THE IMPACT OF SPATIAL BOUNDARIES ON WAYFINDING AND LANDMARK MEMORY: A DEVELOPMENTAL PERSPECTIVE

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ABSTRACT

Spatial boundaries are common structures but their effects on wayfinding and other spatial behaviors have largely been ignored. The "location-updating" effect describes a phenomenon where memory for objects is often worse after a spatial shift, such as moving through a spatial boundary, such as a doorway into another room (Radvansky & Copeland, 2006). Young children are typically worse at wayfinding compared to older children and adults and, consequently, may be more susceptible to effects associated with spatial boundaries. Across two experiments, I assessed the impacts of spatial boundaries on wayfinding and landmark memory in younger children, older children and adults. In the learning phase of Experiment 1, adults completed a wayfinding task where they followed arrows along a route through a virtual environment. In a later test phase, participants navigated the same route without assistance from arrows. To assess the impact of spatial boundaries, the wayfinding task either contained or did not contain doorways. Total wrong turns and landmarks recalled for the testing phase were recorded. In Experiment 2, younger and older children completed a similar, but shorter, wayfinding task.

I hypothesized that: i) wayfinding and landmark memory would be significantly worse when spatial boundaries are present, compared to absent and ii) this effect would be exaggerated in younger children, compared to older children and adults. Results showed that adult wayfinding and landmark recall was not impacted by the presence of spatial boundaries. However, children in Experiment 2 exhibited a spatial boundary effect where more errors were committed and fewer landmarks were recalled when spatial boundaries were present compared to
absent. Verbal memory and visuo-spatial working memory were related to wayfinding and landmark recall performance. Greater verbal memory was found to be predictive of fewer wayfinding errors in the Boundary condition. This research suggests that spatial boundaries may introduce a form of interference during environmental learning that varies with increasing age. Additionally, spatial boundaries may be one feature that aids in a regionalization process that organizes units in a cognitive map.
LIST OF ABBREVIATIONS AND SYMBOLS

$df$  Degrees of freedom: number of values free to vary after certain restrictions have been placed on the data

$F$  Fisher’s $F$ ratio: A ration of two variances

$M$  Mean: the sum of a set of measurements divided by the number of measurements in the set

$p$  Probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value

$r$  Pearson product-moment correlation

$t$  Computed value of $t$ test

$=$  Equal to

$n$  Sample size for group

$SD$  Standard deviation

ANOVA  Analysis of variance
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INTRODUCTION

The location updating effect describes a cognitive phenomenon where memory for objects is often worse after a spatial shift, such as moving through a doorway into another room (Radvansky & Copeland, 2006). The modern environment is filled with complex manmade objects and structures that result in numerous spatial boundaries. Consequently, spatial shifts are very common events during daily activities that involve any kind of movement. Surprisingly, investigations of potential memory disruptions associated with spatial boundaries during common spatial activities are scarce. One activity that likely increases the probability of experiencing a spatial boundary is wayfinding. This particular spatial activity incorporates several sub-processes that utilize multiple properties of an environment. Some of these properties, such as landmarks, have been shown to be critical for learning ones way around. It seems reasonable to consider that wayfinding in an environment containing multiple spatial boundaries may disrupt memory for objects within that environment, and as a consequence, disrupt wayfinding. This would be especially true if landmark memory was affected. It has also been found that children typically perform more poorly at wayfinding, compared to adults. In the current studies, I examine whether some portion of developmental differences in wayfinding can be attributed to developmental differences in location updating. More specifically, this dissertation investigates developmental differences in the influence of spatial boundaries encountered while learning an environment on wayfinding accuracy and landmark memory.
Wayfinding

Wayfinding involves a number of cognitive processes that integrate various sources of information. The culmination of these complex mental processes allows for sophisticated navigation. One factor that may contribute to successful wayfinding is strategy use. There are two main types of strategies typically adopted for wayfinding purposes, each utilizing different aspects of an environment. Route strategies refer to processes of associating landmarks or objects with a turn or direction (Munzer, Zimmer, & Baus, 2012). These strategies involve adopting an egocentric frame of reference and is used to learn basic direction from one location to another. Persons who use these strategies tend to rely on landmarks in the immediate visual field. Additionally, associations between objects (i.e. landmarks) and directional information are encoded in a sequential manner. For example, if one were traveling to the grocery store, they may know they need to turn left out of their neighborhood, right at the stop sign, and then a right at the gas station.

Survey strategies represent another common approach used during wayfinding. Those who employ these survey strategies adopt an allocentric frame of reference that allows for a broad, integrated understanding of the surrounding environment. Hence, persons who use survey strategies acquire configural knowledge and can identify their location in relation to other objects in their environment. This type of strategy is typically considered to be more sophisticated than a route strategy. For example, those employing a survey strategy can typically plan and travel a previously unexplored path better than those using route based strategies (Rizzardo et al., 2013). Also, individuals who use survey strategies during navigation typically exhibit better performance in wayfinding than those who use route strategies (Hund & Mirarik, 2006).

Research has indicated that strategy use may follow a developmental trend. Typically, younger
persons rely on route strategies (Bullens et al., 2010). A study conducted by Lawton and Kallai, (2002) found that more early childhood wayfinding experience is related to higher preference of survey strategies and negatively related to route strategy preference. Interestingly, age was positively associated with survey strategy preference. Indicating that as age increases, the reliance on survey knowledge increases. At an early age, it may be there is a stronger dependence on landmark based navigational practices. Other research has shown that older adults use a mixture of route and survey strategies (Rogers, Sindone, & Moffat, 2012).

Wayfinding involves the use of several cognitive processes and abilities. For example, Visuo-spatial working memory (VSWM) may be a subsystem commonly engaged in wayfinding activities (Hund, 2016). For example, Nori et al. (2009) found that participants who scored high on measures of VSWM showed superior performance on a wayfinding task. Numerous studies have shown that mental rotation tasks, in which participant’s judge how an object would look if rotated in two or three dimensional space, is correlated with wayfinding performance (Lawton, 2010; Malinowski, 2001). Other Studies have provided some evidence that perspective taking may also be related to navigational activities (Kozhevnikov et al., 2006). Perspective taking reflects the ability to mentally adopt another viewpoint (Kessler & Thompson, 2010).

Wayfinding has also been associated with functions of the medial temporal lobe. More specifically, the hippocampal region seems to be particularly important. Ledoux et al. (2014) had participants with and without schizophrenia complete a wayfinding task while being scanned with a Magnetic Resonance Imaging machine. Schizophrenia is associated with impaired hippocampal function. Accordingly, persons without schizophrenia demonstrated superior wayfinding performance compared to those with schizophrenia. Hartley et al. (2003) found that engaging in a wayfinding and route learning task activated multiple regions of the hippocampus.
In addition, older adults are worse at wayfinding compared to younger individuals (Malley, Innes, & Weiner, 2018; Lee & Kline, 2011), and that older adults may show an absence of hippocampal activity when performing a navigational task (Moffat et al., 2006)

Wayfinding can be assessed through a variety of methods. A large amount of research examining wayfinding in adults uses variations of a route learning task. This procedure typically involves participants being exposed to a path through a virtual environment and later being tested on their ability to recall and retrace the previously learned route (Yang et al., 2018; Slone et al., 2015). Other methods involve participants navigating a path through a virtual environment after learning the layout from a map (Sharma et al., 2017). Research on wayfinding in real environments follows similar designs. For example, Farrell et al. (2003) had participants learn the location of objects in a real environment and subsequently tested their ability to locate them. Further, Wallet et al. (2011), had participants learn about a route in a model virtual environment and later tested their ability to recall the route in a real environment. As in studies involving virtual environments, wrong turns are counted as errors and generally used to assess wayfinding performance.

In summary, wayfinding reflects a behavior that makes use of several complex cognitive processes. The hippocampus, as well as the prefrontal cortex, are particularly important for successful wayfinding. Researchers have introduced several methodologies for studying wayfinding. The results of these investigations have revealed several factors that may impact an individual’s ability to successfully navigate their environment. However, the role of spatial boundaries in wayfinding has yet to be explored.

**Landmarks and Route Learning**
Landmarks play an important role in describing, understanding and reasoning about an environment. Presson and Montello, (1988) describe landmarks as any object within an environment that is easily recognizable. The authors also suggest that identifying an object as a landmark also implies the object is used as a reference point within its environment. Hence, landmarks have a functional role within their context. Most environments typically frequented throughout the day contain multiple landmarks. However, the process of selecting landmarks can be rather complex. Research has attempted to isolate the specific aspects of objects that contribute to their identification as landmarks. For example, visibility, frequency among multiple contexts, and relation to decision points have been considered important factors influencing landmark selection (Caduff & Timpf, 2008).

One critical element in determining what objects may be used as landmarks is object saliency. This is typically attributed to inherent features of the objects themselves (i.e. the size of a building or its unique architecture) (Borji, Sihite, & Itti, 2013). Most current definitions consider multiple sources interacting to produce salience. For example, Caduff and Timpf (2008), suggest that relations among cognitive, perceptual, and contextual factors influence the saliency of landmarks. Cognitive salience refers to the degree of cognitive processing that may be involved in selecting landmarks; Individuals need to learn, understand, and reason about objects and their spatial relations within a scene. More importantly, recognition and personal relevance of an object to a navigator may impact its use as a reference point and the allocation of attention in a top down manner (Caduff & Timpf, 2008). Individual differences in these cognitive functions may influence the assessment of object saliency and consequently, their use as landmarks. In order to be perceptually salient, objects must contrast with their environment (i.e. color, spatial relations to other objects). Caduff and Timpf (2008) suggest that perceptual
salience is driven by bottom up allocation of attention to areas visible from the point of view of the navigator. Contextual salience involves aspects of the task at hand, as well as the mode by which the task is completed. For instance, navigating would most likely lead individuals to identify landmarks and select particular paths on the basis of their relevance for completing the navigational goal. Additionally, walking would allow for more processing to occur compared to driving or riding a bike where attention would need to be focused to more immediate contextual details. Caduff and Timpf (2008) suggest it is the combination of these factors that determine the saliency of objects, which in turn increases their probability for use as landmarks.

Saliency has a well-documented impact on memory and attention (Pooresmaeili, Bach, & Dolan, 2014; Santangelo & Macaluso, 2013; Parkhurst, Law, & Niebur, 2002). For example, Fine and Minnery (2009) had participant’s complete an object-location memory task. Specifically, three to five target locations on a map were to be learned and recalled after a brief delay. The researchers found that target salience was associated with better performance on the memory task and this relationship increased with task difficulty. Hence, salience influences the ability to recall target locations and may be used to prioritize information when cognitive resources are taxed (Fine & Minnery, 2009).

There has been a considerable amount of research demonstrating the benefit of landmarks to route learning and wayfinding (Walkowiak, Foulsham, & Eardley, 2015). Ruddle et al. (2011) conducted a study to investigate the influence of global and local landmarks on participant’s ability to learn a route. Specifically, global landmarks (also referred to as distal landmarks) are those that provide orientation information and are visible from most locations within an environment. On the other hand, local landmarks (also referred to as proximal landmarks) provide immediate positional, as well as orientation information and aid in learning specific
paths (Ruddle et al., 2011; Hurlebaus et al., 2008). Adult participants were first guided through a route in a virtual environment. Immediately after, they were tasked with navigating the environment on their own. Routes contained either local, global, both, or no landmarks. Results showed that participants in the local landmarks condition made significantly fewer wrong turns compared to all other groups. Hence, using proximal landmarks to learn a route may improve performance beyond that of distal landmarks.

Landmarks provide different types of information that can be used to navigate to a goal destination. For example, landmarks can serve as beacons or associative cues. In the former case, participants simply travel to a visible landmark located in the direction of a goal destination. In the latter, landmarks are associated with a specific action, such as turning left or right (Waller & Lippa, 2007). Waller and Lippa (2007) examined how people utilize landmarks in a route learning task. Adult participants were randomly assigned to either a beacon, no landmark, or associative landmark group. Subsequently, they were asked to navigate an environment consisting of a series of 20 rooms. Upon entering each room, two doors were located on the opposing wall, one to travel left and one to travel right. A landmark was located in between the two doors (associated condition), or adjacent to each door (beacon condition). Importantly, only the correct doorway opened to the next room. Overall, the study showed that the presence of landmarks improved route learning; participants choose the correct door more often when landmarks were present. Further, landmarks used as beacons compared to associative cues were more effective for route learning. It may be that using landmarks as beacons requires less effortful and explicit processing. Interestingly, these results were found even when participants were instructed to learn the correct sequence of turns.
Overall, landmarks provide contextual information that is important for understanding the details of one’s environment. Thus, the presence of landmarks is necessary for successful wayfinding. Navigation and its associated procedures (i.e. landmark selection) incorporate several cognitive functions. Research has demonstrated that adults possess a strong and sophisticated capacity to navigate their environment.

**Wayfinding and Children**

Research conducted by Lingwood et al. (2018) assessed wayfinding performance in a sample of younger and older children, as well as adults. These researchers were interested in whether participants could learn a route with 12 decision points after only one exposure. Children and adults were guided along a single path in a virtual environment once. Later, their ability to retrace the same path was tested. Specifically, participants had to retrace the path for two consecutive attempts. Wrong turns were counted as errors and used as an index of wayfinding performance. Findings showed that some participants from all age groups were able to retrace the route after a single attempt. Exactly 30% of the younger children were able to retrace the route after a single attempt, compared to 50% of the older children, and 75% of the adults.

Jansen-Osmann (2007) had younger (7-8 years) and older children (11-12 years), as well as adults complete a wayfinding task. Specifically, these researchers were interested in the effects environmental regularities and symmetry may have on wayfinding performance and the acquisition of spatial knowledge. Participants were allowed to freely explore a virtual environment for three minutes. In a later phase, participants were instructed to navigate to a particular location within the environment. Wayfinding performance was assessed by recording the number of turns taken and the distance traveled from starting point to destination. Results
showed that only younger children were influenced by the structure of the environment; younger children made significantly more wrong turns in irregular environments containing beveled routes and an asymmetrical configuration. When wayfinding in regular environments, young children performed similar to that of older adults. However, these results may have occurred because the route contained only two turns.

Jansen-Osmann, (2006) had younger and older children, as well as adults complete a wayfinding task. In their task, participants learned a route to a destination in a virtual environment with or without landmarks. Participants navigated to a goal destination until they could do so without error on two consecutive trials (learning criterion). Compared to older children and adults, younger children showed significantly worse wayfinding performance. More specifically, younger children required significantly more trials to reach the learning criterion compared to older children and adults. Findings from this study also showed participants navigating a route without landmarks needed significantly more trials to reach criterion. Thus, landmarks improved wayfinding performance for children as well as adults.

**Landmarks, Wayfinding, and Development**

There have been several studies that show landmarks increase the wayfinding success of children. For example, Lingwood et al. (2015) had six, eight, and ten year olds complete a route learning task in a virtual environment with six choice points. First, participants were shown the correct path through the virtual environment. Participants were either shown a route with or without landmarks. Immediately following, participants navigated the route until no wrong turns were made on two consecutive trials. The total number of trials to reach criterion and wrong turns were recorded. Overall, the results showed that when landmarks were not present, six year olds required more trials to reach criterion and made significantly more wrong turns compared to
other age groups. It is important to note that the majority of children in this condition were not able to reach criterion. A similar pattern was found when landmarks were present; six year olds took more trials to reach criterion and made more wrong turns. It appears that children have more difficulty navigating when landmarks are not present. When landmarks are present, children are usually better at navigating. Even when they are present, however, six year old children still show a relative weakness compared to older children.

There are several reasons younger children typically perform worse on a route learning task. For example, the cognitive abilities necessary for landmark and route learning may not be sufficiently matured (Lingwood et al., 2018). Purser et al. (2012) conducted a study to examine how executive control and short term memory may relate to children’s route learning ability. Children (5 -11 years) first completed a battery of cognitive tasks. The measures of short term memory included a digit span, corsi span, and pattern span task, in addition to measures of executive control (Go/No Go task). Procedures assessing verbal and visuospatial long term memory were also administered. Participants completed a route learning task as well. In which, children were first shown the correct path through a virtual environment. The virtual environment included six junctions and thirty two landmarks. Immediately after, participants were tasked with navigating the route on their own. Total trials to navigate the route error free and errors made across trials were recorded. Results showed significant associations among measures of verbal (digit span) and visuospatial short term memory (corsi, pattern memory) and route learning. Further, the relationship between the short term memory tasks and route errors was mediated by performance on the Go/No Go task. This study also showed that route learning improved with age and this pattern was complemented by an identical finding for executive control. Thus, route learning involves multiple processes associated with frontal lobe
functioning. Importantly, route learning increases with the development of these cognitive resources. Other research has reported similar findings. For example, Fenner et al. (2000) found that children (5-6 years) who performed better on tasks measuring visuospatial ability made fewer errors when learning a new environment compared to individuals with lower visuospatial ability. The frontal lobe is one of the last portions of the brain to fully develop. Consequently, the immaturity of brain regions necessary for sophisticated wayfinding may be a contributing factor to children’s worse performance.

Attention may be another factor related to areas of the frontal lobe that limits children’s wayfinding ability. Cornell et al. (1989) noted that younger children (6 years) benefited only from local versus distal landmarks in a route learning task. Importantly, children who were instructed to pay attention to local landmarks made more correct choices at decision points and had an associated increase in correct travel. However, younger children were found to be more likely to report using less reliable landmarks. Another example comes from Heth et al. (1997). These researchers guided participants along a route while pointing out specific landmarks at intersections. Prior to participants making a return trip on the same route, some of these landmarks were rotated. Upon arriving at intersections with altered landmarks, younger children (8 years) were more likely than older children (12 years) to report they had traveled off the original route. Additionally, older children reported using more stable and distant landmarks than younger children.

It seems that younger children may be less likely to identify and attend to appropriate landmarks along a path. It could also be that children, compared to adults, may select different objects as landmarks (Allen et al., 1979). This may be an additional factor that explains young children’s poorer route learning. Given that older, compared to younger children, reported using
more stable and distal landmarks, it could be the case that younger children do not adopt the same strategies for learning routes and landmarks.

Evidence also suggests that the relative position of a landmark to a turn or junction may impact its likelihood of being encoded. Jansen-Osmann (2002) conducted a study examining the influence of landmarks and landmark placement on route learning. Adult participants were tasked with navigating a route in a virtual environment with or without landmarks. Each route consisted of six main corridors and two secondary corridors. There were 18 objects in the landmark condition. Participants traversed the route until they were able to do so without making a wrong turn on two consecutive trials. Upon completion of the navigation task, participants in the landmark condition were tasked with recalling the locations of landmarks. Total number of trials to reach criterion, as well as wrong turns and landmark recall were recorded for each participant. The results showed that more trials were required to reach criterion when there were no landmarks present. Thus, the presence of landmarks again significantly improved route learning. Interestingly, landmarks located adjacent to correct turns were better recalled compared to landmarks with no directional relevance or adjacent to wrong turns.

Findings from Jansen-Osmann (2002) parallel other investigations of landmark memory in a route learning task. For example, Cohen and Schuepfer (1980) found that participants were better able to recall objects located near a correct turn after learning a route in a virtual environment (See also Jansen-Osmann & Wiedenbauer, 2004). Additional results from Cohen and Schuepfer (1980) indicate that sixth graders recalled more landmarks at choice points compared to second graders, while college students were able to recall the most landmarks. Davis et al. (2014) had children with Down Syndrome (DS), intellectual disability (ID), and typically developing (TD) children (5 years) complete a route learning task. Specifically,
participants learned a path in a virtual environment containing eight choice points and 16 landmarks. The total number of trials to navigate the route without error, along with total errors and landmarks recalled were recorded. Results showed TD and ID participants required fewer trials to reach criterion and committed less errors than DS participants. In addition, results from the landmark recall task indicated that landmarks located near choice points were recalled more often.

Overall, research has established that landmark memory facilitates route learning. However, a commonality among previous research is the use of routes that may not capture the complexities one may experience in their environment. Accordingly, it is reasonable to suspect that landmark learning may be different in environments with more complicated structures. For example, some elements of indoor environments, such as doorways, separate a route into multiple portions. Currently, it is not known how landmark memory may be impacted by these additional configurations.

**Gender and Wayfinding**

There is a well-documented performance difference between genders in spatial ability. These can emerge for small scale spatial abilities (i.e. mental rotation), as well as large scale tasks such as wayfinding (Linn & Peterson, 1985). Moffat et al. (1998), had males and females complete a route learning task on a computer and measured wayfinding error and time. Males were found to navigate faster and with fewer wayfinding errors. Munion et al. (2019) found that male and female behavior during a wayfinding task influences wayfinding performance. After completing a large scale navigation task, males made fewer pauses, changed direction less, and made fewer returns to previous locations. This was predictive of male’s superior performance over females.
One of the primary explanations for gender differences in wayfinding suggests that males and females tend to rely on different strategies to complete a navigational tasks. Lawton and Kallai (2002) found that males favored using a global orienting strategy, while females reported a preference for strategies focusing on route information. Indeed, males perform better on measures of survey learning compared to females (Castelli et al., 2008). Interestingly, some researchers have noted gender differences in brain activation during a navigation task (Gron et al., 2000).

Previous investigations have also provided evidence that gender differences emerge early in development. Merrill et al. (2016) conducted a study to investigate differences in route learning among children (6-12 years). In their task, participants completed a route containing 8 choice points and several measures of verbal memory and spatial ability. Performance on the route learning task showed that boys were better at navigating compared to females. Interestingly, spatial abilities seemed to be related to route learning for male children, while both verbal memory and spatial abilities were important for female performance. Other work indicates there may be differences in strategy preference among genders in childhood. Male children seem to rely more on spatial processing: spatial perception has been found to relate to boys wayfinding performance and males typically make fewer wayfinding errors (Choi & Silverman, 2003; Gibbs & Wilson, 1998). Females typically remember more landmarks than males and employ verbal strategies (Choi & Silverman, 2003; Gibbs & Wilson, 1998; Schmitz, 1997). Overall, sex differences have been found during early childhood, in addition to evidence for differing strategy preference.

Memory and Spatial Boundaries
Shifts in spatial context seem to influence the ability to remember objects in the environment. Typically, the effects of a shift in spatial context on memory performance have been examined using text comprehension paradigms. For example, participants read brief narratives where an object is either associated (a main character putting on a sweater) or dissociated (taking off a sweater) with a person. The main character would then move to a new location. Results show memory deficits for spatially dissociated objects. This effect in text comprehension is explained using the situation updating model where a disruption in cognitive processing occurs as individual’s process and encode new information presented with each situation. (Radvansky et al., 2003; Glenberg, Meyer, & Lindem, 1987).

Findings from text comprehension studies have been replicated using paradigms involving virtual space. For example, Radvansky and Copeland (2006), conducted a series of experiments designed to assess whether a spatial shift causes processing disruptions. In the first experiment, participants navigated through a sequence of rooms in a virtual environment where they picked up and set down objects on a table before progressing to the next room. At designated points along the route, a memory probe for objects the person was currently carrying or recently set down was presented. Memory was more accurate for associated objects (object currently being carried) after a spatial shift than for dissociated objects. In a second experiment they examined whether the spatial shift or object being associated/dissociated was responsible for differences in memory performance. Participants navigated through a series of large and small rooms. Two tables were located within large rooms and participants were to pick up objects and carry them to another table within the same room or another room. Memory probes were presented at the halfway point between two tables within rooms and upon entering a new room. Results demonstrated the same dissociated/associated effect as in Experiment 1.
Importantly, there was also an effect of spatial shift; memory for objects was more available when probed within a room versus moving through a doorway to another room (a spatial shift).

Results from these experiments may suggest that a change in location can signal the onset of a new event. Event segmentation plays an important role in the location updating effect in which memory for objects within the same location are better than for objects carried to another location (in this case another room). According to Radvansky and Zacks (2017), one event is created for objects experienced in the same room, whereas two events are created for objects carried from room to room; one for each room. Hence, when probed for object memory, poorer performance is observed for objects carried across, rather than within, rooms. This effect is attributed to interference from competition between the two event models; the same object is associated with two locations, causing interference upon retrieval.

Pettijohn and Radvansky (2016) explored how various environmental conditions influence the location updating effect. For example, in one experiment participants navigated through a virtual environment containing 47 small and large rooms, where the latter were three times the size of the former. Large rooms contained two tables whereas small rooms contained one table. The task was to pick up objects located on one table and continue to the next table that was either located in the same room (within room condition) or next room (across room condition). Memory probes for objects (deciding whether or not they were currently carrying the object) were presented midway through large rooms and upon entering a new room. The large difference in room size was created to assess if participants would divide the rooms into smaller sub regions with an increase in spatial distance traveled within rooms. Hence, one would expect to find a location updating effect within rooms. Results showed that increasing the size and the perceptual distance of a room did not produce a meaningful change in memory performance.
In subsequent investigations, Pettijohn and Radvansky (2016), decreased the perceptual differences between rooms. In one experiment they used clear instead of opaque walls and adjusted the rooms so that they would be similar in size. A location updating effect was still observed following these manipulations. In another experiment, the wall textures across rooms was held constant, while varying the walls within rooms. This allowed for the same perceptual experience across rooms and a different experience within rooms. The results indicated that a contextual shift of wall texture within a room did not result in a location updating effect. These studies indicate the structure of the environment (i.e. doorways) may have a specific effect on memory; moving from room to room signals a contextual shift and onset of a new event. Interestingly, this effect does not occur with a simple change in wall color.

To examine whether existing findings could be explained by factors other than a spatial shift, Pettijohn and Radvansky (2016) evaluated the influence of time as it relates to location updating. Participants navigated through a series of 55 rooms of two sizes; small and large, with the larger twice the size of the smaller. A single table was located in small rooms and two tables were located in the larger rooms. By structuring the rooms in this way, the distance between tables within the large rooms (no shift condition) was identical to the distance between tables of two different rooms (shift condition). Thus, the time it took to reach each table in both conditions was equal. Participants were tasked to pick up an object from a table and then move to the next table by traveling across a room, or walking through a doorway. Upon arriving at a table, participants placed the object currently being carried and picked up another. Memory for objects participants were currently carrying or had just placed was probed upon entering a new room or halfway across large rooms. Results showed worse memory for objects in the shift condition. Thus, these findings remain robust while experimentally controlling for time.
Consequently, it is reasonable to suggest that previous findings are not due to differences in retention interval in shift and no shift conditions.

**Spatial Boundaries in Real Environments**

The location updating effect has also been demonstrated in a real environment. Radvansky et al. (2011) conducted three experiments comparing the influence direct experience with an environment may have on the location updating effect. To reduce immersion and sense of presence within their environment, participants in Experiment 1 walked through a virtual environment displayed on a small monitor (compared to a larger/normal monitor). Objects were placed on two tables within 55 rooms and participants were to walk from room to room picking up objects and placing them on the next consecutive table. Thus, participants would pick up and place objects on tables within, as well as across rooms. At various points participants were probed for objects they were currently carrying or had just set down. Results showed worse memory for objects after entering a new room. In the second experiment, participants competed a similar task in a real environment. This environment consisted of three large rooms, thus three spatial shifts were experienced. Again, there were two tables located within each room. Participants walked from table to table within and across rooms. Upon arriving at each table participants uncovered six objects hidden under a black box, loaded the objects into the box, covered it with a lid, and proceeded to the next table. When participants arrived at the next table, the black box was placed on the table and a recognition task was administered on a laptop. The test consisted of a series of object names and participants indicated if those objects were in the box they were just carrying. Overall, results showed that participants were more likely to forget objects when tested after crossing into another room.
In the second experiment, participants experienced procedures identical to the first with one exception. In Experiment 2, half of the participants completed their final trial in the same room they had started. Experiment 3 addresses potential confounds of context dependent memory associated with the location updating effect in Experiment 2. The authors did so by including a return condition where participants would return to their original location after making a spatial shift (i.e. moving across rooms). Hence, memory for this condition should be better. This experiment found that returning to the original context did not improve memory performance. Findings from Radvansky et al. (2011) show that memory disruptions associated with spatial boundaries are not limited to virtual environments. Accordingly, it seems that spatial features in our environment may influence memory structure. Importantly, the location updating effect does not seem to be influenced by context dependent memory.

Radvansky et al. (2011) suggest that their results may be driven by three primary factors. First, participants separate the stream of actions into separate events based on an event boundary (shifts from one room to another through doorways). As one traverses an event boundary, attention moves from one event to the next. This makes information about a current event more accessible and leaves information from a prior event less accessible. The second factor is foregrounding. In Radvansky et al. (2011), as well as other research, memory is probed for objects that are associated or dissociated from the participant. Associated objects are foregrounded in the current event model. Thus, there is more activation for the associated compared to dissociated objects. The final factor is competitive retrieval. When there has been a spatial shift, two event models are created; one for each room. If an object is associated with each event, there is competition upon retrieval. This results in more memory errors. According to these assumptions, memory should be best when objects are associated and there has been no
spatial shift. Conversely, when an object is dissociated and there has been a spatial shift, memory should be worse (Radvansky et al., 2011).

**Spatial Boundaries and Long Term Representations**

Horner et al. (2016) examined how long term memory representations for segmented events are influenced by spatial boundaries. In one study, participants navigated through a virtual environment containing 48 equally sized rooms separated by a door, each containing two tables with objects on them. Upon entering each room, participants approached each table and answered a categorization question about the object (manmade v. natural). Unique to their study, the authors tested recognition, contextual, and temporal memory for these objects after participants completed their interaction with the virtual environment. The results showed that participant’s temporal memory for objects was more accurate when probed for objects that were experienced in the same room in the virtual environment compared to across rooms. Further, participants did not have explicit memory for particular rooms that the objects were in. In a second experiment, these effects were replicated after controlling for time and space differences between objects within versus across rooms.

**The Current Research**

Environments often contain physical features that may be treated as a spatial boundary. For example, the corner where a change of direction occurs may represent a boundary between the travel segments prior to and following a turn. The memory distortion associated with a spatial boundary may be a limiting factor for some elements of spatial learning. It is reasonable to suspect that a spatial boundary may inhibit one’s ability to recall landmarks located in close proximity to a boundary. Memory for landmarks is essential to navigational processes such as
route learning where objects along a path are associated with a sequence of turns or directions (Kelly, Carpenter, & Sjolund, 2015; Munzer, Zimmer, & Baus, 2012). However, if a spatial boundary disrupts the learning of information relevant to wayfinding, it may be more difficult to successfully navigate one’s environment. Currently, there has been no research specifically examining whether a spatial boundary would cause someone to forget a nearby object. Given findings from previous literature, it is reasonable to suggest that spatial boundaries might disrupt memory for information within an environment, or at least make an environment more difficult to learn and navigate.

Given the relative weakness children show for wayfinding, it is also reasonable to consider that the potential negative effects from spatial boundaries may be more detrimental to children compared to adults. This notion is further supported by literature suggesting that children may not possess adequately developed cognitive skills necessary for advanced wayfinding (Beveridge et al., 2014; Brown et al., 2005; Kwon et al., 2002; Holland et al., 2001). This may make it harder for children to overcome any additional complexity that spatial boundaries may introduce. Further, research assessing the effects of spatial boundaries on memory has been done exclusively with adults. It is likely that children are also susceptible to memory failures associated with spatial boundaries. The current investigations utilize a sample of children ranging in age from six to twelve to help understand the developmental trajectories of landmark memory and wayfinding in environments containing spatial boundaries. These effects are compared with those in adults to provide insights into age-related changes in associative and memory processes, as well as reveal the limits of these abilities.

The two experiments described below examine these issues through the use of a wayfinding task in a virtual environment resembling a series of hallways through a building.
Participants are tasked with navigating one of two routes; one containing boundaries and the other without boundaries. Importantly, landmarks are located at various locations throughout each route. A test of landmark memory and wayfinding is used to assess the impact of the boundaries. To gain a more complete understanding of the cognitive mechanisms involved in wayfinding, landmark recall, and dealing with complexities introduced by spatial boundaries, participants also completed measures of VSTM, verbal memory (VM), and executive function (EF).
EXPERIMENT 1

The first goal of Experiment 1 was to investigate the effects spatial boundaries have on landmark memory in adults. Participants were first guided to a destination through a series of hallways and later tasked with navigating back the destination on their own. The virtual environments either contained or did not contain spatial boundaries. After navigating the environment, memory for landmarks located at spatial boundaries was compared to memory for landmarks that were not located near boundaries. The second goal of Experiment 1 was to assess whether spatial boundaries reduced the typical memory facilitation effect found for landmarks at choice points. To accomplish this, recall for landmarks at intersections and hallways was compared across environments with, and without boundaries. The third goal of Experiment 1 was to examine the effect that spatial boundaries have on wayfinding. If spatial boundaries result in worse memory for landmarks, and landmarks are a prime factor in route learning, then wayfinding may suffer when boundaries are present.

Hypotheses. Predictions for the first experiment are as follows:

1. Significantly more landmarks will be missed when spatial boundaries are present compared to when spatial boundaries are not present.

2. The increase in landmarks recalled at intersections will be greater for the No Boundary compared to Boundary condition.

3. Significantly more wayfinding errors will occur when spatial boundaries are present compared to when spatial boundaries are not present.
4. A significant negative correlation will exist among measures of VSWM, VM, EF, and wayfinding errors.

5. A significant positive correlation will exist among measures of VSWM, VM, EF, and landmark recall.

Participants

A power analysis using G*Power software indicated that 82 participants would be needed to reach .80 power and detect a medium effect size ($f=.25$) using $\alpha=.05$. Adult participants were recruited through the University of Alabama subject pool. The final sample included 83 participants. The average age was 18.53 (SD = 1.07) years. There were 42 participants randomly assigned to the No Boundary condition and 41 assigned to the Boundary condition. Overall there were 44 females and 39 males. For the No Boundary condition there were 22 females and 20 males. There were 22 females and 19 males in the Boundary condition. Participants were given course credit for their participation.

Methods

**Design and Materials.** Experiment 1 was a single factor between subjects design. The independent variable was “Environment” and consisted of two levels (Boundary and No Boundary), each corresponding to differences in the location of doors along a route through a hallway in a virtual environment. There were two dependent variables, each assessing a different aspect of route learning. The number of errors a participant made while navigating a route in a virtual environment was recorded and used as a measure of wayfinding performance. At the end of the main procedure, participants were asked to recall as many objects as they could from the route. This was used as a measure of landmark memory. Recalled landmarks were further distinguished on the basis of landmark type for subsequent analyses: at intersections or at
hallways. Environments were created using the HAMMER editor software. This is a computer program used to create realistic environments in a virtual world. The routes were indoor environments and resembled a series of hallways with turns and choice points. In one route, doors were included along the path. No doors were present in the other route. Landmarks were placed at intersection and hallway locations. Landmarks were items easily recognizable to participants (table, book shelves, signs, etc.). Routes for the Boundary and No Boundary conditions differed only in respect to the presence of doors along the route.

**Wayfinding Task**

**No Boundary Route.** The No Boundary condition served as a control for wayfinding performance and landmark memory. There were 24 landmarks throughout the route. Eight were placed at intersections, eight were located in the middle portion of hallways. The final eight landmarks were in visible locations off of the correct path. No spatial boundaries (doors) were located within this route. Therefore, the environment appeared as a single continuous hallway. The route for this condition contained 20 decision points. All wrong turns lead to a dead end. If participants made a wrong turn, they were instructed to self-correct and continue to navigate to the goal destination.

**Boundary Route.** Doorways were used as spatial boundaries for this condition. The route was the same as the No Boundary condition in terms of complexity (20 turns) and number and locations of landmarks (24). However, unlike the No Boundary condition, doors were present in the environment. The locations of these doorways corresponded to the locations of landmarks in the No Boundary condition. Hence, all landmarks in the No Boundary condition now had a doorway located near them, even those located off the correct path. Wrong turns lead
to a dead end. In which case, participants self-corrected and continued travel to the goal destination.

**Wayfinding Errors.** Performance was assessed by recording the total number of wrong turns participants made while navigating the environment. A wrong turn was defined as taking a turn that lead off the correct path. More wrong turns was indicative of worse wayfinding performance.

**Landmark recall.** After completing the route learning task, participants were asked to recall as many landmarks from the route as possible. The total number of landmarks recalled was recorded. Recalled landmarks were subsequently identified by the researcher as being located at intersections or hallways.

**Visuo-Spatial Working Memory**

The VSWM task used in this research was adopted from Simmering (2012; see also Merrill et al., 2016). Participants were shown a series of displays that included 3 to 8 colored squares. Displays were shown in pairs, where the first display in each was presented for 250ms followed by a blank screen that remained for 750ms. The second display was then presented and remained on the screen until a response was made. The two displays of each pair presented the same number of squares in the same locations. The second display could present squares with either identical colors to that of the first, or with one square differing in color (see Appendix 1). Participants indicated if they thought the squares were all the same colors as the first display, or if there was a change. This was accomplished by pressing the F key for a color change, and the J key for no change in color. There were 8 test displays for each set size, totaling 48 trials. The overall number of correct responses was used as the indicator of VSWM. Higher scores indicated
better performance. Previous investigations have demonstrated the reliability of this measure to assess VSWM (Merrill et al., 2016).

**Word learning**

Verbal memory was measured using a list learning task. Participants were read a list of 15 words. Immediately following, participants were instructed to recall as many words as they could. The total number of recalled words was recorded and this process repeated for 5 trials. Hence, this task measured verbal learning and memory over repeated exposures. If a participant recalled all 15 words before the last trial began, the task ended and they were credited with recalling all words for each remaining trial. Total words recalled over the 5 trials was calculated and used as a measure of verbal memory. Higher scores were indicative of better performance. This task has been used in previous investigations and found to have high reliability (Merrill et al., 2016; Pennington et al., 2003). Only one person recalled the entire list before the final trial began.

**Response Inhibition**

Stimuli for this task were displays of four arrows, arranged pointing either to the left or right (e.g. <<<<, >>>>). In an initial baseline period, participants were sequentially shown these displays on the computer for 18 trials. Participants were to indicate which way the arrows were facing by pressing the left arrow key (<) if the arrows were facing left and the right arrow key (>) if the arrows were facing right. Specific instructions were given to complete this task as fast as possible. After baseline, 36 more arrow displays were presented. For 20 of these displays, a tone was presented 200ms after the arrows appeared on the screen. Instructions were to still respond as fast as possible. However, participants were to make no response when a tone was
presented. The 200ms delay between presentation of the arrow and tone required participants to inhibit carrying out their response to the arrows. Overall errors for the displays that contained a tone were recorded. Higher scores indicated worse inhibition and executive function ability.

**Procedure**

Participants volunteered to participate in the study via the University of Alabama subject pool website. As they arrived at the lab room, they were presented with a consent form. After obtaining consent, participants were randomly assigned to either the Boundary or No Boundary condition. Prior to the start of the wayfinding task participants were asked how many hours a day they spent playing video or computer based games. This was recorded by the researcher. Following this, participants completed a familiarization map to orient them to the general procedure. This map tasked participants to navigate a turn through an intersection and back. This also allowed them the opportunity to ask additional questions about the movement controls.

Participants were told that they would be navigating a route through a virtual environment. Specifically, they were informed their goal was to navigate to a specific destination after first being guided along the correct path. This destination was a person positioned in a specific location at the end of the route. For both conditions, participants first completed a learning phase where they navigated the route following arrows placed on the walls of hallways. Participants used the computer mouse to direct travel through the route. Following the learning phase, the testing phase began. Here, participants navigated through the same route experienced in the learning phase, without the arrows. During the test phase the experimenter recorded the number of wrong turns participants made while navigating to the goal destination. Upon arriving at the goal destination, the landmark memory task was given. After participants completed the
wayfinding and landmark recall tasks, the VSWM, VM, and EF task were administered. The order of these three tasks was counter-balanced.

**Results**

**Preliminary Analysis**

Total wayfinding errors during the testing phase and total landmarks recalled after the testing phase were recorded for each participant. The overall averages for landmarks recalled at intersection and hallway areas are presented in Table 1. Average landmark recall and wayfinding errors within each condition are presented in Table 2. Data for VSWM and VM are found in table 3. All assumptions for statistical tests were assessed prior to completing the main analysis and analysis of landmarks. Correlations among the dependent measures were calculated to address significant covariation and assumptions of MANOVA. A significant negative correlation among wayfinding errors and landmark recall, \( r = -.293, p = .000 \), was found. Assumptions for normality were examined through visual inspection of the data. There was a ceiling effect for the EF data. Data were then transformed by taking the square of participant’s responses. However, this did not bring the data within acceptable skewness values. Consequently, no further analyses were conducted using data from this task.
Table 1.
*Means and Standard Deviations for hallway and intersection landmark recall for adults.*

<table>
<thead>
<tr>
<th></th>
<th>No Boundary</th>
<th>Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
<td>2.8810 (1.6109)</td>
<td>2.8537 (1.4926)</td>
</tr>
<tr>
<td>Hallway</td>
<td>2.5476 (1.4517)</td>
<td>2.6341 (1.3182)</td>
</tr>
</tbody>
</table>

Table 2.
*Means and Standard Deviations for wayfinding errors and missed landmarks for adults in each environment group.*

<table>
<thead>
<tr>
<th></th>
<th>No Boundary</th>
<th>Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors</td>
<td>6.2857 (2.5403)</td>
<td>6.9756 (2.8678)</td>
</tr>
<tr>
<td>Missed</td>
<td>17.1429 (2.6739)</td>
<td>17.2683 (2.6079)</td>
</tr>
</tbody>
</table>
Table 3.

*Means and Standard Deviations for Visuo-spatial working memory (VSWM) and verbal memory (VM) for younger and older children, and adults. Possible range of scores for VSWM and VM were 0-48 and 0-75, respectively.*

<table>
<thead>
<tr>
<th></th>
<th>Younger (6-8 years)</th>
<th>Older (9-12 years)</th>
<th>Adult (18-25 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VM</td>
<td>27.0500 (12.7338)</td>
<td>37.9750 (11.3487)</td>
<td>50.5422 (7.4331)</td>
</tr>
<tr>
<td>VSWM</td>
<td>27.6154 (7.4361)</td>
<td>34.0000 (6.0448)</td>
<td>38.2771 (3.3288)</td>
</tr>
</tbody>
</table>

**Correlations**

An evaluation of how VSWM and VM relate to wayfinding errors and total landmarks recalled was carried out through correlational analysis. These correlations, in addition to age and gender, can be found in table 4. Females were coded as “1”, while males were coded as “2”.

There were no significant correlations found among VSWM, VM, and wayfinding errors or landmark recall. Moreover, no significant correlations existed among VSWM and VM. That is, these measures were not significantly associated with each other. This analysis also showed that neither age, nor gender, was associated with wayfinding error, landmark recall, VSMW, or VM.

Hours per week playing video games was also assessed in relation to wayfinding errors and landmark recall. There was no significant association found among either measure and hours spent playing video games.
Table 4.
Correlations among VSWM, VM, wayfinding errors, landmark recall, age, and gender in adults.

<table>
<thead>
<tr>
<th></th>
<th>VSWM</th>
<th>VM</th>
<th>Age</th>
<th>Gender</th>
<th>Errors</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSWM</td>
<td>1</td>
<td>-.042</td>
<td>.047</td>
<td>.118</td>
<td>-.001</td>
<td>-.182</td>
</tr>
<tr>
<td>VM</td>
<td>-.042</td>
<td>1</td>
<td>.022</td>
<td>-.082</td>
<td>-.179</td>
<td>.210</td>
</tr>
<tr>
<td>Age</td>
<td>.047</td>
<td>.022</td>
<td>1</td>
<td>.301**</td>
<td>.031</td>
<td>.035</td>
</tr>
<tr>
<td>Gender</td>
<td>.118</td>
<td>-.082</td>
<td>.301**</td>
<td>1</td>
<td>.023</td>
<td>.213</td>
</tr>
<tr>
<td>Errors</td>
<td>-.001</td>
<td>-.179</td>
<td>.031</td>
<td>.023</td>
<td>1</td>
<td>-.293**</td>
</tr>
<tr>
<td>Recall</td>
<td>-.182</td>
<td>.210</td>
<td>.035</td>
<td>.213</td>
<td>-.293**</td>
<td>1</td>
</tr>
</tbody>
</table>

Main Analysis

The number of missed landmarks was calculated and used for the main analysis. This was done by taking the difference between the number of landmarks recalled and total possible landmarks recalled. To evaluate the effects of spatial boundaries, a one-way (Environment: Boundary v. No Boundary) between subjects MANOVA was conducted on wayfinding errors and missed landmarks. Lower scores on both dependent measures indicated better performance. The results showed a non-significant effect of Environment, $F (2, 80) = .674, p = .513$. Wayfinding errors and missed landmarks did not depend on environment. No significant differences between environments were found for either dependent measure. Thus, no support for hypotheses 1 and 2 was revealed.
Analysis of Landmarks

A 2 (Environment: Boundary v. No Boundary) x 3 (Landmark Type: Hallway v. Intersection v. off) mixed ANOVA was conducted for total landmarks recalled. The within subjects factor was Landmark Type, while the between subjects factor was Environment. There was a non-significant main effect for Environment, $F (1, 81) = .047, p = .829$. Landmark recall was similar in the No Boundary and Boundary conditions. A significant main effect of Landmark Type was found, $F (2, 162) = .35.394, p = .000, \eta^2_p = 304$. Pairwise comparisons indicated no significant differences between hallway and intersection landmarks, $p = .196$. However, recall for both hallway and intersection landmarks were significantly higher compared to off route landmarks, $p = .000$, and $p =.000$, respectively. These findings indicate that hallway and intersection landmarks were recalled more often than those located off of the wayfinding route. In addition, there was no evidence that intersection landmarks were better recalled than hallway landmarks.

Gender and Wayfinding

During the data collection process, gender was controlled for by roughly equating the Boundary and No Boundary conditions for males and females. However, to assess the potential differences between males and females, a 2 (Gender: Male v. Female) x 2 (Environment: No Boundary v. Boundary) between subjects ANOVA was conducted on wayfinding errors. Results showed non-significant main effects of gender, $F (1, 79) = .070, p = .793$, and environment, $F (1, 79) = 1.810, p = .182$. There were no differences in wayfinding errors between males and females, or the environment conditions. A significant interaction was revealed $F (1, 79) = 6.356, p = .014$. The average wayfinding errors for each gender within the environment conditions
indicated that males were more impacted by the presence of spatial boundaries compared to females. These averages can be found in table 5.

A 2 (Gender: Male v. Female) x 2 (Environment: No Boundary v. Boundary) between subjects ANOVA was also conducted on landmark recall. There was a non-significant main effect of Gender, \( F(1, 79) = 3.738, p = .057, \eta_p^2 = .045 \), and Environment, \( F(1, 79) = .034, p = .853, \eta_p^2 = .000 \). There were no statistical differences between males and females for landmark recall, nor were there differences in recall among the environment conditions. A non-significant interaction was also found, \( F(1, 79) = .017, p = .896, \eta_p^2 = .000 \). It seems that spatial boundaries do not impact landmark recall in adults, and, this is true for both males and females.

Table 5.

*Means and Standard Deviations for wayfinding errors for adults in each environment condition.*

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Boundary</td>
<td>6.9091 (2.5431)</td>
<td>5.6000 (2.4148)</td>
</tr>
<tr>
<td>Boundary</td>
<td>6.2273 (2.6535)</td>
<td>7.8421 (2.9210)</td>
</tr>
</tbody>
</table>

**Discussion**

In the current experiment spatial boundaries took the form of doorways placed along a route through a virtual environment. It was hypothesized that the presence of these doorways would have an impact on participant’s ability to navigate the route after a guided exposure. Results of this experiment did not provide support for this hypothesis. Participants were remarkably similar in their wayfinding performance in the two environments. Average
wayfinding errors in the Boundary (M = 6.9756) condition were only .6899 more than in the No Boundary condition (M = 6.2857). These findings suggest that spatial boundaries had a negligible effect on participants’ ability to successfully navigate under the current conditions.

Experiment 1 also hypothesized that doorways would have a significant effect on participant’s ability to recall information from the wayfinding task (i.e. landmarks). Indeed, existing research concerning any effects of spatial boundaries on cognition indicates that fewer items should be remembered as a result of event segmentation processes. Hence, in the current research, individuals should remember more in the No Boundary, compared to Boundary, condition. Findings did not provide any support for this hypothesis. Similar to wayfinding errors, the total number of recalled landmarks were almost identical for the Boundary and No Boundary conditions, M = 17.2683 and M = 17.1429, respectively.

There are differences between tasks of the current research and those used in prior work. In previous investigations, participants pick up and set down objects on tables within and across rooms (Radvansky et al., 2011; Radvansky & Copeland, 2006). Memory for these objects is probed as participants enter a new room (i.e. crossing a doorway) and when they are midway between tables within rooms. Hence, after each spatial shift participants are given a memory test. Memory probes present participants with an object and ask them to indicate if it were one they had just set down or were currently carrying (Pettijohn & Radvansky, 2016; Pettijhon & Radvansky, 2011; Radvansky & Copeland, 2006). However, location updating effects have been found using free recall memory probes as well (Pettijohn & Radvansky, 2018). In the Boundary condition of Experiment 1, participants potentially experienced more than 16 landmarks and 16 spatial shifts before the landmark memory test was administered. Considering that more spatial shifts were experienced and there was a longer delay for free recall of landmarks, one might
expect that spatial boundaries would have a more pronounced effect on landmark memory in the current task. However, there was no indication of this, given the non-significant differences in missed landmarks between the environment conditions.

Procedures for Radvansky and Copeland (2006) included as many as 50 memory probes. While participants were not specifically instructed to learn anything about the objects, it is likely they deduced it was important to remember objects as they moved from room to room. Despite this, object memory was still worse after making a spatial shift. Participants in the current study were informed they would be tasked with independently navigating to a specific destination, which gave motive to learn about the landmarks. In the present research, however, similar landmark recall was found among environments with and without spatial boundaries. The lack of any spatial boundary effect in Experiment 1 may relate to a strategy preference used to complete the navigation task. For example, participants may have been employing a form of route strategy where they learn to navigate the path by encoding the sequence of turns. If this were the case, attention may have been focused on learning which direction to travel, opposed to associating a landmark with a direction. In essence, participants may not have been effected by doorways because they were not trying to learn any information that was located near them. It could also be that because of the amount of doorways, they did not provide any useful information. This may have lead participants to ignore them, which may explain why there was not a boundary effect.

Other reasons for the null effect in Experiment 1 could be due to potential power issues. However, comparing the sample size for this experiment to information provided by the power analysis (see participants section) there seems to be an appropriate amount of participants to reach sufficient power. An additional alternative could be that the spatial boundaries in Experiment 1 do not provide a large enough effect to be detectable. However, our null effect
does not necessarily mean that spatial boundaries do not impact cognition and behavior. It is possible that we were simply unable to capture its effect with the current measures. Perhaps, including additional measures of wayfinding and configural knowledge would have better illuminated the spatial boundary effect in adults.

An interesting finding from this experiment concerns the absence of a relationship among measures of VSWM and VM with wayfinding errors and landmark recall. Current theory on spatial boundary effects suggests that the presence of boundaries increases cognitive load, which is the mechanism for memory distortions. Considering this, it would be reasonable to suggest that the larger the capacity individuals have at maintaining multiple items, the better they would be able to deal with spatial boundaries and location updating. In this research, however, there was no indication of this.
EXPERIMENT 2

The second experiment addressed developmental differences in the impact of spatial boundaries on wayfinding. Experiment 2 used the same procedures as Experiment 1. However, a sample of younger and older children completed the wayfinding and landmark recall tasks. Previous research consistently reported that younger children were comparatively worse at wayfinding than older children and adults. In Experiment 2, younger and older children were compared on their wayfinding performance and landmark memory in environments that did or did not contain spatial boundaries. These manipulations allowed an assessment of whether younger children were worse at wayfinding, and if they remember fewer landmarks compared to older children. This experiment also addressed landmark memory in relation to intersection and hallway locations across environmental conditions, as in Experiment 1.

Piloting Route Complexity

A cross study comparison of wayfinding and landmark memory among age groups for the spatial boundary conditions is presented in the results section of Experiment 2. The comparison of child and adult performance required that baseline performance be proportionally similar for the children and adults to make any differences between the boundary and no boundary conditions meaningful. Hence, I wanted a wayfinding task in which both groups made approximately the same percentage of errors. This was done through piloting children’s performance using mazes of different complexity and selecting the maze that resulted in the
performance levels that roughly matched the percentage of errors in wayfinding exhibited by the adults in Experiment 1.

Prior to the start of Experiment 2, children (N = 20) were piloted in a route containing 10 turns and 15 landmarks without doorways. The pilot sample included 10 older (9-12 years) and 10 younger (6-8 years) children, each age group was equated for gender. Procedures for the pilot task were the same as Experiment 1. Because of the need to use different complexity mazes for adult and child participants to perform at similar levels, proportion of errors and proportion of recalled landmarks during the piloting phase were used to compare performance rather than absolute values. Proportion wayfinding errors for the adults of Experiment 1 were calculated by dividing wayfinding errors by the total possible wayfinding errors (i.e. 20). Total landmark recall scores were divided by 24 (i.e. total possible recalled landmarks) to calculate proportion recall scores. Proportion wayfinding error scores and proportion landmark recall scores were calculated in a similar fashion for children in the pilot procedure and compared to adults of Experiment 1.

For children, a route complexity of 10 turns resulted in proportion wayfinding error rates of M = .3400 (34%), and proportion landmark recall scores of M = .2900 (29%). After comparing these to adult proportion error rates (M = .3142; 31.42%) and proportion landmark recall scores (M = .2857; 28.57%), it was reasonable to conclude that complexity was approximately scaled to children and adults respective ability. Thus, the final sample of children in Experiment 2 completed a wayfinding task that entailed 10 turns and contained 15 landmarks. Proportion wayfinding errors and proportion landmark recall scores were used in the cross study analyses.

Hypotheses. Predictions for the second experiment are as follows:
1. Young children will make significantly more wayfinding errors compared to older children.

2. Young children will miss significantly more landmarks compared to older children.

3. The increase in landmarks recalled at intersections will be greater for the No boundary compared to Boundary condition.

4. Significantly more wayfinding errors will occur when spatial boundaries are present compared to when spatial boundaries are not present.

5. Significantly Fewer landmarks will be recalled when spatial boundaries are present compared to when spatial boundaries are not present.

6. The increase in wayfinding error for the Boundary compared to No Boundary condition will be greater for younger children compared to older children, compared to adults.

7. The decrease in landmark memory for the Boundary compared to No Boundary condition will be greater for younger children compared to older children, compared to adults.

8. A significant negative correlation will exist among measures of VSWM, VM, EF, and wayfinding errors.

9. A significant positive correlation will exist among measures of VSWM, VM, EF, and landmark recall.

**Methods**

**Participants.** A Power analysis using G*Power software was conducted for a between subjects factorial ANOVA. The analysis indicated that 162 participants would be needed to reach
.80 power and detect a medium effect size ($f = .25$) using $\alpha = .05$. The final sample of children was $N = 80$. Both younger and older children were recruited for the second experiment. Children in the younger age group ranged in age from 6 to 8 with an average age of $M = 6.9$ (SD = .8589) years. Older children ranged in age from nine to twelve and averaged $M = 9.7$ (SD = .9661) years. There were a total of 40 children in the younger age group and 40 children in the older age group. For each age group, 20 children were randomly assigned to either the Boundary or No Boundary conditions. Moreover, each condition for each age group was roughly equated for gender. Children were recruited from Faucett-Vestavia Elementary school in the Tuscaloosa county area. Student demographics for this school are 60.1% Caucasian, 24.2% African American, 7.3% Hispanic, and 4.7% Asian. Parents were provided the study details via consent form presented by the researcher as they picked their child up from school.

**Design and Materials.** Experiment 2 employed a two factor between subjects design. The first factor was “Environment” and consisted of two levels: Boundary and No Boundary. As in Experiment 1, doorways were used as spatial boundaries. The second factor was “Age” and entailed two levels, each representing a different age group; younger and older children. There were two dependent variables: total wayfinding errors and total landmark recall. During the navigation task, wayfinding errors were recorded. After navigation participants recalled as many landmarks as possible. As was done in Experiment 1, the virtual routes used in the Boundary and No Boundary conditions were made using the HAMMER editor software.

**Wayfinding Task**

**No Boundary Route.** Wayfinding performance and landmark recall for this route was treated as a control condition. A total of 15 landmarks were distributed throughout the route: 5 landmarks placed at choice points, 5 in hallways, 5 in off route locations. Importantly, no spatial
boundaries (doors) were present in this route. The wayfinding route contained 10 decision points. All wrong turns lead to a dead end. If participants made a wrong turn, they were instructed to self-correct and continue to navigate to the goal destination.

**Boundary Route.** Performance in this condition was used to assess the influence of spatial boundaries on wayfinding and landmark recall. The environment for this condition was identical to the No boundary condition in reference to complexity (10 turns) and landmark abundance and location (15). However, doors were now placed throughout the route. As in Experiment 1, locations for these corresponded to the locations of landmarks in the No Boundary condition, with landmarks now situated near a doorway. Specifically, these landmarks were placed adjacent and prior to each door. Again, wrong turns lead to a dead end, where participants self-corrected and continued their travel to the goal destination.

**Wayfinding.** Wayfinding ability was assessed by recording the total number of wrong turns participants made while navigating environments. Wrong turns were defined as taking a turn that lead off of the correct path. Committing more wrong turns indicated worse wayfinding performance, whereas fewer wrong turns suggested better wayfinding performance.

**Landmark recall.** After completing the route learning task, participants recalled as many landmarks as possible. These were identified by the researcher as being located at choice points or at non choice points.

**VSWM, VM, and Response Inhibition.** These measures were identical to Experiment 1.

**Procedure**

Participation for Experiment 2 was voluntary. Informed consent was obtained from parents of children who participated. Prior to formally enrolling in the study, assent was also
obtained from children. Procedures and instructions for the second experiment were identical to the first. Younger and older children were randomly assigned to either the Boundary or No Boundary condition and given task instructions. Prior to the start of the wayfinding task, participants were asked how many hours a week they spent playing video or computer based games. Next, the familiarization map was completed. For each condition, a learning phase was completed followed by a testing phase in the same manner as Experiment 1. The goal destination was indicated by a person situated at a particular location. Wrong turns were recorded while participants completed the test phase. After arriving at the goal destination participants were asked to recall as many landmarks as possible. Finally, children completed the same VSWM, VM, and EF tasks as adults in Experiment 1.

Results

Preliminary Analysis

As in Experiment 1, total landmarks recalled and wayfinding errors during the testing phase were recorded. Scores for missed landmarks were obtained by subtracting total landmarks recalled by 15. Overall averages for these for the younger and older children age groups are presented in Table 6. Recalled landmarks were also identified as located at intersection and hallway areas. Average recall for these can be found in Table 7. Assumptions for normality were assessed via visual inspection of the data. All tasks met this assumption, with the exception of EF. Responses again demonstrated a ceiling effect for both age groups, resulting in a highly skewed distribution (Skewness = -3.348, and -2.440). To control for this, data were transformed by squaring responses. However, despite this transformation the data were still highly skewed. Consequently, no further analyses using the EF task were conducted. Averages for VSWM and VM for younger and older children are presented in Table 3.
Table 6.
Means and Standard Deviations for wayfinding errors and missed landmarks for younger and older children.

<table>
<thead>
<tr>
<th></th>
<th>Younger (6-8 years)</th>
<th>Older (9-12 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors</td>
<td>4.9500 (2.5914)</td>
<td>3.500 (2.6603)</td>
</tr>
<tr>
<td>Missed</td>
<td>11.6750 (1.5256)</td>
<td>10.0750 (1.6546)</td>
</tr>
</tbody>
</table>

Table 7.
Means and Standard Deviations for hallway and intersection landmark recall for children in each environment group.

<table>
<thead>
<tr>
<th></th>
<th>No Boundary (Intersection)</th>
<th>Boundary (Hallway)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
<td>1.5750 (.9842)</td>
<td>0.8000 (.6076)</td>
</tr>
<tr>
<td>Hallway</td>
<td>2.3000 (.9923)</td>
<td>1.9500 (1.0365)</td>
</tr>
</tbody>
</table>

To ensure compliance with assumptions of MANOVA, a Pearson correlation was used to determine the relationship between total landmark recall and wayfinding errors for the child participant’s. A significant negative correlation between wayfinding error and landmarks recalled, $r = -.585, p = .000$, was found. Recalling more landmarks was associated with making fewer wrong turns in the wayfinding task.

For the cross study analysis of Experiment 2 (described above), proportion error rates and proportion landmark recall scores were used. For children and adults, wayfinding errors and
recalled landmarks were divided by the total possible wayfinding errors and recalled landmarks. Proportion error rates and proportion landmark recall scores for each age group are presented in Table 8. Average proportion wayfinding errors for each age group and environment condition are presented in Table 9. Average proportion landmark recall for each age group and environment condition are presented in Table 10. The cross study analysis described in Experiment 2 includes all adult participants from Experiment 1. The analysis was also conducted using a randomly selected sample of 54 adults from Experiment 1. Given this analysis showed the same pattern of results, the cross study analysis using the entire sample from Experiment 1 is reported.

Table 8.

*Means and Standard Deviations for proportion wayfinding errors and proportion landmark recall for adults, younger children, and older children.*

<table>
<thead>
<tr>
<th></th>
<th>Adult (18-25 years)</th>
<th>Older (9-12 years)</th>
<th>Younger (6-8 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion Errors</td>
<td>.3313 (.1356)</td>
<td>.3500 (.2660)</td>
<td>.4950 (.2591)</td>
</tr>
<tr>
<td>Proportion Recall</td>
<td>.2831 (.1094)</td>
<td>.3283 (.1103)</td>
<td>.2217 (.1017)</td>
</tr>
</tbody>
</table>
Table 9.
*Means and Standard Deviations for proportion wayfinding errors for each age group and environment condition.*

<table>
<thead>
<tr>
<th></th>
<th>Adult (18-25 years)</th>
<th>Older (9-12 years)</th>
<th>Younger (6-8 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Boundary</td>
<td>.3143 (.1270)</td>
<td>.1750 (.1293)</td>
<td>.4150 (.2777)</td>
</tr>
<tr>
<td>Boundary</td>
<td>.3488 (.1434)</td>
<td>.5250 (.2531)</td>
<td>.5750 (.2173)</td>
</tr>
</tbody>
</table>

Table 10.
*Means and Standard Deviations for proportion landmark recall for each age group and environment condition.*

<table>
<thead>
<tr>
<th></th>
<th>Adult (18-25 years)</th>
<th>Older (9-12 years)</th>
<th>Younger (6-8 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Boundary</td>
<td>.2857 (.1114)</td>
<td>.3733 (.1250)</td>
<td>.2733 (.0889)</td>
</tr>
<tr>
<td>Boundary</td>
<td>.2805 (.1087)</td>
<td>.2833 (.0713)</td>
<td>.1700 (.0878)</td>
</tr>
</tbody>
</table>

**Correlations**

Correlations for the dependent measures, gender, VSWM, and VM were evaluated for younger and older children age groups separately. These are presented in Tables 11 and 12. For both child age groups there were no significant relationships found among any measures with wayfinding errors or landmark recall scores. Females were coded as “1”, while males were coded
as “2”. Time spent playing video games per week was not correlated with wayfinding errors and landmark recall.

Table 11.

*Correlations among VSWM, VM, wayfinding errors, landmark recall, age, and gender in older children.*

<table>
<thead>
<tr>
<th></th>
<th>VSWM</th>
<th>VM</th>
<th>Age</th>
<th>Gender</th>
<th>Errors</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSWM</td>
<td>1</td>
<td>.139</td>
<td>.096</td>
<td>-.009</td>
<td>-.124</td>
<td>.275</td>
</tr>
<tr>
<td>VM</td>
<td>.139</td>
<td>1</td>
<td>.177</td>
<td>-.047</td>
<td>-.240</td>
<td>.082</td>
</tr>
<tr>
<td>Age</td>
<td>.096</td>
<td>.177</td>
<td>1</td>
<td>.137</td>
<td>-.140</td>
<td>.226</td>
</tr>
<tr>
<td>Gender</td>
<td>-.009</td>
<td>-.047</td>
<td>.137</td>
<td>1</td>
<td>-.306</td>
<td>.235</td>
</tr>
<tr>
<td>Errors</td>
<td>-.124</td>
<td>-.240</td>
<td>-.140</td>
<td>-.306</td>
<td>1</td>
<td>-.486**</td>
</tr>
<tr>
<td>Recall</td>
<td>.275</td>
<td>.082</td>
<td>.226</td>
<td>.235</td>
<td>-.486**</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 12.
Correlations among VSWM, VM, wayfinding errors, landmark recall, age, and gender in younger children.

<table>
<thead>
<tr>
<th></th>
<th>VSWM</th>
<th>VM</th>
<th>Age</th>
<th>Gender</th>
<th>Errors</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSWM</td>
<td>1</td>
<td>.106</td>
<td>-.023</td>
<td>.240</td>
<td>-.034</td>
<td>-.068</td>
</tr>
<tr>
<td>VM</td>
<td>.106</td>
<td>1</td>
<td>.310</td>
<td>.199</td>
<td>-.175</td>
<td>.006</td>
</tr>
<tr>
<td>Age</td>
<td>-.023</td>
<td>.310</td>
<td>1</td>
<td>.206</td>
<td>-.416**</td>
<td>.313*</td>
</tr>
<tr>
<td>Gender</td>
<td>.240</td>
<td>.199</td>
<td>.206</td>
<td>1</td>
<td>-.098</td>
<td>.116</td>
</tr>
<tr>
<td>Errors</td>
<td>-.034</td>
<td>-.175</td>
<td>-.416**</td>
<td>-.098</td>
<td>1</td>
<td>-.476**</td>
</tr>
<tr>
<td>Recall</td>
<td>-.068</td>
<td>.006</td>
<td>.313*</td>
<td>.116</td>
<td>-.476*</td>
<td>1</td>
</tr>
</tbody>
</table>

Primary Analyses - Children

Developmental differences in wayfinding and missed landmarks were evaluated for younger and older children. A one-way (Age: Younger v. Older) between subjects MANOVA was conducted for wayfinding errors and missed landmarks. Results from this analysis showed there were significant differences in wayfinding errors and missed landmarks based on age, $F (2, 77) = 10.038, p = .000$; Wilk's $\Lambda = .793, \eta^2_p = .207$. Wayfinding errors and missed landmarks were subsequently examined separately. A significant main effect of Age was found for wayfinding errors, $F (1, 78) = 6.089, p = .016, \eta^2_p = .073$. There were significantly more wayfinding errors committed by younger (M = 4.95, SD = 2.59) compared to older children (M = 3.50, SD = 2.66). Older children were better at wayfinding relative to younger children. Thus,
support for hypothesis 1 was revealed. For missed landmarks, a main effect indicating younger children (M = 11.68, SD = 1.53) missed significantly more landmarks compared to older children (M = 10.08, SD = 1.65) was found, $F (1, 78) = 20.216, p = .000$, $\eta^2_p = .206$. In addition to making fewer errors, older children were recalling more landmarks compared to younger children. This result provides evidence in support of hypothesis 2.

**Analysis of Landmarks**

A 2 (Environment: Boundary v. No Boundary) x 3 (Landmark Type: Hallway v. Intersection v. off) mixed ANOVA was conducted for proportion landmarks recalled. The within subjects factor was Landmark Type, while the between subjects factor was Environment. There was a non-significant main effect for Environment, $F (1, 81) = .047, p = .829$. Landmark recall was similar in the No Boundary and Boundary conditions. A significant main effect of Landmark Type was found, $F (2, 162) = .35.394, p = .000$, $\eta^2_p = 304$. Pairwise comparisons indicated no significant differences between hallway and intersection landmarks, $p = .196$. However, recall for both hallway and intersection landmarks were significantly higher compared to off route landmarks, $p = .000$, and $p =.000$, respectively. These findings indicate that hallway and intersection landmarks were recalled more often than those located off of the wayfinding route.

In addition, there was no evidence that intersection landmarks were better recalled than hallway landmarks.

**Cross Study Mean Comparisons**

To assess potential developmental differences between children and adults, two separate 3 (Age: Younger v. Older v. Adult) x 2 (Environment: Boundary v. No Boundary) between subjects ANOVA’s were conducted on proportion wayfinding error scores and proportion
landmark recall scores. For proportion wayfinding errors, significant main effects for Environment $F(1, 157) = 34.846, p = .000, \eta^2_p = .182$, and Age, $F(2, 157) = 11.050, p = .000, \eta^2_p = .123$, were found. There were higher proportion wayfinding errors in the Boundary compared to No Boundary condition, supporting hypothesis 4. In addition, differences in proportion wayfinding errors existed among age groups. These results were qualified by a significant Age x Environment interaction, $F(2, 157) = 9.855, p = .000, \eta^2_p = .112$. In order to breakdown this interaction, and specifically address hypothesis 6, I compared performance in the Boundary to the No Boundary condition within each age group. For the adults, no significant differences in proportion wayfinding error rates were found between the Boundary ($M = .3488, SD = .1270$) and No Boundary ($M = .3143, SD = .1434$) conditions, $t(81) = 1.161, p = .249$. Adult performance was not impacted by the presence of doorways. This was not the case for older children. Significant differences in proportion wayfinding errors were found between the environment conditions, $t(38) = 5.507, p = .000, d = 1.74$. Specifically, older children committed an average of $M = .5250 (SD = .2531)$ proportion wayfinding errors in the Boundary condition and $M = .1750 (SD = .1293)$ in the No Boundary condition. A similar pattern was found for the younger children. There was a significantly higher proportion of wayfinding errors in the Boundary ($M = .5750, SD = .2173$) compared to No Boundary ($M = .4150, SD = .2777$) condition, $t(38) = 2.029, p = .05, d = .64$. In sum, children were more impacted by doorways compared to adults. Hypothesis 6 predicted that younger children would be comparatively more impacted by spatial boundaries. However, it seems that older children actually displayed a larger spatial boundary effect. Considering this, definitive support for hypothesis 6 was not obtained. Nevertheless, both groups of children displayed a significant weakness in dealing with doorways in the wayfinding task.
Regarding proportion landmark recall, a significant main effect of Age was found, $F(2, 157) = 10.813, p = .000, \eta^2_p = .121$, indicating differences in proportion landmark recall existed among age groups. This was accompanied by a significant main effect of Environment, $F(1, 157) = 14.921, p = .000, \eta^2_p = .087$, that suggested there were more landmarks recalled in the No Boundary compared to Boundary condition, supporting hypothesis 5. In addition, a significant Age x Environment interaction was also observed, $F(1, 157) = 4.041, p = .019, \eta^2_p = .049$.

This interaction was evaluated by examining differences in proportion landmark recall scores among the Boundary and No Boundary conditions for each age group. No significant differences were found in proportion recall scores for adults in the Boundary ($M = .2805$, $SD = .1087$) and No Boundary ($M = .2857$, $SD = .1114$) conditions, $t(81) = .216, p = .829$. Older children showed higher proportion recall scores in the No Boundary ($M = .3733$, $SD = .1250$) compared to Boundary ($M = .2833$, $SD = .0713$) condition $t(81) = 2.797, p = .008, d = .88$. For the younger children, significantly higher proportion landmark recall scores also occurred for the No Boundary ($M = .2733$, $SD = .0889$) compared to Boundary ($M = .1700$, $SD = .0878$) condition, $t(38) = 3.698, p = .001, d = 1.17$. It was predicted that children would exhibit a boundary effect, whereas the adults would not. Given that no differences in recall were found among environments for adults, and children showed a significant boundary effect, general support for hypothesis 7 was found.

**Predicting Performance across Development within Environments**

Correlations using data from both experiments were conducted among proportion wayfinding errors, proportion recall scores, VSWM, VM, age, and gender. These are presented in Table 13. VM was positively associated with VSWM, and proportion recall scores, $r = .491, p = .000$, and $r = .185, p = .018$, respectively. Better VM was related to higher VSWM performance.
and greater landmark recall. A negative correlation existed for VM with proportion wayfinding errors, $r = -.334$, $p = .000$, indicating that higher VM performance leads to lower wayfinding errors. VSWM was negatively associated with proportion error scores, $r = -.233$, $p = .003$, but no significant relationship among VSWM and proportion recall scores were found. Hence, better VSWM performance is related to fewer wayfinding errors. These findings lend support to hypotheses 8 and 9. Age was positively correlated with VM, $r = .695$, $p = .000$, and VSWM, $r = .598$, $p = .000$. As age increased, so did performance on VM and VSWM measures. There was a negative relationship among age and proportion wayfinding errors, $r = -.271$, $p = .000$, indicating an increase in age was associated with a decrease in wayfinding errors. No relation among age and proportion landmark recall scores was found. Gender was found to correlate positively with proportion recall scores, $r = .194$, $p = .013$: males exhibited higher proportion recall scores. No other associations with gender were found.
Table 13.

*Correlations among VSWM, VM, proportion wayfinding errors, proportion landmark recall, age, and gender for all age groups.*

<table>
<thead>
<tr>
<th></th>
<th>Prop. Error</th>
<th>Prop. Recall</th>
<th>VSWM</th>
<th>VM</th>
<th>Age</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prop. Errors</td>
<td>1</td>
<td>-.436**</td>
<td>-.233**</td>
<td>-.334**</td>
<td>-.271*</td>
<td>-.108</td>
</tr>
<tr>
<td>Prop. Recall</td>
<td>-.436**</td>
<td>1</td>
<td>.113</td>
<td>.185*</td>
<td>.119</td>
<td>.194*</td>
</tr>
<tr>
<td>VSWM</td>
<td>-.233**</td>
<td>.113</td>
<td>1</td>
<td>.491**</td>
<td>.598**</td>
<td>.077</td>
</tr>
<tr>
<td>VM</td>
<td>-.334**</td>
<td>.185*</td>
<td>.491*</td>
<td>1</td>
<td>.695**</td>
<td>-.013</td>
</tr>
<tr>
<td>Age</td>
<td>-.271*</td>
<td>.119</td>
<td>.598**</td>
<td>.695**</td>
<td>1</td>
<td>-.002</td>
</tr>
<tr>
<td>Gender</td>
<td>-.108</td>
<td>.194*</td>
<td>.077</td>
<td>-.013</td>
<td>-.002</td>
<td>1</td>
</tr>
</tbody>
</table>

To gain a better understanding of which ability was important for dealing with cognitive complexities introduced by spatial boundaries, relations among VSWM and VM with proportion recall scores and proportion wayfinding errors were examined for each environment condition separately. To control for type 1 error, alpha for these was set at .01. For the No Boundary condition, neither VSWM, nor VM correlated with proportion wayfinding errors or proportion recall scores.

Interestingly, the pattern of relationships seemed to change for the Boundary condition. Here, VM was positively correlated with proportion recall scores, \( r = .350, p = .001 \), and proportion wayfinding errors, \( r = -.487, p = .000 \). VSWM was negatively related to proportion wayfinding error scores, \( r = -.342, p = .002 \). No significant relations among VSWM and
proportion recall scores were found in this environment condition. These findings seem to suggest that for the No boundary condition, greater VM and VSWM are not associated with efficient wayfinding and better landmark recall. However, when spatial boundaries are introduced to the environment, these abilities become important for navigating and learning features of the environment. It is interesting that these relationships are modified by the presence of spatial boundaries.

To better comprehend the magnitude of change in these relationships, an exploratory $t$ test on the difference between correlation coefficients for VSWM and VM with proportion wayfinding errors and proportion landmark recall scores across the No Boundary and Boundary conditions was conducted. Alpha for these were set at .01 to correct for type 1 error. The difference between the correlation coefficients for VM across the environment conditions for both proportion wayfinding and proportion recall scores were non-significant, $z = 1.959, p = .025$, and $z = 1.982, p = .024$. For VSWM with proportion wayfinding errors, non-significant differences were found for the correlation coefficients across the environment conditions $z = 1.425, p = .077$. Hence, there was no significant change in the strength of any correlation across environment conditions. Given there was no significant change in the relationship of VSWM with proportion recall scores across the environment conditions, there was no need to test the differences between correlation coefficients.

Assuming the above correlations indicated the pattern of relationships among abilities may have been different among environment groups, multiple linear regression analysis was conducted for the Boundary and No Boundary conditions separately. In model 1 of the No Boundary condition, proportion wayfinding errors were regressed on VM and VSWM. In the next step of the model, age was added. Model 1 produced non-significant results, $F (2, 78) =$
2.014, \( p = .140, R^2 = .049 \). Age did not add any significant prediction in model 2, \( F(3, 77) = 1.952, p = .132, R^2 = .070 \). In sum, VSWM, VM, and age were not significant predictors of wayfinding performance in the No Boundary condition. A second multiple regression analysis was conducted with proportion recall scores in the No Boundary condition. In model 1, proportion recall scores were regressed on VSWM and VM. In step 2, age was added. Both models produced non-significant results, \( F(2, 78) = .236, p = .790, R^2 = .006 \), and \( F(3, 77) = 1.260, p = .294, R^2 = .047 \), respectively. It seems that performance in the No Boundary condition of the wayfinding task was not related to variability in VSWM and VM.

Multiple regression was also used to determine if the predictive power of VSWM and VM to proportion recall and wayfinding errors changed in the Boundary condition. Proportion wayfinding error scores were first analyzed. Models 1 and 2 for this test were the same as for the No Boundary condition. That is, VSWM and VM were included in model 1 and age was added in model 2. Both models produced significant results. Overall results for model 1 were \( F(2, 76) = 12.104, p = .000, R^2 = .242 \). VM was found to be a significant predictor of proportion wayfinding errors, \( B = -.007, SE = .002, \beta = -.438, p = .001 \), while VSWM was not a significant predictor. Overall results for model 2 were \( F(3, 75) = 8.914, p = .000, R^2 = .263 \). However, with the addition of age, the slopes for both VSWM and VM were now not significant. Age was associated with a non-significant slope as well. Considering this, and that there was no significant \( F \) change between the two models, model 1 was selected as the best fit for the data.

To better elucidate the relationship among these factors with proportion wayfinding errors, a multiple regression analysis was conducted where age was entered in model 1 and VM and VSWM were entered in model 2. Here, both model 1, \( F(1, 77) = 22.232, p = .000, R^2 = .224 \), and 2, \( F(3, 75) = 8.914, p = .000, R^2 = .263 \) were significant. Model 2 of this analysis is
identical to model 2 of the previous regression. However, now when model 1 includes only age there is significant prediction, $B = -.019$, $SE = .004$, $\beta = -.473$, $p = .000$. This finding is likely due to VSWM, VM, and age accounting for similar portions of explained variance. Nevertheless, unlike the No Boundary condition, VM was found to be a significant predictor of wayfinding performance in the Boundary condition. This condition seemed to introduce a complexity to wayfinding that verbal memory may have helped to overcome. Thus, better verbal memory was predictive of fewer wayfinding errors. This finding also indicates that age was not directly predictive of fewer wayfinding errors.

In the final regression analysis, VSWM and VM were entered as predictors of proportion recall scores in model 1 and age was added in model 2. Here, both models also produced significant results. However, after examining parameters for each, model 1 was chosen to best represent the data. Overall results for model 1 were $F (2, 76) = 5.465$, $p = .006$, $R^2 = .126$. VM was found to be a significant predictor of proportion landmark recall scores, $B = .003$, $SE = .001$, $\beta = .394$, $p = .004$. The slope for VSWM was not significant. As for proportion wayfinding errors, an additional regression analysis on proportion recall scores was conducted where age was entered in model 1 and VSWM and VM were added in model 2. Both model 1, $F (1, 77) = 9.380$, $p = .003$, $R^2 = .109$, and Model 2, $F (3, 75) = 4.096$, $p = .010$, $R^2 = .141$, were significant. Here, when age was entered in model 1 there was significant prediction, $B = .006$, $SE = .002$, $\beta = .330$, $p = .003$. However, with the addition of VSWM and VM in model 2 the slopes for each predictor become non-significant. Comparing this with the initial regression where VSWM and VM were entered first, it seems that age, VSWM, and VM may be explaining similar portions of variance for proportion recall scores.
Gender and Performance

Proportion wayfinding errors were assessed for potential gender differences by conducting a 2 (Gender: Male v. Female) x 2 (Environment: No Boundary v. Boundary) between subjects ANOVA on proportion wayfinding errors. A non-significant main effect of Gender was found, $F(1, 159) = 1.218, p = .271$. There were no differences in proportion wayfinding errors between males and females. Results also showed a significant main effect of Environment, $F(1, 159) = 18.773, p = .000, \eta^2_p = .106$. Significantly more proportion wayfinding errors occurred in the Boundary compared to No Boundary condition. There was no significant interaction. Overall, no evidence for gender differences were found. Data for this analysis are shown in table 14.

A 2 (Gender: Male v. Female) x 2 (Environment: No Boundary v. Boundary) between subjects ANOVA was conducted on proportion landmark recall scores. A significant main effect of Gender was found, $F(1, 159) = 5.397, p = .021, \eta^2_p = .033$. This finding indicated that males exhibited higher proportion recall scores than females. There was also significant main effect of Environment, $F(1, 159) = 7.430, p = .007, \eta^2_p = .045$. Higher proportion landmark recall scores occurred in the No Boundary compared to Boundary condition. A non-significant interaction was found, $F(2, 128) = .454, p = .501, \eta^2_p = .03$. Overall, it seems that males were recalling more landmarks and participants were worse at recalling landmarks when spatial boundaries were present. This analysis differed from the gender analysis of Experiment 1 in that children were included. Hence, the gender effect found in this analysis may be driven by differences primarily among the child participants.

To examine how age, gender, and spatial boundaries interact a 3 (Age Group: Adult v. Older v. Younger) x 2 (Environment: No Boundary v. Boundary) x 2 (Gender: Male v. Female) between subjects ANOVA was conducted for proportion wayfinding errors. This showed a
significant main effect of Age Group, $F(2, 151) = 10.731, p = .000, \eta^2_p = .124$. Hence significant differences in proportion wayfinding errors existed among age groups. A significant main effect of Environment was also found, $F(1, 151) = 34.297, p = .000, \eta^2_p = .185$ where more errors occurred in the Boundary compared to No Boundary condition. There was a non-significant main effect of gender, $F(1, 151) = 1.639, p = .202$, indicating males and females were similar in proportion wayfinding errors. In addition, there was a significant Age Group x Environment interaction, $F(2, 157) = 9.068, p = .000, \eta^2_p = .107$, and Age Group x Environment x Gender interaction, $F(2, 151) = 4.500, p = .013, \eta^2_p = .056$.

Considering that gender was not a component to the two way interaction, it seemed reasonable that gender was moderating the Age Group x Environment interaction. Hence, the three way interaction among Age Group, Environment, and Gender was first examined by evaluating the two way interaction for each gender. A 3 x 2 between subjects ANOVA was conducted for proportion wayfinding errors for males and females separately. For males, there were significant main effects for both Age Group, $F(2, 75) = 6.252, p = .003, \eta^2_p = .143$, and Environment, $F(1, 75) = 12.248, p = .001, \eta^2_p = .140$. However, there was no significant interaction, $F(2, 151) = 1.810, p = .171, \eta^2_p = .046$. For females, there were significant main effects for Age Group, $F(2, 76) = 5.771, p = .005, \eta^2_p = .132$, and Environment, $F(1, 76) = 22.017, p = .000, \eta^2_p = .225$. Importantly, unlike for the males, the Age Group x Environment interaction was significant, $F(2, 76) = 10.339, p = .000, \eta^2_p = .214$. Thus, the two way interaction was absent in males, but present for females. Post hoc tests for the Age Group x Environment interaction for females showed significant differences between the environment conditions for younger female children, $t(18) = 2.326, p = .032$. This was also true for older female children, $t(18) = 3.511, p = .003$, but not the adult females, $p > .05$. These effects suggest
that female children, both younger and older, were making more errors in the Boundary compared to No Boundary condition.

Table 14.

*Means and Standard Deviations for proportion wayfinding errors for males and females in each environment condition.*

<table>
<thead>
<tr>
<th></th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Boundary</td>
<td>.3211 (.1777)</td>
<td>.2909 (.2069)</td>
</tr>
<tr>
<td>Boundary</td>
<td>.4670 (.2630)</td>
<td>.4257 (.1465)</td>
</tr>
</tbody>
</table>
GENERAL DISCUSSION

The current dissertation integrated concepts from multiple areas of research to create a new approach to understanding developmental differences in wayfinding and fundamental aspects of cognition. The two experiments were designed to address several hypotheses. First, it was predicted that differences in wayfinding and landmark recall would emerge among environments with and without spatial boundaries. Second, I expected that developmental differences would be observed for these effects. Specifically, younger children were expected to show a larger effect of spatial boundaries during wayfinding. Third, it was hypothesized that spatial boundaries would impact memory for landmarks located at intersections more than landmarks located in the middle of hallways. Finally, a significant association among VM, VSWM, and EF with performance in the route learning task was predicted. Although there are several complexities in the results of this research, general support was found for many predictions.

Adult participants in Experiment 1 were relatively unaffected by the presence of physical boundaries during wayfinding. In the Boundary and No Boundary conditions there was a near identical number of wayfinding errors and recalled landmarks. Hence, the hypotheses for a spatial boundary effect in adult performance was not supported in Experiment 1. An equally surprising finding in the first experiment was that neither of the visual or verbal memory measures was related to better wayfinding performance and landmark recall. Previous research has consistently found relationships among these abilities and wayfinding (Hund, 2016; Purser et
Moreover, these prior investigations used a wayfinding task that was considerably shorter than the one employed in the current investigation. It seems intuitive to expect that with a more complex wayfinding route, visual and verbal processing would become more important to successful wayfinding performance. However, there was no relationship between wayfinding error, VM, and VSWM.

Although adult differences were not observed in Experiment 1, developmental differences emerged in Experiment 2. The hypothesis that children would be substantially more impacted by spatial boundaries than adults was well supported. Children exhibited a higher proportion of wayfinding errors and a higher proportion of recall errors in the Boundary relative to the No Boundary conditions. This was true for both younger and older children.

The developmental difference for the effect of spatial boundaries may be due to reduced cognitive capacity in children relative to adults. More specifically, verbal memory and VSWM were correlated with wayfinding errors in the Boundary condition. In addition, multiple regression showed that verbal memory was predictive of wayfinding errors in this condition. Considering the significant correlations among age, VSWM, and VM, children may have been worse at dealing with spatial boundaries due to an immaturity in the areas of the brain associated with VSWM and VW. For example, Broca’s area and other areas of the frontal lobe (i.e. PFC, DLPFC), are not as developed in children relative to adults (Beveridge et al., 2014; Brown et al., 2005; Kwon et al., 2002; Holland et al., 2001). While the VM task likely required input from some of these brain regions, the task measured verbal memory over time (i.e. long term memory; episodic memory). Consequently, activation of the hippocampus may have accompanied this task (Fernandez et al., 1998). Very early on, the basic components and function of the hippocampus are developed and continue to mature throughout middle childhood (6-11 years).
Ghetti et al., 2013; Gogtay et al., 2006). The predictive relationship of VM with wayfinding may be due to the word learning task and wayfinding task incorporating overlapping areas of the brain that are both improving with increasing age.

Why was VM and VSWM not correlated to performance in adults? It could be that in adults, EF is more important for dealing with spatial boundaries than VW and VSWM. As previously reviewed, EF was found to mediate the relationship of verbal and visual memory to wayfinding (Purser et al., 2012). Comparatively, children do not have the same EF skills as adults (Zelazo et al., 2004; Bedard, 2002), which might be why they seem to rely on VM and VSWM in the Boundary condition. However, spatial boundaries may not have an effect on adults by virtue of their superior executive function skill. Indeed, the advanced cognitive skills of adults could also account for the null effect for recall among hallway and intersection landmarks. Unfortunately, given that our EF data was rather limited and could not be used, I was unable to evaluate this possibility.

What, exactly, is the spatial boundary effect and how might it operate during wayfinding? Location updating is a process an individual uses to reappraise their current understanding of their location after making a spatial shift (Radvansky & Zacks, 2017; Radvansky et al., 2011). To complete this “update”, an individual must attend to, encode, process, and store a host of new visual information. In the wayfinding task, landmarks were always located adjacent and prior to doors. Hence, time and physical space is introduced during the acquisition of the landmark-direction associations that gives landmarks their navigational importance. It is likely that while the directional component to the association is being encoded, the location updating process introduces competition for working memory capacity as individuals make a spatial shift (i.e. walk through a doorway). This competition due to location updating could have inhibited
learning navigational items and associations in a manner analogous to retroactive interference. Decay-rehearsal models of working memory suggest that bursts of distracting stimuli intermixed between target items in a serial order of to-be-remembered information can disrupt memory for items presented before the onset of distracting stimuli. When distracting items are presented, individuals shift from encoding and rehearsing target items to processing the distracting information. While distractors are encoded, decay for stored target items occurs over time (Farrell et al., 2016; Lewandowsky et al., 2010). A version of this form of disruption in cognitive processing could explain the spatial boundary effect found in the current research. This notion is further supported by the finding that children recalled more hallway landmarks, and that fewer landmarks were recalled in the Boundary condition. Cognitive competition introduced by the location updating process may have a more pronounced effect for intersection landmarks, given there is more information to be processed at these locations. Unlike intersection landmarks, there is no directional information to be encoded at hallway landmarks, which may reduce the interference effect.

This explanation implies that information experienced after doorways should be better encoded relative to that experienced prior to crossing them. Later studies could strategically place landmarks on either side of a doorway and compare memory for each location. Better recall for landmarks immediately after, compared to before, a doorway would support the notion that location updating causes a form of retroactive interference for previously experienced items.

**Gender and Performance**

Experiment 1 provided evidence suggesting males were more disrupted by the presence of spatial boundaries compared to females. It is reasonable to suspect that the spatial boundary effect in this research may interfere to a greater extent with spatial, than verbal processing. Males
have been found to rely more on visual spatial processes (Choi & Silverman, 2003; Saucier et al., 2002). Consequently, if males were relying on a spatial skillset that was likely compromised by the presence of spatial boundaries, they may have been more susceptible to the spatial boundaries effect. However, when data from children were included in the analysis in the cross study comparison, there was no gender difference. It may be that gender differences develop with age as males grow to increasingly rely on spatial abilities for wayfinding. While this is certainly a possibility, given power limitations this research is unable to further address this notion.

**Development and Wayfinding**

Multiple aspects of the environment have been found to impact children’s wayfinding ability (Lingwood et al., 2015; Jansen-Osmann, 2007). It could be that spatial boundaries are an additional environmental structure that contributes to children’s relative weakness for wayfinding. Spatial boundaries in the current research took the form of doorways. However, these are not the only features of an environment that can be treated as spatial boundaries.

Intersections within an environment can be perceived as a form of implicit spatial boundary. Sturz and Bodily (2016) had participants make distance judgements from their location to a colored wall on the other side of a room. Space between the individual and the colored wall could contain one, two, or no intersections. Even though the distance from the participant’s location and the colored wall remained the same across these conditions, participants overestimated distance judgments when there were 2 intersections present. Distances between objects that are remembered in the same spatial region tend to be underestimated, while distances between remembered objects that occupy different regions is over estimated (Sturz & Bodily, 2016; McNamara, 1986). In Sturz and Bodily (2016), the over estimation of distance when intersections were present was used to infer that participants were treating the intersections
as a form of illusory boundary. Spatial boundaries had a greater impact on children’s wayfinding ability relative to adults in the current research. Provided that spatial boundaries can be illusory and not just physical barriers, it is likely that children commonly experience boundaries and this disrupts their ability to navigate.

**Theoretical Implications**

Radvansky et al. (2011) explain that event segmentation processes in episodic memory create competition at retrieval that leads to memory distortion effects. More specifically, objects in Radvansky’s experiments are carried from room to room. Hence, each item is associated with two locations and introduces competition when object information is retrieved. In the current wayfinding task, this does not occur; landmarks were not carried across doorways. Consequently, the retrieval interference explanation does not apply to my results. Nevertheless, I believe that event segmentation is occurring in the current task. Radvansky (2011) describes that experiencing a spatial shift leads to location updating and produces event segmentation. The spatial boundary effect in the present research is likely due to the location updating process shifting cognitive resources away from encoding landmarks to processing new visual information from a new location. Provided that location updating occurs, event segmentation should follow. This suggests that, although distinct from prior work on spatial boundary effects, event segmentation is very likely happening in the current wayfinding task.

The notion that event segmentation takes place in the current research has important implications for fundamental theories of survey learning and the formation of cognitive maps. Survey learning allows the most flexible understanding of one’s environment. Individuals who acquire survey representations of their surroundings understand large scale directional
relationships, distance judgements, and can plan shortcuts (Rizzardo et al., 2013). It is this integrative representation that is often referred to as the cognitive map (Couclelis et al., 1987).

There are several theories of wayfinding and environmental learning that relate to the formation of cognitive maps. Siegel and White (1975) suggest that wayfinding occurs in stages. That is, individuals first learn about landmarks, followed by turns and directional information. Montello’s (1998; see also Ishikawa & Montello, 2005) more recent framework posits that these are encoded continuously, not in a stage-like manner. After this initial spatial learning, integrative processes occur. Montello (2003) describes a “regionalization” process, whereby individuals begin to define cognitive regions within an environment based on previously learned features (i.e. landmarks) and conceptualizations. These regions are then integrated to form a cognitive map of an area. Indeed, several theories explain that spatial memory is nested in hierarchical representations of geographic space (Weiner & Mallot, 2003; McNamara, 1986; Hirtle & Jonides, 1985). For example, the anchor point hypothesis proposed by Couclelis et al. (1987) suggests that nodes, or reference points, anchor unique regions in cognitive maps to organize space. Episodic memory of environmental information is one mechanism for which regions are learned and recalled. Results from the current research show that spatial boundaries potentially serve as a natural event boundary and can separate events in episodic memory (i.e. event segmentation). Accordingly, spatial boundaries could be an important component to the regionalization process. Hence, they could be important in determining the specific cognitive units that form a cognitive map.

Spatial boundaries aid in segmenting environments. These segments can be used as a mechanism to organize environmental space in memory. The capacity to utilize this mechanism, however, may develop with age. It is likely that spatial boundaries disrupt children’s wayfinding.
by overloading their cognitive resources. In addition, children may also lack the wayfinding experience necessary to develop a strategic framework to deal with spatial boundaries and regionalization. Instead of being harmed by the presence of boundaries, adults may have been using the segmented route portions to help them organize the environment in memory to reach the destination. Indeed, adults in the Boundary condition were able to navigate the route with similar errors to those in the No Boundary condition. The lack of this strategy, and immaturity in relevant areas of the brain, is what likely left children confused about direction and remembering fewer landmarks in the Boundary condition. This may provide insights to other studies that indicate children typically defer to route, opposed to survey strategies for navigation (Nazareth et al., 2018; Bullens et al., 2010; Lawton & Kallai, 2002). It may be that children are not yet capable of organizing the cognitive units necessary to build a cognitive map.

**Limitations and Future Directions**

Although this research produced significant and interesting findings, several limitations are evident. First, the piloting phase prior to Experiment 2 was intended to create a wayfinding tasks that equated for wayfinding ability among age groups. While this goal was accomplished for comparing adults with children, there was still a noticeable difference between the older children and other two groups. As previously discussed, this group completed the wayfinding task with relative ease. Future studies should consider using a wayfinding task that is intermediate in complexity for testing older children compared to the 20 and 10 turn routes used in this dissertation.

Considering prior research implies that executive function plays an important role in navigation, an additional aim of this research was to evaluate its relationship to wayfinding in the presence of spatial boundaries. Unfortunately, I observed ceiling effects for the EF task used in
the current study. It is likely that participants picked up on an effective strategy to complete the task. More specifically, participants seem to have come to anticipate the tone and delayed all responding until it was clear if a tone would or would not sound. This is most likely the reason for the extremely high success rate in this task. Hence, no conclusions about EF could be made in the current research. The addition of other EF measures may have provided better data to evaluate relationships between EF and the spatial boundaries effect. An observation made from one researcher conducting this work was that individuals in the Boundary condition seemed to be spending far more time navigating compared to those in the No Boundary condition. If there were significant differences in navigation time, this could have provided more insight to the magnitude of the boundaries effect. Participants in the Boundary condition seemed to become very confused after making a wrong turn. Perhaps a measure of time could have been used to indicate how boundaries affected participant’s sense of direction about the environment.

It is reasonable to suspect that spatial boundaries had an impact on individual’s ability to keep track of their direction. Future investigations could include a measure that evaluates momentary disorientation during navigation. Moreover, an additional task embedded within the wayfinding route that requires participants to point to the start of the map could help illuminate how spatial boundaries disorientate wayfinding. An inability to accurately judge the direction they started from could indicate that spatial boundaries disrupt participant’s configural representations of their surroundings.

As previously noted, spatial boundaries may help form the units in memory that can be integrated to form a cognitive map, implying that spatial boundaries would aid wayfinding. For children, however, that is not what the current research showed. Moreover, it is probable that boundaries elicit a momentary disorientation effect. How is it that spatial boundaries could be
both beneficial and detrimental to wayfinding? It is reasonable to suggest that there may be a position effect to how boundaries impact learning and wayfinding. It could be that information specifically located at a boundary, such as that in the current task, is more easily forgotten. However, information experienced before a boundary may still be encoded. Indeed, event segmentation theory suggests that episodic memory is segmented as a form of chunking to facilitate memory (Radvansky & Zacks, 2017). In the Boundary condition, all landmarks were always presented adjacent and prior to a boundary. Therefore, there were no additional landmarks present that were not accompanied by a doorway. Hence, I could not assess whether the memory distortion effects of spatial boundaries were isolated to information experienced just prior to them. Future studies could address this by including landmarks in a map containing spatial boundaries that are located prior to, as well as away from, spatial boundaries. The No Boundary condition of the current study could not address this issue, given no doorways were present at all. It could be that event segmentation as a function of spatial boundaries results in more overall information being learned (i.e. more landmarks remembered between doorways), but also has a negative impact on memory for items near them through retroactive interference related to location updating.

Conclusions

This dissertation was designed to evaluate whether environmental features can have a profound impact on how individuals learn about and interact with their surroundings. Specific goals were to evaluate whether spatial boundaries within an environment can interfere with learning information important for navigation and consequently, can impair wayfinding. In addition, it was predicted that these effects would differentially impact age groups. Overall, the goals of this research were met and provided general support for the main hypotheses.
Experiment 1 showed that the performance of adults is robust against the effects presented by spatial boundaries. In Experiment 2, children were found to be significantly influenced by spatial boundaries such that their ability to recall landmarks and navigate were considerably diminished. Completing the difficult route learning tasks seemed to be related to verbal and visual processing, where verbal memory may have had a more substantial role. Insights from the current research provide a new dialog to how the environment may shape basic cognitive processes, and the complex relationship it may have with the formation of cognitive maps. There is still much research needed to fully understand how spatial boundaries impact navigation and cognition in general.
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APPENDICES

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Appendix A

Sample VSWM stimuli used in Experiment 1 and 2

Display of 3 colored square pairing

Display 1: presented for 250ms

Display 2: remained on screen until a response was made

Note: The second display presents squares with one color change. The correct response to this trial was F (change).

Display of 7 colored square pairing

Display 1: presented for 250ms

Display 2: remained on screen until a response was made

Note: The second display presents squares with one color change. The correct response to this trial was F (change).
Appendix B

Screenshot from the No Boundary route for Experiment 1
Appendix C

Screenshot from the Boundary route for Experiment 1
Edward C. Merrill, Ph.D.
Professor
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Box 870348

Re: IRB # 18-OR-420-R1 “The Impact of Spatial Boundaries on Landmark Memory and Wayfinding: A Developmental Perspective”

Dear Dr. Merrill,

The University of Alabama Institutional Review Board has granted approval for your renewal application. Your renewal application has been given expedited approval according to 45 CFR part 46. You have also been granted the requested waiver of documentation of informed consent. Approval has been given under expedited review category 7 as outlined below:

(7) Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The approval for your application will lapse on October 21, 2020. If your research will continue beyond this date, please submit a continuing review to the IRB as required by University policy before the lapse. Please note, any modifications made in research design, methodology, or procedures must be submitted to and approved by the IRB before implementation. Please submit a final report form when the study is complete.

Please use reproductions of the IRB approved parental permission and child assent form to solicit consent to participate.

Good luck with your research,

Sincerely,