this task. Furthermore, Trials 2-5 had significantly less error than Trial 1 for both groups. Additionally, there was not a significant difference in performance between Trials 2-5. This finding suggests that both groups had similar learning curves and that after the novelty of the task wore off, participants were consistent in their performance in the study phase.

The fourth hypothesis predicted that younger adults would make smaller errors than older adults would. The results supported this hypothesis: younger adults made significantly smaller errors than older adults. The fifth hypothesis was that the stability of performance on the SWM recall task would be related to performance on the test phase of the LTM task and that the SWM recall performance would be more predictive of LTM test phase results for older adults. There was not any evidence supporting this hypothesis.

There are three potential explanations for this difference between younger adults' and older adults' performance on the test phase of the LTM task. One explanation is that there is a difference in how well each group learned the locations during the study phase. Simulations 9 and 10 of the DFT model predicted that older adults’ working memory would be more unstable than younger adults’ working memory. From a behavioral standpoint, this instability may be connected to the previously discussed research of Iachini, Ruggiero, and Iavarone (2005). They found that older adults had trouble remembering metric information on a location memory task that involved scanning a mental image of a layout. It is possible that the struggle with the encoding of metric information may be one of the causes of the predicted instability of performance in the older adult group.. . However, the explanation that younger adults had significantly better performance than older adults due to encoding differences is not likely. The reason that this explanation is unlikey is based on the finding that there was not a significant difference between the performance of older adults and younger adults in the study phase. A second potential explanation is that for older adults, the transfer of information from working memory to long-term memory could be disrupted or not properly stored during the delay between the study phase and test phase. DFT could potentially describe how this disruption of memory could play a role in the behavioral results. Hypothesis 4 discussed how Simulations 9 and 10 showed that the older adult models had more variation in the working memory layer, which would have a negative impact on the strength and accuracy of the memory trace in long-term memory. One way to address how the transfer of location memory from working memory to long-term memory is disrupted would be to add a long-term memory layer to the DFT model. A LTM layer would allow the simulation of different disruptions to LTM. For example, the model could test whether or not weakening connections between the SWM layer and the long-term memory layer could capture the difference between younger and older adults.

The older adults may have had a lower level of accuracy because the older adults' memory for the target location was not effectively stored in long-term memory during the delay between the study phase and test phase. A latent trait model developed by Park et al. (1996) may provide an explanation for the present study's behavioral findings. Park et al. examined different components that influence long-term memory. The three constructs used for long-term memory were spatial recall, verbal free recall, and verbal cued recall. The authors used perceptual speed as a construct for processing speed. They used the Backward Digit span of the WAIS-R, reading span task, and a computation span task as measurements for working memory. Park et al. found that across the lifespan, perceptual speed was a significant mediator for working memory, spatial recall, free recall, and cued recall. Their latent traits model also found that working memory ability was a significant predictor for the free recall and cued recall constructs of long-term memory. They also found that this contribution of working memory was mediated by processing speed. The contribution of processing speed to working memory ability is bolstered by prior research that found that increases in processing speed abilities were related to stronger working memory abilities (e.g. Fry and Hale, 1996). While Park et al. found that working memory contributed to free recall and cued recall constructs of long-term memory, they found that working memory did not directly predict spatial long-term memory.

.Given that Park et al. found that processing speed, and not working memory, predicted spatial long-term memory, perhaps performance on the present study's long-term memory task relied more on processing speed abilities than working memory abilities. Additionally, the long-term memory task might not have been mentally challenging enough for the participants' working memory to play a significant role. In other words, it is possible that the long-term memory task was not hard enough for the participants to heavily rely on their working memories to complete the task. Instead, they may have only relied on processing speed to complete the task. In order to test this speculation, future research should include a measurement of processing speed and should have different levels of complexity to the task (e.g. a 3-target condition, 5-target condition, and 7-target condition). While working memory did not contribute to the 3-target condition used in the present study, working memory may contribute to a more difficult condition, such as one with 5 targets or 7-targets.

A third potential explanation stems from the PASA model, which, as discussed in the introduction, demonstrates that activation in the medial parts of the brain, such as the hippocampus, decline with age while activation in the prefrontal cortex increases with age (Gutchess et al., 2005; Dennis & Cabeza). Furthermore, the prefrontal cortex is involved with working memory (Reuter-Lorenz et al., 2000) while the hippocampus is involved with spatial encoding (Burgess, Maguire, & O’Keefe, 2002) and long-term memory (Graham and Hodges, 1993). Together, these findings could potentially explain why there was not a significant difference between the two age groups on the study phase, while older adults did significantly worse on the test phase of the LTM task. The current study’s results, combined with the neurological research, suggests that older adults are less accurate on long-term memory tasks, less biased on working memory tasks, and that changes in working memory abilities do not necessarily directly predict changes in long-term memory abilities. Therefore, spatial working memory abilities remain relatively unchanged with age while long-term memory abilities decline with age.

An alternative explanation is that older adults had a harder time with memory retrieval than younger adults. This explanation is supported by prior research demonstrating that it is easier to disrupt older adults’ retrieval processes than it is to disrupt younger adults’ retrieval processes (e.g. Hashtroudi, Johnson, & Chrosniak, 1990; Wais, Martin, & Gazzaley, 2012). For example, Wais, Martin, and Gazzaley found that the presence of irrelevant information was more likely to impair older adults’ long-term memory than younger adults’ long-term memory. Hashtroudi, Johnson, and Chrosniak had participants complete a recall task involving episodic memory. The researchers found that younger adults were better than older adults at remembering objective features about the event, such as spatial information and descriptions of different items in the event. Older adults were better at remembering more subjective information about the event, such as how the event made them feel and their opinions of the event. There are two possible implications from Hashtroudi, Johnson, and Chrosniak's study. One potential explanation is that the older adults' subjective memories of the event was easier to recall and interfered with recalling the more objective memories of the event. The other implication is that the older adults had an easier time encoding the subjective event-related information than the objective event-related information. Regardless of which potential explanation is correct, the key finding was that the presence of task-irrelevant information hindered older adults' memory performance. For the current study, there was not any task-irrelevant information on the screen during the study phase and test phase. Additionally, non-experimental distractions were minimized. However, the distractor task may have been a greater hindrance for the older adults' ability to maintain memories from the study phase than it was for the younger adults. There was not a measure for subjective perceptions or memory. From an anecdotal perspective, older adults were more likely to comment on the stimuli from the LTM task and the distractor task.

In terms of the fifth hypothesis, which examined whether variation in performance on the SWM task predicted LTM performance, there are pros and cons to this comparison surrounding the methodological differences between the two studies. The strength of this comparison is that the tasks are relatively different, e.g., take place on different sized monitors, such that any relationship between the two tasks is not confounded by the similarity of the tasks. However, these differences raise the question of whether or not this specific working memory task is a valid measure of working memory's contribution to LTM recall abilities. While the SWM recall task only had one target, the LTM test phase had three targets. Remembering three target locations is harder than remembering one target location. The difference in task complexity could potentially be a reason why neither constant error nor variable error from the SWM recall task predicted error in the LTM task. However, the explanation of task complexity being a factor is limited by Crawford et al. (2016)'s finding that individuals with a higher spatial working memory capacity had less bias on the single dot and multiple dot paradigms. One way to examine whether or not the difference in task complexity between the SWM recall task ant LTM test phase would be to add a second, more complex condition with more targets to the SWM recall task. Alternatively, a measure of SWM capacity might be a better measure of working memory in this study. Therefore, it may be interesting to examine how performance on a paradigm similar to Crawford et al. changes across the lifespan and whether performance on this type of working memory has a different influence on the long-term memory of older adults compared to the long-term memory of younger adults.

In conclusion, there were mixed support for the hypotheses related to long-term memory. There was support for the hypothesis that compared to older adults, younger adults would commit smaller errors on the long-term memory task. This age-related decline in long-term memory performance cannot be attributed to learning ability because younger adults and older adults performed equally well on the study phase of the LTM task. There was not support for the hypothesis that the stability of working memeory recall performance (measured by stand deviation) would predict performance on the long-term memory task. Additionally, working memory recall performance did not predict the participants' long-term memory performance. Compared to the other tasks, the implication is that long-term memory abilities more likely to decline with age than working memory recall abilities and working memory recognition abilities.

5.4 Limitations related to unequal gender distribution

One potential limitation in testing these goals is that there is a large gap between the number of older adult females (*N* = 18 (72%)) and older adult males (*N* = 7 males (28%)). First, this sub-section will review previous research that discusses the relationship between gender and spatial memory. Second, this section will discuss the how prior research on gender differences in spatial memory applies to the results of this study's recognition task. Third, this sub-section will address what prior research has found with regards to how gender relates to processing metric information and categorical information. This last point is particularly relevant for the SWM recall task and the LTM task used in the present study.

First of all, prior research has found mixed results about whether or not gender plays a role in location memory. Some prior research has not found a gender difference in working memory for location memory (e.g. Recker, Plumert, Hund, & Reimer, 2007; Honda & Nihei, 2009; Yamamoto & DeGirolamo, 2012; Crawford, Landy, & Salthouse, 2017). For example, Crawford, Landy, and Salthouse (2017) found that gender was not a significant contributor to individual differences in location working memory tasks involving one target or multiple targets. Additionally, they excluded gender from their analysis because it did not account for amount of variance in their models. Other researchers have found a gender difference between men and women. Lejbak, Crossley, and Vrbancic (2011) found that males were significantly better than females on a spatial 2-back task, which tests how well participants remembers a spatial location that they saw two places previously. Conversely, in Honda and Nihei (2009)'s study of younger adults, they found that women were significantly more accurate than men on a recognition task that entailed studying the locations of 27 objects and then being asked to differentiate between those objects that were in the same location and those that were in different locations. However, when the participants were re-tested after a week had passed, there was not a significant difference between males and females. Furthermore, Honda and Nihei (2009) did not find a difference between males and females on a recall version of the same task. The lack of a gender difference occurred both at the 3-minute mark and the one-week mark (Honda & Nihei, 2009).

Based on the mixed results the studies cited in this sub-section, it is difficult to determine how the results of the present study's working memory recognition task would be different if there was a more equal gender distribution within the older adult sample. However, having more older adult women than men may have influenced the lack of group*task complexity interaction in the SWM recognition task Both Honda and Nehei (2009)'s recognition task and the SWM recognition task from the present study tested a person's ability to detect whether or not an object's location was the same as a previously seen location. While the two tasks use different methods of assessing this ability and a different time frame between when the targets disappeared and the testing phase, it is plausible that both tasks involve some of the same cognitive processes. Although gender was controlled for in the analyses it is speculated that the current study's sample of older adults may have been more accurate on the SWM recognition task than a group of older adults with a more equal gender distribution. This speculation is based on Honda and Nehei (2009)'s finding that women were better than men on detecting a change in position. This potential effect may have caused the present study's results to differ from Nagel at al.'s finding that accuracy declined at a greater rate for older adults than younger adults as complexity increased. The best way to test this proposition would entail comparing the present study's SWM recognition task and Honda and Nehei (2009)'s recognition task and collect an equal number of males and females.

Another reason that the unequal gender distribution in the older adult group limits this study's ability to make generalizations is related to the SWM recall task. Holden, Duff-Canning, and Hampson (2015) found that when learning and recalling spatial locations, young adult women tend to use categorical information while young adult men tend to use metric information. The implication stemming from their results is that men and women encode location information in spatial recall tasks differently. This finding could impact the interpretability of the present study's findings for the SWM recall task and LTM task. However, the present study found that the older adults did not show any categorical bias on the SWM recall task when the target was close to the midline (20º) and were biased away from the midline and toward the categorical center when the target was further from the midline (40º). The biases in this study appear to be the opposite of what the literature on gender differences in spatial cognition would predict. However, the unequal gender distribution for older adults prevents comparing the performance of older adult males and females to see if the results replicated Holden, Duff-Canning, and Hampson (2015)'s finding. Additionally, for the LTM task, it was found that older adults were less accurate than younger adults. Given that the processing metric information is one sub-component of the LTM task, is difficult to determine whether the older adults' performance is attributed to age-related declines in long-term memory or related to males having more accurate performance on tasks that involve recalling metric information (e.g. Iachini, Sergi, Ruggiero, & Gnisci, 2005).

In conclusion, although gender was included in the analyses, the unequal gender distribution of the older adult group raises the issue of whether there was sufficient control for any potential effect of gender. As the cited research in this section demonstrates, the unequal gender distribution is a concern for each of the paradigms used in the present study. The researcher made every effort to collect an equal number of males and females, but there were more women than men in the older adult group. All analyses controlled for gender; however, given the difference in number of males and females, statistical controls may not have been enough. Future research should have a more equivalent gender distribution for both age groups and test to see if the present study's results are replicable.

5.5 Implications for dynamic field theory

Overall, DFT can be useful for modeling changes in cognition across the lifespan. An advantage of DFT is that it can be used as a post hoc model to explain how mental representations change with age, such as the very first set of simulations in this study that replicated the findings of Nagel et al. (2009). To review, these post hoc simulations replicated Nagel et al.'s behavioral results by showing how the mental representation of target locations declined as task complexity increased. These simulations also showed that mental representations for the target locations declined at a greater rate in the older adult model. DFT models can then be used to make a priori predictions of how mental representations change, such as the simulations in the present study that examined how the mental representation of locations changed when targets were paired close to each other and how distance from the midline influence the representation of a target's location. These a priori models were beneficial in providing a framework for most of the hypotheses that this thesis tested. A priori models were particularly helpful given that the study of geometric biases in spatial memories in late adulthood is a relatively new area with little research. The advantage of using DFT for developing a priori models is that it provides a framework to help guide novel research paradigms or extend paradigms in a new direction.

The drawback of using a these types of models is that they do not always match the behavioral data, which was the case with a number of simulations in the current study. When this circumstance arises, it raises three questions regarding validity of the model and/or the behavioral study. The first question is whether the model is an accurate depiction of how memory changes. The second question deals with whether the behavioral data is replicable or if there was something unique about the participants in the study. The third question is whether there is an issue with the experimental design, such as whether the paradigms measure the same phenomenon that the model is trying to capture. The two potential solutions for these issues are to either revise the model or collect more behavioral data to replicate the effects. With regards to the third issue, a few potential solutions would be to use structural equations modeling approach, such as principal components analysis, and to see if performance on that task correlates with other paradigms attempting to measure the same cognitive process. The remainder of this section will first summarize which DFT models were supported by the behavioral paradigms and which models were not supported. Then this section will discuss simulations for the SWM recognition task in detail. Specifically, this discussion will speculate why the model was not supported and how the model and task could be improved to any discrepancies between the two items. Afterwards, the section will discuss the same topics in relation to the SWM recall task. Finally, this section will discuss the ability of DFT to model cognitive changes in late adulthood.

Support for DFT was mixed, with several of the specific hypotheses predicted by DFT simulations not supported. Performance on the SWM recognition task supported the part of the models that predicted that performance would decline as task complexity increased. However, the models' prediction that the older adults' accuracy would decline at a greater rate than the younger adults' accuracy was not supported. There was little support for the DFT models of the SWM recall task. The models predicted that there would not be a significant difference between younger adults and older adults in the level of directional bias. However, the older adult participants had less bias than younger adults when the target appeared at 20º. While there was not a significant difference between older adults and younger adults when the target appeared at 40º, the DFT models had predicted that the target's location from the midline should not have a significant influence on the level of bias. Furthermore, the DFT model of the SWM recall task predicted that the older adults' performance would be more variable than the younger adults' performance. These simulations were not supported by the behavioral data.

The parameters for the DFT models were developed using the results of Nagel et al. (2009). These simulations established that DFT could model changes in cognition in late adulthood. These parameters were used to model other forms of spatial memory using DFT. The results for the SWM recognition task did not support the DFT models or the hypotheses related to these models. The accuracy of older adults did not decline at a more rapid rate than younger adults as the task complexity increased. In addition to not supporting the DFT model, these results did not support the findings of Nagel et al., on which the model and hypothesis were based. The difference in the results of the current study and Nagel et al. raises the question of whether the parameters in the DFT model are correct or if they need to be adjusted. One way to test the parameters would be to run follow-up studies for this study's paradigm and for Nagel et al.'s paradigm. These follow-up studies would see if the findings from each study would be replicated.

The DFT model also predicted that participants would be more likely to forget objects that were located close to each other. The behavioral results found the opposite effect. People were more accurate if the targets were paired together. The models proposed in this thesis assume that attention is equally distributed to all locations. However, attention may not have been equally distributed between locations. This result suggests that a modification of DFT is needed to capture memory for multiple targets. To account for attention in DFT, it is possible to change the level of excitation that each stimulus introduces into the perceptual field. This approach would increase the excitatory connections of the stimuli clustered together and lower the strength of excitation for those stimuli that are further away from the other stimuli. Another possible option is to introduce the targets into the model using a serial manner instead of simultaneously presenting them. This method would allow the model to better capture shifts in attention.

A final issue to consider for the DFT models of the SWM recognition task is the structure and formulas that were used for this model. The initial structure and formulas underlying the model were derived from Schutte and Spencer (2009). However, they were modeling a spatial working memory recall task, which raises the issue of whether a model of location memory on a recall task can accurately be generalized to location memory for a recognition task. In future studies, it would be more beneficial to run a second model using formulas similar to those found in Simmering and Perone (2017). Their model of working memory recognition had the same three layers that the current study used: perceptual field, inhibitory layer, and working memory layer. However, their connections between their three layers were different than those used in the present study. Simmering and Peron (2017) discuss how the recognition model sends activation from the working memory layer, to the inhibitory layer and the inhibitory layer sends inhibition to the perceptual field, which prevents encoding of non-target locations. Conversely, the model from the present study focused on maintenance of location memory in the working memory layer and did not examine the inhibition of non-targets. This approach was used for both the model of the recognition task and the model of the recall task.

The third hypothesis was based on DFT models of spatial working memory recall. This model predicted that older adults and younger adults would have a similar level of bias on the SWM recall task, but older adults would have more variability in their responses than younger adults. There was mixed support for the model. The model was supported by the behavioral data when the target appeared at 40º: there as not a significant difference in bias between the two groups. However, the models were not upheld by the behavioral data when the target appeared at 20°. Behaviorally, younger adults were biased more than older adults at the 20° target. Furthermore, there was not a significant difference in variability between younger and older adults in the behavioral data. The behavioral findings that this model accurately predicted were that older adults and younger adults would have similar distance error and that both age groups would have similar levels of directional bias when the target appeared at 40º. Because this study is one of the first attempts to extend DFT to model changes in cognition in late adulthood, one potential explanation is that parameters in the model need to be adjusted. The current models used the same parameters for the models of SWM recognition and SWM recall. Prior research has found that older adults tend to do better on memory tasks that test recognition abilities and familiarity abilities than recall abilities (e.g. Permlmutter, 1979; Craik & McDowd, 1987; Craik, 1994; Daselaar et al., 2006). Therefore, future studies should consider adjusting the parameters based on whether the model is for a recognition task or a recall task. One change to the older adult model's parameters would be using lower parameters on recall tasks than recognition tasks given the weaker performance on recall tasks compared to recognition tasks (e.g. Permlmutter, 1979; Craik & McDowd, 1987). A way to double check our adjusted models would be to run a second batch of participants in order to ensure the behavioral findings can be replicated.

It is hard to say why the older adults were less biased at the 20° target than the 40° target. This finding is not what the DFT models predicted, which was that there would be an equal magnitude of bias when the target appeared near the midline or further away from the midline. One potential explanation is the previously described spatial precision hypothesis, which describes how location memory becomes more precise over the course of childhood until young adulthood (Schutte & Spencer, 2009, Schutte &

Spencer, 2002, Schutte, Spencer, & Schöner, 2003). DFT can capture the decrease in spatial bias by strengthening the excitatory and inhibitory connections in the models (Schutte, Spencer, & Schöner, 2003; Schutte & Spencer 2009). Schutte, Spencer, and Schöner discuss how the peak of activation for the location memory of younger children tends to have a lower amplitude and wider peak of activation (suggesting less precision in the model). They state that for older children, the increase in the strength of excitatory and inhibitory connections leads to the peak of activation in working memory to be stronger and narrower. The narrower peak of activation means that there is less bias in the model.

Both the target and midline create excitatory peaks of activation in the perceptual field and SWM field (Schutte & Spencer, 2009). For the model of young adults and older children, the inhibitory connections are strong enough that the inhibition from the midline input “pushes” the target’s peak of activation away from midline in the SWM layer. This represents a response that is biased away from midline. Because the young child model has weaker inhibitory connections, the target’s peak of activation in the SWM layer is biased toward the peak of activation from midline. Behaviorally, this means that the response would be biased toward midline. The inhibitory connections in the older adults’ model are weaker than young adults’ model (to account for neuronal atrophy), but greater than the parameters used for young children. This change in the inhibitory parameters could mean that the peak of activation for older adults is not as strongly influenced by midline. This explanation accounts for why older adults are less biased away from the midline than younger adults at the 20° location. From a DFT perspective, one potential reason the older adults show a bias at the 40°, but 20° location, is that perhaps the older adults in the sample divided the screen into fewer spatial categories than the younger adults and more spatial categories than children or older adults that are significantly older than those in this study's sample. However, the DFT model was not able to capture this effect. A possible reason the model was not able to capture the transition to fewer spatial categories could be related to the neural interaction kernel that stems from the excitatory and inhibitory parameters for the older adult group.

Furthermore, it is interesting that the older adults did not have more variability in their performance than younger adults. The reason this mismatch between the model and behavioral task is child model also used weaker parameters than the young adult model, but does not have this mismatch between the behavioral results and the model. Both the children's' DFT model and behavioral data have more variability than the younger adult model and behavior (Schutte & Spencer, 2009, Schutte & Spencer, 2002, Schutte, Spencer, & Schȍner, 2003). This suggests that the age-related change in the DFT models is different than the behavior-related changes associated with age

Based on this explanation, it may be necessary to use a different neural interaction for the SWM recall than for SWM recognition in older adult model. This change in the neural interaction can be accomplished by using different input parameters for modeling SWM recall. As discussed earlier, this change is based on the prior research has found that relative to younger adults', older adults' performance declines on certain recall tasks, but not on recognition tasks (e.g. Permlmutter, 1979; Craik & McDowd, 1987; Craik, 1994; Daselaar et al., 2006). Given that the older adult model has stronger inhibition than the young child model, the peak of activation for the target location is not attracted toward the excitatory input from the midline. This weakening of the model's inhibition helps to capture the older adults' performance on the behavioral task.

Overall, DFT has some imperfections with regards to taking an interdisciplinary approach to cognitive aging. However, it is better suited to encompass different types of neurocognitive change than many of the theories described by Schroots (1996) and summarized above in Table 3. The most similar theory from Schroots (1996)'s review is gerodynamics. While there is overlap between these two theories, DFT is more applied than gerodynamics and has the framework to model changes in cognition while Gerodynamics is does not have a framework to mode changes in representation. DFT is more applied in that it uses simulated neurons to generate a priori and post hoc models of specific changes in cognition over time. While Gerodynamics can describe how multiple factors influence cognitive changes over time, it is unable to generate models to predict how cognition changes.

A limitation of DFT models is that while it combines cognitive and developmental theories with neuroscientific principles, the neurons in the model are simulated instead of being based on actual neurons in the brain (though see Bastian, Riehle, Erlhagen, & Schὂner (1998) for an exception). However, some researchers are starting to work on overcoming this limitation. For example, Wijeakumar, Ambrose, Spencer, and Curtu (2017) used DFT to develop a using dynamic neural field model to simulate fMRI recordings of partcipants who completed a Go-No Go Task. It is important to develop a modeling system similar to DFT that could model mental representation while more accurately accounting for neurological changes in specific parts of the brain (e.g. PFC and hippocampus). This new modeling system would hopefully lead to more accurate models that are based on specific findings from the neuroscience literature to make predictions about cognitive development.

5.6 Conclusion

The SWM recognition task was an example of how some spatial working memory abilities do not decline with age, although this finding is at odds with the similar paradigm that Nagel et al. (2009) used. There are several ways that future studies could examine this difference. One future study could examine the strategies that younger adults and older adults used to study the layouts. Anecdotally, some participants reported trying to focus on clusters while ignoring targets that appeared further away. Other participants reported trying to find a pattern in the layout of the targets. For example, one participant commented that the layouts looked like constellations. One possible explanation for why the present study did not find an interaction between age and task complexity could be difference between groups. The older adults in the present study may have more experience learning spatial layouts, and, therefore, are better than younger adults are at discerning what spatial strategies work best for them. This future study should also examine whether participants changed strategies from one level of complexity of the task to the next level of complexity. Furthermore, it would also be beneficial to use eye-tracking to see if there are differences in how participants scan the layouts.

Finally, results from the test phase of the LTM recall task supported the claim that some spatial memory abilities decline with advanced age. The lack of difference in performance between the two age groups on the study phase demonstrated that the ability to learn spatial layouts, at least in this task, did not decline with age and that the difference in performance on the test phase was either due to older adults struggling to retrieve the memories or the older adults' memories decaying more than younger adults' memories. Researchers can improve this paradigm for future studies in a few ways. While the current study minimizes error in each layout presentation, there is not a method for knowing with absolute certainty which target each response was intended for. One change is that participants would make their responses in the same order each time, such as instructing them to always respond left-to-right (respond to the left-most location, then the target that appeared in a location between the other two targets), and then to the target that is the furthest on the right). Another way the researchers could get the participants to respond to the three locations in the same order as other participants would be to have the three targets appear, one at a time (and the first target would remain visible as the others appeared), and have participants respond in the order in which the targets appeared. Ideally, this approach would allow the researchers to be more certain which target each response was intended for. The current study did not take this approach in order to allow the participants to choose a response strategy that they thought would increase the odds of making a correct response.

This research is important for several reasons. This study contributes towards is the understanding of healthy cognitive aging and how spatial working memory and long-term spatial memory change from young adulthood to late adulthood. This area of research has implications for clinical research, such as how to prevent dementia, how memory changes when a person develops this disease, and how to treat the cognitive-related changes associated with disease. Conducting research with healthy older adults is a beneficial for more effectively conducting research with older adults who are a part of a clinical population. In order to understand what clinical aging looks like and what factors contribute to clinical neurocognitive decline, it is important to first understand what contributes to healthy neurocognitive aging and what factors can describe healthy cognitive aging. Finally, this thesis extends the applicability of DFT to model cognitive development in late adulthood. While the a priori models did not accurately predict all of the behavioral results, post hoc models can be developed to better capture the behavioral results, and future behavioral studies can help fine-tune the parameters that are entered into the post hoc DFT models. In summary, this study found that older adults either showed the same about of midline bias or were less biased than younger adults. Older adults also had similar overall accuracy as younger adults on the SWM recognition task. Finally, older adults performed worse on the LTM task than younger adults. Overall, this study demonstrates that there is a noticeable difference between younger adults on older adults on some spatial tasks and a lack of a difference in performance on other spatial tasks.

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