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How do young children and adults use relative distance to scale location?

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HOW DO YOUNG CHILDREN AND ADULTS USE RELATIVE DISTANCE TO SCALE LOCATION?

by

Kara Marie Recker

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Psychology
in the Graduate College of
The University of Iowa

August 2008

Thesis Supervisor: Professor Jodie M. Plumert

ABSTRACT

The goal of this thesis is to understand how children and adults scale distance. My preliminary work has shown that young children can accurately scale distances along a single dimension (i.e., length) even when the magnitude of the scale difference is very large. In these studies, 4- and 5-year-olds and adults first saw a location marked on a narrow mat placed on the floor of one testing space. They then reproduced that location on another narrow mat that was either the same length (i.e., the memory task) or a different length (i.e., the memory + scaling task) placed on the floor of an adjacent testing space. These experiments illustrated that both children and adults had more difficulty scaling up than scaling down (i.e., had more difficulty going from a small to a large mat than from a large to a small mat).

In the present thesis, I used this difference between scaling up and scaling down as a tool to examine the processes underlying the ability to scale distance more generally. I predicted that the difficulty children and adults have scaling up can be attributed to mapping relative distances onto spaces that are too large to be viewed from a single vantage point. Experiment 1 demonstrated that although a visible boundary dividing a large space influenced how children and adults remember locations, scaling up was still more difficult than scaling down. Experiments 2 and 3 examined the influence of absolute size on mapping relative distance. When the absolute size of the test space was reduced, scaling up was no longer more difficult than scaling down. In contrast, when the absolute size was large, both scaling up and scaling down were more difficult, illustrating the importance of absolute size in using relative distance to scale. These findings suggest that when the absolute size of the space is large, children and adults have more difficulty using multiple edges of the space to accurately scale distance. More generally, these experiments underscore how the cognitive system and task structure interact to give rise to the ability to use relative distance to scale.

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Graduate College
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CERTIFICATE OF APPROVAL

PH.D. THESIS

This is to certify that the Ph.D. thesis of

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To Nick, who always stands beside me

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ABSTRACT

The goal of this thesis is to understand how children and adults scale distance. My preliminary work has shown that young children can accurately scale distances along a single dimension (i.e., length) even when the magnitude of the scale difference is very large. In these studies, 4- and 5-year-olds and adults first saw a location marked on a narrow mat placed on the floor of one testing space. They then reproduced that location on another narrow mat that was either the same length (i.e., the memory task) or a different length (i.e., the memory + scaling task) placed on the floor of an adjacent testing space. These experiments illustrated that both children and adults had more difficulty scaling up than scaling down (i.e., had more difficulty going from a small to a large mat than from a large to a small mat).

In the present thesis, I used this difference between scaling up and scaling down as a tool to examine the processes underlying the ability to scale distance more generally. I predicted that the difficulty children and adults have scaling up can be attributed to mapping relative distances onto spaces that are too large to be viewed from a single vantage point. Experiment 1 demonstrated that although a visible boundary dividing a large space influenced how children and adults remember locations, scaling up was still more difficult than scaling down. Experiments 2 and 3 examined the influence of absolute size on mapping relative distance. When the absolute size of the test space was reduced, scaling up was no longer more difficult than scaling down. In contrast, when the absolute size was large, both scaling up and scaling down were more difficult, illustrating the importance of absolute size in using relative distance to scale. These findings suggest that when the absolute size of the space is large, children and adults have more difficulty using multiple edges of the space to accurately scale distance. More generally, these experiments underscore how the cognitive system and task structure interact to give rise to the ability to use relative distance to scale.

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CHAPTER 1: INTRODUCTION

The ability to use symbolic representations is a fundamental aspect of human cognition. Symbolic representations allow people to obtain information about environments in the absence of direct experience (Huttenlocher, Vasilyeva, Newcombe, & Duffy, 2007; Newcombe & Hutterlocher, 2000). In fact, symbolic representations can act as the primary means for acquiring accurate information about distance and direction among objects and locations in large-scale environments (Uttal, 2000; Uttal & Wellman, 1989). For example, a map depicting the layout of a city can help people acquire information about the distance and direction of one landmark (or landmarks) relative to another in the absence of viewing the large-scale space. The scaled information provided on a map can allow people to represent information that is not readily available from isolated experiences in the real world. Although maps and models are commonly used in everyday life, much remains to be learned about the underlying processes contributing to the ability to accurately transform distance across spaces that differ in size. The goal of this thesis is to further the understanding of how children and adults scale distance by examining the factors that influence spatial scaling.

Previous research on children and adults' ability to scale has largely been focused in two directions. First, a large body of work has examined how young children come to understand that a space can be used to represent another space of different size (DeLoache, 1987). For example, do young children understand that a chair in a model room can be used to represent a chair in an actual room? Although objects may differ in size, and possibly differ in shape and color, to use a symbol as a representation to scale, children must recognize that one object represents the other. Second, previous research has examined how children use distance represented on a symbolic space to determine the corresponding distance in a real space (Bluestein & Acredolo, 1979; Liben & Downs, 1989; Presson, 1982). For example, can young children use a distance depicted on a map to find a location in a real environment? If a map depicts a grocery store as being close to a shopping center, then the map can be used to find these locations close to one another in the real world. I will first discuss how children's understanding of symbolic representations influences how they use representations in different size spaces. I will then turn to discussing how young children use relative distance to translate information from one size space to another. This latter issue is the primary concern of this paper as I further investigate the processes underlying how young children and adults scale relative distance.

Understanding Symbolic Representations

In order to use a symbolic representation to act in the world, people must have the basic understanding that a symbol can be used to represent something else. Thus, a prerequisite for symbol use is an understanding of the basic function of symbols. Although adults seem to understand and recognize relational properties among different objects and spaces quite easily, previous research has suggested that young children have difficulty understanding these relational mappings (Blades & Cooke, 2001; DeLoache, 1987, 1989; DeLoache, Kolstad, & Anderson, 1991; Liben & Yekel, 1996; Marzolf, DeLoache, & Kolstad, 1999; Uttal, 1994, 1996).

Standard Model-Room Task

A commonly used technique for examining young children's understanding of spatial symbols is to ask young children to use a model room to find a location in a corresponding real room (DeLoache, 1987). In DeLoache's standard model-room task, 2.5- and 3-year-old children watched an experimenter hide a miniature dog in a small model room (e.g., under the pillow on the couch) and then searched for a large dog in the identical hiding place in a real room. Three-year-olds, but not 2.5-year-olds, were able to search in the correct hiding location on a majority of trials. Thus, only 3-year-old children were able to use information provided in the model room to find objects in the real room.

A basic question these findings raise is why did 2.5-year-olds have difficulty searching in the correct hiding location? One possible reason is that the 2.5-year-olds could not remember the original hiding location. To address this possibility, children were asked to search for the original object in the model room after they searched in the real room. Both 2.5-year-olds and 3-year-olds were able to retrieve the toy in the original hiding location, indicating that the failure of 2.5-year-olds to search in the correct hiding location in the real room was not due to an inability to remember the hiding location in the model room.

A second possible reason for the 2.5-year-olds failure is that they lacked an understanding that a representation can both be a thing in and of itself and also be a representation of something else (DeLoache, 1987, 1989; DeLoache et al., 1991; DeLoache & Marzolf, 1992; Kuhlmeier, 2005; O'Sullivan, Mitchell, & Daehler, 2001). DeLoache and her colleagues call this the "dual representation hypothesis." To directly examine this hypothesis, 2.5-year-olds participated in either a standard model-room task that required children to use the model to symbolically represent the larger room or a non-symbolic model-room task that did not require children to use the model to symbolically represent the larger room (DeLoache, Miller, & Rosengren, 1997). In the non-symbolic task, children watched the experimenter hide an object in a larger room. Children were then told that a "shrinking machine" was going to make the objects in the room smaller. When children were shown the model room, they believed that the room was the same room as before, but had been magically reduced to a smaller size. Children were able to search correctly in the model room because the "shrinking machine" allowed them to treat the task primarily as a memory task that did not require dual representational thought. Thus, young children have little difficulty remembering the location of the hidden object, but have difficulty when a task requires them to form a dual representation of the symbol.

Recently, Troseth, Pickard, & DeLoache (2007) further investigated the type of representational understanding that was necessary to succeed in the model-room task. Specifically, these researchers examined whether understanding the relations between objects in the model room and the larger room (e.g., the chair in the model room is like the chair in the large room) is sufficient for 2.5-year-olds to succeed in the standard model-room task or whether relations between the model room and larger room (e.g., the model room represents the larger room) are necessary. The latter explanation would require children to form a dual representation whereas the former would not. Children were given a matching task that involved the experimenter pointing to an object in the model room and having the child point to the same object in the large room. Thus, by correctly identifying the objects, the children were shown to have understanding of the relations between objects. After the matching task, children completed the standard model-room task. Findings revealed the 2.5-year-olds were able to match objects pointed to in the model room to objects in the large room, but were still unsuccessful at finding the correct hiding location during the standard model-room task. Thus, these findings suggest that children must be able to think of the model as both an object and also a representation of the larger room. Knowing the relations between objects is not adequate to successfully complete the model-room task.

What Factors Influence How Young Children Understand Symbolic Representations?

The ability to understand symbolic representations is not an all-or-none ability that can be linked to a specific age (DeLoache, 2000; Newcombe & Huttenlocher, 2000). Rather, the ability of children to use symbols to represent something else is influenced by several factors. Researchers have examined these factors by modifying the standard model-room task (DeLoache, 2000; DeLoache et al., 1991; DeLoache, Peralta de Mendoza, & Anderson, 1999; Marzolf et al., 1999; Uttal, Schreiber, & DeLoache, 1995).

Specifically, by manipulating features in the model-room task, researchers have examined how physical similarity and concrete symbols influence how children use a model room to represent another room.

Physical Similarity Between a Symbol and a Referent Space

One factor that affects children's ability to understand spatial symbols is the physical similarity between the symbol and the referent (DeLoache et al., 1999; DeLoache et al, 1991; DeLoache, Miller, & Pierroutsakos, 1998; DeLoache & Sharon, 2005; Marzolf & DeLoache, 1994). An example of physical similarity that influences children's understanding of symbolic representations is similarity in size to the referent. DeLoache et al. (1991) examined how 2.5-year-old children performed on the standard model-room task when the size of the large room was reduced to only being twice the size of the model room. Recall that 2.5-year-old children were unsuccessful at searching in the correct hiding location in the original model-room task when the large room was seven times the size of the model room (DeLoache, 1987). In contrast, 2.5-year-olds successfully searched in the large room when the model and the room were more similar in size. In general, these findings are consistent with previous research suggesting that children have less difficulty succeeding on scaling tasks in smaller spaces (Acredolo, 1977; Liben, Moore, & Golbeck, 1982; Siegel, Herman, Allen, & Kirasic, 1979; Uttal, 2000; Vasileya & Huttenlocher, 2004).

However, the question still remains as to why reducing the size of the large room helped young children search in the correct hiding location in the model-room task? One possibility is that decreasing the scale difference between the model and the room increased the physical similarity between the two spaces (i.e., made the spaces look more alike) and hence enabled children to more easily see the relational similarity between the two spaces. Alternatively, the larger space in the original study was more difficult to view from a single vantage point, leading children to have more difficulty noticing the similarities between the model and the room. One way to examine these different perspectives would be to examine searching behavior by using two large-scale spaces that are similar in size (see discussion in DeLoache et al., 1991). If children have difficulty understanding relational correspondence because the large referent space cannot be viewed simultaneously, then children should continue to have difficulty searching in the large room when the scale difference between the spaces is small. This manipulation has yet to be done, and is necessary to further understanding of the processes involved in forming a dual representation.

Another example of physical similarity that affects how young children understand symbols is object similarity. Specifically, when objects in the model room were highly similar in shape, material, and color (i.e., in the standard model-room task), 3-year-olds were able to correctly search in the larger room. In contrast, when objects in the model room were less similar to those in the large room, 3-year-olds were no longer able to search correctly in the large room (DeLoache et al., 1991; Marzolf & DeLoache, 1994). Thus, the ability to use a symbolic representation can be made more difficult by decreasing the physical similarity between the symbol and the referent.

Together, these findings show that the ability to recognize relational correspondence is not an all-or-none ability but rather is dependent on task context. Specifically, physical similarity (i.e., size and object similarity) affects the extent to which young children appear to understand the relationship between two spaces. Although these studies provide important information as to the types of factors that may influence how children use a model to represent a larger room, further work is needed to understand *why* these factors influence young children's ability to treat a scale model as a spatial symbol.

Concrete Properties of Symbols

Another factor that affects young children's understanding of spatial symbols is concreteness. As previously noted, success in the model-room task requires that children understand that a model room is both an object in its own right and also a representation of a larger room. Research has suggested that concrete symbols are more difficult to view as abstract representations (DeLoache, 1987, 1991, 2000; Dow & Pick, 1992). Thus, decreasing the salience of a model as an object in its own right should make it easier to view the model as a symbol used to represent something else. To test this hypothesis, DeLoache and colleagues examined how 2.5-year-old children searched for a hidden object in a large room when the hiding location was shown in a picture rather than a model (DeLoache, 1987, 1991). By using a picture of a model room instead of a real model room, 2.5-year-old children were able to understand and use the picture as a representation of the large room and search correctly in the larger room. Why did the picture help children search correctly in the large room? One possibility is that the picture decreased the concreteness of the model room, allowing children to view the picture as being more symbolic in nature. In contrast, 2.5-year-olds more than likely know that the primary function of a picture is to represent something else (DeLoache & Burns, 1994). Thus, it may be easier for young children to use pictures to find locations in larger environments because they have previous experience using pictures as representations.

To further support the hypothesis that decreasing the salience of a symbol as an object in itself helps young children use a symbol as a representation, researchers decreased the physical salience of the model room in the standard model-room task by placing it behind a window so that children were unable to touch the model (DeLoache, 2000). When children were never given the opportunity to have physical contact with the model, 2.5-year-olds searched at the correct hiding location in the larger room. These findings provide further support that decreasing the salience of a representation as a concrete object can help children understand that symbols can be used to represent something else.

If decreasing the salience of a symbol helps children use a symbol as a representation, then increasing the salience of a symbol should make it more difficult for children to use the symbol as a representation. To test this hypothesis, 3-year-old children (who correctly search in the standard model-room task) were encouraged to play with a model room for five to ten minutes prior to participating in the standard model-room task (DeLoache, 2000). This initial experience with the model room was designed to increase the concreteness of the model's features, and hence make it more difficult for children to view it as a symbol for something else. Three-year-olds searched less often in the correct hiding location when they were allowed to play with the model at the beginning of the experiment than when they were given no initial experience with the model. These findings suggest that playing with the model room increased the salience of the model room as an object in itself, decreasing the ability for children to use the space as a symbol to represent the large room.

These findings illustrate the difficulty that young children can have understanding that a symbol can be used to represent something else. In particular, this ability becomes more difficult when concrete symbols are used as representations. Similar ideas have been applied to explain why young children have difficulty using concrete manipulatives to solve math problems (DeLoache, Uttal, & Pierroutsakos, 1998; Uttal, Liu, & DeLoache, 2006; Uttal, Scudder, & DeLoache, 1997).

Conclusions

Together, this line of research highlights the difficulty that young children have understanding that a symbol can be both an object and a representation for something else. Importantly, the development of this understanding is not an all-or-none process, but rather is dependent on many features of the task. For example, increasing the physical similarity (i.e., size or object similarity) between a symbol and its referent helps young children recognize the relation between the symbol and the referent space. In addition, decreasing the concreteness of the symbol (e.g., using a picture rather than a model or using a model that could not be manipulated) helps young children understand the relationship between the symbol and the room. Importantly, understanding symbolic representations provides children with the basic knowledge needed to use symbols to scale information in more complex tasks. For example, children must understand the function of symbols before they can begin to use symbols to search for hidden objects among identical hiding locations (Blades & Cooke, 1994), and translate metric information from one space to another.

Using Symbolic Representations to Scale Distance

Using a distance represented on a symbolic space to determine the corresponding distance in a real space is helpful for distinguishing among identical locations. For example, a map depicting the type of food served at restaurants located downtown may use the symbol of a star to note all restaurants that serve Italian food. To distinguish between these Italian restaurants (all marked with the same symbol), one can use distance information provided on the map to determine how far each restaurant is from one's current location. In addition, the ability to use symbolic representations to scale distance becomes an important task when locations are not directly adjacent to landmarks. Thus, when landmarks cannot be used to perceptually ground where something is located, reliance on relative distance among multiple locations is necessary. In the sections below, I review evidence from animal and human studies on scaling distance.

A Special Case: Scaling Distance Using the "Middle" Relation

Over the last few decades, several studies have examined how various animal species code distance when searching in the center of an array of landmarks. Of particular interest is whether particular species rely on relative distance or absolute distance to find a location when the distance between landmarks is expanded (Gray & Spetch, 2006; MacDonald, Spetch, Kelly, & Cheng, 2004; Spetch, Cheng, MacDonald, 1996; Spetch, Cheng, MacDonald, Linkenhoker, Kelly, & Doerkson, 1997, Spetch & Parent, 2006; Sutton, Olthof, & Roberts, 2000; Uttal, Sandstrom, & Newcombe, 2006). For example, Collett, Cartwright, and Smith (1986) trained gerbils to search for a sunflower seed hidden between two landmarks a fixed distance apart. During training, the landmarks and hiding locations were moved around the task space so that animals could not use cues other than the landmarks to find the hidden seed. At test, the landmarks were expanded so that the distance between the landmarks was doubled. When gerbils searched for the seed, they searched a distance from each landmark that corresponded to the absolute distance from each landmark during training. The fact that the gerbils did not search in the middle of the expanded array but instead relied on absolute distance from each individual landmark indicates that they did not code the relative distance between the two landmarks.

To what extent do young children preserve relative distance when searching in the middle of an array? In one study, children between the ages of five and nine years were shown hiding locations arranged in a 5 x 5 matrix (MacDonald et al., 2004). During learning, four landmarks surrounded one hiding location, and children were to search in this middle location. As with the gerbils, the landmarks moved throughout learning (but the distance between landmarks remained fixed), forcing children to use the landmarks when searching. When the distance between landmarks was expanded, even 9-year-olds had difficulty using relative distance to search in the middle of the array of landmarks. In fact, children often searched in locations outside of the array, indicating that they did not preserve relative distance or direction information when the distance between landmarks was expanded.

One difference between this study and the gerbil study previously discussed (Collett et al., 1986) is that the gerbil study involved coding distance relative to two rather than four landmarks. Can young children preserve relative distance when coding locations relative to two landmarks? Uttal et al. (2006) examined this issue by having 4- and 5-year-old children search for a hidden toy between two landmarks. When the distance between the landmarks was doubled, children continued to search in the middle of the landmark array. Thus, children were able to preserve relative distance and search in the correct location, suggesting that the ability to code relative distance may develop earlier than previous research has suggested. In addition, when children were presented with a single landmark, eliminating the need to use relative distance to code location, they searched for the hidden toy at an absolute distance from the landmark. This illustrates that young children have the ability to flexibly shift between relative and absolute coding when necessary.

Recently, Spetch and Parent (2006) further examined how young children use relational strategies to code distance between two landmarks. Three-, 4-, and 5-year-old children were shown a linear array of 15 identical boxes. During learning, two small toys were placed on two boxes with three boxes in between. A sticker was hidden in the middle box relative to the two toys. After children learned to search in the middle, the distance between the toys was expanded with five boxes in between. If children used relative distance to code the location, they should search in the middle box. All 5-year-old boys learned to search in the middle box during learning. In contrast, over half of the children in the other age groups never learned to use the toys to search in the middle box. For children who learned to search in the middle during learning, a majority of them searched in the middle box after the distance between toys was expanded. Again, most of these children were 5-year-old boys. These findings illustrate that the ability to use relative distance to scale a middle relation develops in the preschool years, although the ability is not as consistent as has been seen in adults.

Why can humans (especially adults) preserve relative distance of a middle relation whereas other species seem to rely solely on absolute distance? One possibility is that humans readily extract an abstract relational rule that identifies a goal relative to two or more landmarks (MacDonald et al, 2004; Spetch et al., 1997; Spetch & Parent, 2006). In contrast, other species may focus on a single landmark when coding distance relative to something else. This especially may be the case when training involves searching between landmarks at a fixed distance. When the distance between landmarks remains constant, either absolute or relative distance can be used to accurately find the middle location. Even when coding relative distance is not necessary, human adults may continue to reliably code relative distance whereas other species may solely code absolute distance. In contrast, when distance between landmarks is varied from trial to trial, one must use relative distance to accurately find the middle location throughout learning. In these cases when relative distance is necessary, other species can learn to rely on relative distance to find a hidden location (Jones, Antoniadis, Shettleworth, & Kamil, 2002; Kamil & Jones, 1997, 2000; Spetch, Rust, Kamil, & Jones, 2003). For example, when the distance between two objects varies between 20 cm. and 100 cm. during training, pigeons and nutcrackers were required to use relative distance rather than absolute distance to continue to search correctly in the middle of each array (Jones et al., 2002; Kamil & Jones, 1997, 2000; Spetch et al., 2003). In this procedure, when the landmarks are then expanded to be greater than 100 cm. apart, nutcrackers and pigeons accurately search in the middle of expanded array at test.

Together, these findings suggest that humans (especially adults) appear to spontaneously code relative distance (and absolute distance) in tasks that may not require coding of this information. Other species, on the other hand, may only code and use relative distance when trained to do so. The ability for humans to attend to relative distances becomes especially important in tasks that require scale transformations. For example, reading a map requires one to preserve relative distance and not absolute distance. Differences in how children and adults spontaneously code relative distance when searching in the middle of an array of two or more landmarks suggests that young children may have more difficulty using relative distance in more complex tasks (e.g., using a map to scale distance).

Scaling Distance Along a Single Dimension

Although young children can preserve relative distance to find a location in the middle of an array, do they also preserve relative distance involving locations that are not in the middle of an array? Huttenlocher, Newcombe, & Vasilyeva (1999) examined how children scale distance in a simple task that required scaling distance along a single dimension. Children were shown the location of a dot on a small rectangular map (8 in. long x 2 in. wide) and asked to use the map to point to the corresponding location in a long, rectangular sandbox (60 in. long x 15 in. wide). When comparing response locations (i.e., where participants pointed) to the corresponding true locations, 4-year-old children showed a mean error score of 3.5 in., indicating that they were quite accurate in their responses. In addition, children preserved the order of their placements. For example, the leftmost true location was reproduced in the leftmost position relative to other positions at test and the rightmost true location was reproduced in the rightmost position relative to other positions at test. These researchers conclude that together, the small magnitude of error and the correct ordering of locations demonstrate that young children can accurately use a map to scale distance along a single dimension.

Recently, Huttenlocher and colleagues further examined children’s ability to scale distance along a single dimension by comparing tasks that required children to either search for a hidden object or place an object in its correct location (Huttenlocher et al., 2007). Three-, 3.5-, and 4-year-old children were shown a model of a sandbox (8 in. long x 2 in. wide) with a dot marking a location. Children were instructed to use the model to either search or place an object in the corresponding location in the large sandbox (60 in.

long x 15 in. wide). The results of the searching task were similar to previous work suggesting that by 4 years of age, children can accurately scale distance to find a hidden location (see Huttenlocher et al., 1999). However, the placement task revealed that children as young as 3.5 years of age can accurately scale distance along a single dimension when placing objects on a larger size space. Thus, children were able to use relative distance to scale six months earlier in the placement task than in the search task. These results suggest that the ability to scale distance along a single dimension develops early in childhood. However, young children's ability to scale distance in even simple scaling tasks is influenced by task variations.

Scaling Distance Along Multiple Dimensions

One question is whether the ability to use relative distance is limited to scaling along a single dimension or whether young children can scale distance along multiple dimensions in more complex tasks. Recently, Vasileva and Huttenlocher (2004) examined how children scale distance along two dimensions when varying amounts of a scale translation is required. Specifically, 4- and 5-year-old children were shown a target location marked on a small map. Children then used the map to reproduce the target location on a small (30 in. wide by 42 in. high) or large (96 in. wide x 134.4 in. high) rug placed on the floor. Four-year-old children reproduced locations significantly farther from their correct locations than did 5-year-old children. In addition, both 4- and 5-year-old children exhibited significantly more error when scaling from the map to the large space than when scaling from the map to the small space. Thus, scaling distance was more difficult when the two spaces were more different in size. To further support this hypothesis, a second experiment was conducted to examine how children reproduced locations in the absence of a scale translation. Children learned the location of an object on the small rug and reproduced the location on the small rug or learned the location of an object on the large rug and reproduced the location on the large rug. The same rugs used in the previous study were used in this study so that comparisons could be made across studies. The findings revealed that reproducing locations on the large rug lead to significantly more error than when reproducing locations on the small rug in both the scaling and non-scaling tasks. In addition, the increase in error on the large rug was greater in the scaling than in the non-scaling task. Thus, children's difficulty in scaling distance on the large rug was not due to the inability to remember locations on the large rug. Rather, these researchers conclude that the difficulty that children have in scaling distance depends on the magnitude of scale difference between the two spaces. When the scale difference between the two spaces is large, using relative distance to scale locations becomes more difficult.

Why is scaling distance more difficult when spaces are more different in size? Siegel et al. (1979) examined whether mapping relative distances onto larger spaces is generally more difficult than mapping relative distance onto smaller spaces. Children reproduced layouts of a town by either learning the layout from a small model and reproducing the layout in a larger room (scaling up from small to large) or learning the layout in a large room and reproducing the layout in a smaller model (scaling down from large to small). In these tasks, children were relatively more accurate when scaling from the large to the small space (scaling down) than when scaling from the small to the large space (scaling up). Again, this finding illustrates the difficulty young children have scaling distance on larger scaled space.

Additional research has indicated that young children have difficulty scaling distance along multiple dimensions, especially when reproducing configurations of multiple locations (Liben & Downs, 1993; Liben et al., 1882; Liben & Yekel, 1996; Uttal, 1994, 1996; Uttal, Gregg, Tan, Chamberlin, & Sines, 2001). Uttal (1996) examined how configurations of objects may influence how children and adults use information about relative distance and direction when transforming information from a small space to larger space. Specifically, preschoolers (4- and 5-year-olds), first graders (6- and 7-

year-olds), and adults were shown a small-scale map depicting a configuration of six objects. After all object locations were memorized, participants were given larger objects one at a time, and asked to place them on the correct location in a large room. Findings revealed that 4- and 5-year-old children formed accurate spatial configurations based on angular information, but were unable to accurately scale configurations using distance information (i.e., configurations were too large or too small). Six- and 7-year-old children scaled configurations significantly more accurately than preschoolers, and adults were significantly more accurate than both age groups. Interestingly, even adults exhibited a marginal level of error in accurately translating distance from the small to the large space. In a similar study, Liben & Yekel (1996) found that 4- and 5-year-old children accurately placed items of furniture in the correct region of their classroom, but were inaccurate in the precise locations of those items. Together, these results suggest that young children are able to preserve the overall shape of a configuration of objects when scaling from a small-scale space to a large-scale space, but have difficulty using distance to accurately scale configurations from one space to another. That is, the objects within the configurations were reconstructed as being closer together or farther apart than they actually were.

To determine whether the demand of having to remember the configurations of the objects from the time they were learned on the map to the time they were reproduced in the large room influenced preschool children’s lack of ability to scale distance, 4- and 5-year-old children reproduced configurations in the absence of a scale translation (Uttal, 1996). That is, children learned locations on a map and reproduced them on an identical sized map or learned locations in a large room and reproduced them in an identical sized room. Findings revealed no significant difference between learning and reproducing locations on the map versus the room. In addition, placements were significantly more accurate in this study than in the other studies that required children to make a scale translation. Thus, the difficulty that 4- and 5-year-olds have at using distance to accurately scale is not due to the inability to remember locations, but rather difficulty with using distance to scale a group of locations.

What Processes Underlie Children's Ability to Scale Distance?

A major question the studies reviewed above raise is what processes underlie the ability to scale distance? A traditional Piagetian perspective would suggest that children must achieve the formal operational skill of proportional reasoning before they can accurately scale distance from one size space to another (Herman & Siegel 1978; Liben & Yekel, 1996; Piaget & Inhelder, 1967). This perspective suggests that scaling distance first requires people to calculate the metric difference between two spaces (e.g., the map is eight times smaller than the real room). Then, people must calculate proportions for individual distances based on the scale difference of the two spaces (e.g., if the map is eight times smaller than the real room, then a distance of 2 in. on the map would correspond to 16 in. in the real room). Not surprisingly, this ability to scale by calculating mathematical proportions does not develop until well into childhood. However, previous findings showing that even 4-year-olds can scale distance suggest that a formal understanding of proportions is not necessary to scale. Rather, children may be relying on some sort of informal proportional reasoning skills (Huttenlocher et al., 1999; Huttenlocher et al., 2007; Spetch & Parent, 2006; Uttal et al., 2006). As suggested in the research examining how different species scale the middle relation, scaling requires visually coding distance relative to at least two landmarks or edges (Uttal et al, 2006). After distance is coded relative to two or more landmarks or edges, this relation must be maintained and accurately mapped onto another space using the corresponding landmarks or edges. For example, children may visually code a location as being *halfway* or in the *middle* of two landmarks in a small space. Children then must maintain this relation and reproduce a location halfway between the two corresponding landmarks in the large space (Huttenlocher et al., 1999). Importantly, this type of coding does not require one to calculate metric proportions. Rather, one must visually code a location relative to two landmarks and then map that visual representation onto another space.

How do children and adults map visual representations on spaces that differ in size? One possibility is that they reproduce visual angles by equalizing the image on the retina with a stored representation of the original environment. This type of equalization strategy has been found to reflect how honeybees return to a food source when the surrounding environment is either expanded or contracted (Cartwright & Collett, 1982). Honeybees have been found to store two-dimensional images of their environments relative to a goal. When landmarks are expanded, honeybees adjust their positioning until the current retinal image matches the stored image of the original array. This process leads honeybees to search for a goal using relative distance. This type of visual angle matching may help children and adults expand or contract distances when scaling from one size space to another. Alternatively, one may mentally transform distances from one size space to another through mental operations. For example, it may be possible to mentally imagine the time it would take to expand a small location on a small size space to a larger size space. The time it takes to mentally expand or contract a distance should be proportional to the amount of scale difference between the spaces (i.e., it should take more time to expand an image from small to large than from small to medium). This type of mental transformation would lead to an estimation of distance and may allow one to accurately map relative distances onto spaces that differ in size.

Conclusions

The ability to use spatial representations to scale distance emerges at a very young age (Huttenlocher et al., 1999; Uttal et al., 2006). Specifically, 4-year-old children are able to scale distance to find a middle location and scale a variety of distances along a single dimension. These findings are important in understanding how children use relative distance to scale because they suggest that processes other than formal proportional reasoning are playing a role in how young children scale distance, although the processes involved in mapping relative distances are largely unknown.

The Present Investigation

The goal of the present investigation is to further understand how children scale distance by systematically examining factors that may influence spatial scaling. The basic procedure involves comparing how children and adults remember distances with how they remember and scale those same distances. Why study how children and adults scale by using a task that requires memory? First, scaling often requires the use of memory. People use maps to find locations, construct diagrams to represent microscopic entities, and draw architectural plans to visualize spaces. As children enter school, they are introduced to drawing and interpreting simple maps and diagrams. These symbolic representations all require the use of memory to systematically transform distances from one size space to another size space. The importance of using memory to scale in everyday life lends support for using a memory task to further understand how children and adults scale distance. In addition, previous research has provided an excellent foundation for understanding the processes underlying memory for location. By directly examining how children and adults remember and scale remembered locations, we can use what we know about the processes underlying memory for location to better understand how children scale distance.

Recent work has shown that both children and adults exhibit systematic bias toward the centers of geometric regions and spatial groups (Huttenlocher, Newcombe, & Sandberg, 1994; Plumert & Hund, 2001; Spencer & Hund, 2002). This systematic bias in memory for location is seen as an important signature of the underlying processes involved in reproducing previously seen locations (Huttenlocher, Hedges, & Duncan, 1991; Plumert, Hund, & Recker, 2007; Spencer, Simmering, Schutte, & Schöner, 2007).

A key question is where this bias comes from. According to the category adjustment model originally proposed by Huttenlocher et al., 1991, retrieval of locations from memory involved the use of both fine-grained and categorical information. When trying to remember a location, people make estimates based on their memory of fine-grained metric information such as distance and direction from an edge. However, because memory for fine-grained information is inexact, people adjust these estimates based on categorical information about the location represented by a prototype located at the center of the spatial region or group. Hence, adjustments based on categorical information lead to systematic distortions toward the centers of spatial categories. According to this model, the magnitude of distortion toward category centers depends on the certainty of the fine-grained, metric information. When memory for fine-grained information is relatively certain, categorical information receives a low weight, resulting in only small distortions toward category centers. Conversely, when memory for fine-grained information is relatively uncertain, categorical information receives a high weight, resulting in large distortions toward category centers. The end result of such systematic bias is that responses are less variable, leading to greater overall accuracy.

More recently, Spencer, Schöner, and colleagues have developed a Dynamic Field Theory (DFT) of spatial memory to account for the kinds of spatial biases described above (Johnson, Spencer & Schöner, 2008; Simmering, Schutte, & Spencer, 2008; Spencer et al., 2007). The DFT is a neural network model that captures how location-related activation in a network of neurons can be sustained from moment-to-moment and drift over short time periods. The model consists of several interconnected layers (i.e., fields). These layers include perceptual, working memory, and long-term memory fields, as well as inhibitory interneurons. The perceptual field forms peaks of activation generated by input from perception of visible reference frames and the current target’s (visible) location. The perceptual field passes activation about both the reference frame and the target location to the working memory field. This moves the working memory field into a state of self-sustained activation whereby peaks of activation can be maintained even when the target is no longer visible. Sustained activation occurs in the model because “neighboring” neurons influence one another through a local excitation/lateral inhibition interaction function. Specifically, an activated neuron will excite neurons that code nearby locations and inhibit neurons that code far away locations. If local excitation is strong and focused, dynamic fields can enter a self-sustaining state in which peaks of activation are maintained in the working memory field even after the perceptual input is removed. The working memory field passes this self-sustained activation on to an associated long-term memory field. This field accumulates traces of activation representing the locations of other previously seen targets, with stronger traces associated with more frequently seen targets. The long-term memory field also passes activation back to the working memory field. Drift over time (i.e., bias) can occur through the interaction of the working memory and long-term memory fields, producing bias toward frequently remembered targets (Spencer & Hund, 2002, 2003). Drift can also occur via the shared layer of inhibitory interneurons. For example, the inhibitory activation produced by a perceptually available reference frame (e.g., an axis or boundary) can “repel” the peak of activation representing the target location in working memory.

The present experiments adopt a new approach to examining early scaling abilities by using a within-subjects design to test how children and adults complete a memory task with and without a scaling component. Four-, and 5-year-old children and adults completed a memory task (e.g., learned a location on a large, narrow mat and reproduced that location on an identical mat) and a memory task involving scaling (e.g., learned a location on a small mat and reproduced that location on a large mat). During learning, children and adults viewed the location of an object along the length of a homogenous mat then attempted to reproduce the location on another homogeneous mat that was either the same or a different size. Differences between these two tasks provide information about how the addition of a scaling component to a memory task affects how young children and adults reproduce distances along a single dimension.

To better understand the processes underlying how children and adults scale distance, I examined whether scaling influenced memory for location. First, I examined whether the ability to scale distance is influenced by the direction of the scale translation. Previous research has suggested that scaling up from a small space to a larger space is more difficult than scaling down from a large space to a smaller space (Siegel et al., 1979). These experiments further explored differences between scaling up and scaling down to determine whether and why one task may be more difficult than the other. The DFT model predicts that spaces of large absolute size will lead to less stability of peaks. The process of scaling remembered locations adds noise to the system, which could lead to more bias when scaling relative distance onto larger than smaller size spaces and could help explain possible differences between scaling up and scale down. I also examined if the ability to scale distance was influenced by the specific locations children and adults were trying to scale. For example, are locations near the edges of a space or near the middle of a space easier to scale than other locations? This issue was examined with respect to both absolute and directional error. Again, the CA and DFT models would predict that locations near the edges of the mats were more perceptually grounded, allowing for more precise memory of the location and less drift away from true locations. Lastly, I examined whether it was more difficult to scale distance when spaces are considerably different in size than when spaces were more similar in size, a problem specific to scaling. Although the main focus of these experiments was to examine how young children (4- and 5-year-olds) use relative distance to scale, adults were also tested for comparison. It was predicted that adults would generally exhibit less error than children, but the patterns of error may differ across the age groups. Together, these studies were designed to lead to a better understanding of the underlying cognitive processes involved in scaling distance.

CHAPTER 2: PRELIMINARY EXPERIMENTS

The goal of these preliminary experiments was to begin to understand *how* children and adults scale distance. Previous research suggests that young children can accurately scale distance along a single dimension (Huttenlocher, et al., 1999; Huttenlocher, et al., 2007). However, the processes underlying this ability are largely unknown. The first step towards understanding the development of spatial scaling involves systematically examining factors that may influence how people use relative distance to scale. These experiments examined the influence of three factors on children and adults' ability to scale distance. First, is the ability to scale distance influenced by the direction of the scale translation? Specifically, previous research has suggested that scaling up from a small space to a larger space might be more difficult than scaling down from a large space to a smaller space (Siegel, et al., 1979). These experiments further explored differences between scaling up and scaling down to determine whether and why one task may be more difficult than the other. Second, is the ability to scale distance influenced by the specific locations children and adults are trying to scale? For example, are locations near the edges of a space easier to scale than those near the middle of a space? This issue was examined with respect to both absolute and directional error. Finally, these studies examined whether age interacted with directionality and location to produce particular patterns of error in scaling estimates. Together, these studies provided a framework for understanding how children and adults use relative distance to scale.

Preliminary Experiment A

As a starting point for addressing the issues outlined above, Experiment A examined how 4- and 5-year-old children and adults scaled distance along a single dimension when the size difference between the two spaces was very large. To determine how scaling affects how children and adults remember locations, participants completed a memory task that involved scaling and a memory task that did not involve scaling. Any difference in performance between the two tasks provides an estimate of the impact of scaling on memory.

Method

Participants

Seventy-two 4- and 5-year-old children and adults participated in this study. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 4 years and 6 months (range = 4 years 4 months to 4 years 10 months), 5 years and 4 months (range = 5 years 2 months to 5 years 6 months), and 19 years and 4 months (range = 18 years 1 months to 19 years 11 months). Children were recruited from a child research participant database maintained by the department of psychology at the University of Iowa. Parents received a letter describing the study followed by a telephone call inviting their child to participate. Ninety-two percent of the children were European American, 4% were Asian American, 2% were Black, and 2% were Hispanic/Latino. Two percent of mothers had completed their high school education or less, 26% had completed some college education, and 72% had a 4-year-college education or beyond. Adults participated to fulfill research credit for an introductory psychology course. Ninety-two percent of adult participants were European American and 8% were Asian American.

Apparatus and Materials

The experiment took place in an 11.5 ft. x 10.5 ft. room. A white canvas curtain surrounded the periphery of the room from floor to ceiling. In addition, the canvas curtain divided the room into two equally sized enclosures (each 11.5 ft. x 5.25 ft.). One enclosure was used during learning and the other enclosure was used to during test (see Figure A1). Extra large (128 in. long x 16 in. wide) and small (8 in. long x 2 in. wide) light-brown, vinyl mats were used as the referent spaces. Each enclosure had a single mat centered on the floor at all times. The size of the mat in each enclosure varied throughout the session and depended on the experimental condition. An “x” marked on the floor of each enclosure was used to show participants where to stand during learning and test. The “x” was approximately 1.75 ft. away from center of each mat. Ten laminated circles with pictures of objects were used to help participants learn the locations: an apple, ball, butterfly, chicken, fish, ladybug, penguin, present, star, and tiger. The present and tiger were used during practice trials, whereas the other eight objects were used during test trials. The diameter of the circles was half the width dimension of each mat. Thus, objects placed on the extra large referent mats were 8 in. in diameter and objects placed on the small referent mats were 1 in. in diameter. With the exception of size, all features of the objects were the same for the extra large and small mats. A measuring tape located on the underside of each mat was used to measure the location of each object during learning and test.

Design and Procedure

All participants were tested individually in the laboratory in a single session. Participants were randomly assigned to one of two conditions: test on extra large mat or test on small mat. The experimental session consisted of memory trials and memory + scaling trials. For the memory trials, the mats in the learning and test enclosures were the same size (both extra large or both small). For the memory + scaling trials, the learning mat was changed for all participants so that the learning mat was a different size than the test mat (small learning mat and extra large test mat or extra large learning mat and small test mat). Importantly, for each participant, the test mat remained the same size throughout the experiment (see Figure A2).

Warm-up

At the beginning of the experiment, the experimenter pulled back the curtain that divided the room, exposing the mats from both enclosures. Both mats were either extra large or small, depending on the experimental condition. The participant then stood at the center line on one side of the room and faced both mats. The experimenter directed the participant's attention to the mats and said, "Can you look at both of these mats and see that they look exactly the same?" The participant was then told that he or she would "see an object on one mat and should try to remember exactly where it goes because you will have to put another object in exactly the same place on the other mat." Two experimenters were present throughout the experiment. One experimenter was with the participants at all times and gave them instructions throughout the session. The other experimenter placed objects in their correct locations during learning and measured participants' placements at test.

Practice Trials

Children and adults completed two practice trials. The first trial was a memory trial and the second trial was a memory + scaling trial. For the children, an additional trial was set up before each practice trial so that the experimenter could demonstrate to the child how to complete each task. Adults were not given the demonstration trials. Practice locations were randomly selected out of seven possible locations (see Table A1). The practice locations consisted of positions halfway between adjacent test locations.

Practice trials began when the experimenter closed the curtain dividing the room and had participants stand on the "x" marked on the floor and look at the object that was on the learning mat. The object was either a picture of a present or a tiger. The order that the objects were presented was randomized. The memory and memory + scaling trials used different pictures. For the children, the demonstration trial and corresponding practice trial used the same picture. Participants were told to "look at the object and remember exactly where it goes." The experimenter then showed participants another object that was identical to that object and explained to them that they had to put the new object in the same place on the other mat as the current object was on the current mat.

The experimenter then walked participants over to the test enclosure and had them stand on the “x.” For children, the experimenter then placed the object in the correct location, demonstrating to children how to complete the task. Children then walked over to the learning enclosure where the object was located in a new location on the learning mat. Children were then told that it was their turn, and that they should try to remember the location so that they can put the identical object in the same place on the other mat. Children then walked over to the test enclosure and stood on the “x.” They were then allowed to step off of the “x” and replace the object in the correct location. If placements were not close to their actual locations, they were corrected. Adults completed a single memory practice trial and did not have the experimenter demonstrate how to complete the task.

Before the memory + scaling practice trials began, the learning mat was changed, and the experimenter pulled back the curtain that divided the room to expose the mats from both enclosures. The participant then stood at the center line on one side of the room and faced both mats. The experimenter highlighted that the mats were now different sizes and told participants that they would see an object on one mat and should try to remember exactly where it goes because they will have to put another object (that is different in size) in exactly the same place on the other mat. The curtain was closed, and participants were told to stand on the “x” and look at the object that was on the learning mat so that they could “remember exactly where it goes.” The experimenter then showed the participant another object that was identical to that object except in size, and explained to them that they had to put the new object in the same place on the other mat as the current object was on the current mat. The experimenter then walked the participant over to the other enclosure and had them stand on the “x.” Again, for the child participants, the experimenter placed the object in the correct location, demonstrating how to complete the task. Children then walked over to the learning enclosure where the object was located in a new location on the learning mat. The child was told to remember the location and walk over to the other side and put the other object in the same place on the other mat. If placements were not close to their actual locations, they were corrected. Adults completed a single memory + scaling practice trial and the experimenter did not demonstrate how to complete the task.

Test Trials

Following practice trials, participants completed a total of 16 test trials (two blocks of 8 trials). Each block of trials consisted of eight locations (see Table A1). Location 1 corresponded to the leftmost location and location 8 corresponded to the rightmost location (see Figure A3). For one block of trials, participants completed the memory task and for the other block of trials, they completed the memory + scaling task. To allow for comparison between the tasks, true test locations were the same for each block of trials. The order of task was counterbalanced and order of locations were randomized for each participant.

Coding

Participants' placements were measured to the nearest ¼-inch using the ruler attached to the underside of each mat. Occasionally, participants preserved the relative distance of an object's location, but incorrectly placed the object relative to the appropriate edge (i.e., exhibited mirror reversals). I corrected for these errors by calculating when placement values were within our criterion for a "true" reversal error. Our criterion included three types of reversal errors: far between reversals, far within reversals, and double reversals. Far between reversals included locations that were on the wrong side of the mat but were a correct distance from the corresponding edge of the mat. A correct distance was determined to be within the range of being half the distance from the corresponding true location to the adjacent location on either side of the placement. For example, if a participant placed the leftmost location on the rightmost side of the mat, I considered this to be a between reversal if it was within half the distance from the true rightmost location to the next rightmost location. These between reversals included reversals between the outermost locations (one and eight), second outermost locations (two and seven), and second innermost locations (three and six). Reversals between the innermost locations (four and five) were not included because these locations were adjacent to one another, making it difficult to distinguish between a mirror reversal and an error in placement. Far within reversals were placements that were on the correct side of the mat, but had the outermost location substituted for the innermost location (e.g., locations 1 and 4) and vice -versa. Again, I corrected for these placements if they were within the range of being half the distance from the corresponding true location to the adjacent location on either side of the placed location. Adjacent locations (i.e., two and three, six and seven) were not included as reversals. Double reversals were those reversals that included a between and a within reversal. For example, these reversals included placements that had the left outermost target in the right innermost location (e.g., locations 1 and 5), reflecting judgments using relative distance from the midline rather than the left outermost edge. As shown in Table A2, the number of reversals differed significantly across age group, F (2, 66) = 10.61, $p < .001$. Four- and 5-year-olds made significantly more reversal errors than adults.

After all reversals were corrected, I classified placement values that were larger than the mean ± 3*SD*s (rounded to the nearest .25 in.) for each age group, location, and condition as outliers and omitted these values from all analyses. I omitted 3.13% of locations for 4-year-olds (6 out of 192), 2.60% for 5-year-olds (5 out of 192), and 1.04% for adults (2 out of 192). In addition, I omitted one location for a 4-year-old because an experimenter error occurred during the experimental session.

Measures

Absolute Error Scores

Participants received an absolute error score for each test trial, reflecting the degree to which they placed objects near their actual locations on the test mat. These scores were calculated by determining the absolute distance between each remembered location and the corresponding actual location for each trial. Difference scores for corresponding locations on the two halves of the mat were then averaged, giving participants four scores for each task (memory and memory + scaling). That is, I averaged the two outermost (one and eight), second outermost (two and seven), second innermost (three and six), and innermost (four and five) locations for each task.

Directional Error Scores

Participants received a directional error score for each test trial, reflecting the direction in which they placed objects from the actual locations. These scores were calculated by determining the signed distance between each remembered location and the corresponding actual location for each trial. Negative directional error scores indicate outward bias away from the midline. In contrast, positive directional error scores indicate inward bias toward the midline. To examine directional errors near the edges and midline of the mats, I calculated two directional error scores for each task by averaging the two outermost locations (one and eight) and the two innermost locations (four and five) for each participant.

Results

Absolute Error Scores

Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in error across the memory and memory + scaling tasks for each condition (test on extra large mat and test on small mat), absolute error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, two/seven, three/six, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors. Direct comparison between the test on small mat condition and test on extra large condition was not made because the true test locations as well as amount of error were different for each condition. For example, the leftmost location was 1.875 in. from the left edge of the small test mat and 15 in. from the left edge of the extra large test mat. Placing an object 1.875 in. on the small test mat is not necessarily equivalent to placing an object 15 in. on the extra large mat, requiring separate analyses to be performed for each condition. In addition, an error of ¼-in. on the small mat is not necessarily equivalent to an error of 2-in. on the extra large mat, making the direct comparison between error scores on the small and extra large mats difficult.

Test on small mat

For the test on small mat condition, this analysis yielded significant main effects of age, F (2, 33) = 40.56, $p < .0001$, and location, F (3, 99) = 14.78, $p < .0001$. Both 4-year-olds (M = 1.32 in., SD = 1.00) and 5-year-olds (M = 1.37 in., SD = .90) exhibited significantly greater overall error than adults (M = .46 in., SD = .31). Moreover, participants placed objects significantly more accurately for locations one/eight than for all other sets of locations. Placements on locations two/seven were significantly more accurate than placements on locations three/six and four/five. The absolute mean error scores were .58 in. (SD = .39), 1.04 in. (SD = .89), 1.28 in. (SD = .91), and 1.29 in. (SD = 1.06) for locations one/eight, two/seven, three/six, and four/five, respectively. There was no main effect of task, F (1, 33) = 1.45, *ns*, indicating that children and adults reproduced locations similarly on the memory (M = 1.01 in., SD = .90) and the memory + scaling (M = 1.09 in., SD = .89) tasks.

There was also a significant Age x Location interaction, *F* (6, 99) = 4.40, $p <$ .001. Simple effects tests revealed a significant effect of location for the 4- and 5-year-olds, *F*s (3, 33) ≥ 7.91, *p*s < .001, but not for the adults, *F* (3, 33) = 1.05, *ns* (see Figure A4). Follow-up tests for the 4-year-olds indicated that placements were significantly more accurate for locations one/eight and two/seven than locations three/six or four/five. Similarly, follow-up tests for the 5-year-olds showed that placements were significantly more accurate for locations one/eight than for all other sets of locations. Thus, the accuracy of children's placements varied depending on where the locations were on each mat, whereas adults exhibited similar levels of accuracy across all locations. Children exhibited significantly less error on locations near the edges of the mats (one/eight) than locations farther from the edges of the mats (four/five).

Test on extra large mat

For the test on extra large mat condition, the overall analysis yielded significant main effects of age, *F* (2, 33) = 33.11, $p < .0001$, location, *F* (3, 99) = 14.43, $p < .0001$, and task, *F* (1, 33) = 13.48, $p < .001$. As with the small mat condition, both 4-year-olds (*M* = 11.26 in., *SD* = 8.96) and 5-year-olds (*M* = 9.08 in., *SD* = 5.71) exhibited significantly greater overall error than adults (*M* = 3.77 in., *SD* = 3.09). In addition, 4-year-olds were significantly less accurate than 5-year-olds. Moreover, participants placed objects significantly more accurately on locations one/eight than on all other sets of locations. The absolute mean error scores were 3.78 in. (*SD* = 2.59), 9.89 in. (*SD* = 9.36), 10.18 in. (*SD* = 6.73), and 8.29 in. (*SD* = 6.16) for locations one/eight, two/seven, three/six, and four/five, respectively. Finally, in contrast to performance with the small test mat, both children and adults had more difficulty reproducing locations of objects in the memory + scaling task (*M* = 8.96 in., *SD* = 7.33) than in the memory task (*M* = 7.11 in., *SD* = 6.77). Thus, when participants had to scale up (going from the small mat to the extra large test mat) they had more difficulty than when scaling down (going from the extra large mat to the small test mat).

There was also a significant Age x Location interaction, *F* (6, 99) = 2.81, $p < .05$. Simple effects tests revealed a significant effect of location for the 4-year-olds, *F* (3, 33) > 5.24, $p < .01$, 5-year-olds, *F* (3, 33) > 15.03, $p < .0001$, and adults, *F* (3, 33) > 3.22, $p < .05$ (see Figure A5). However, the pattern of differences among locations differed slightly by age. Follow-up tests for the 4-year-olds showed that placements were significantly more accurate for locations one/eight than for all other sets of locations. Likewise, follow-up tests for the 5-year-olds indicated that placements were significantly more accurate for locations one/eight than for all other sets of locations. In addition, locations four/five were significantly more accurate than locations three/six. Finally, follow-up tests for adults revealed that placements were more accurate for locations one/eight than for locations three/six and four/five. Thus, all ages exhibited less error on locations closest to the edges of the mats than on other locations.

Directional Error Scores

To test for differences in directional error between locations near the midline (four/five) and locations far from the midline (one/eight) for each condition and task, mean directional error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat

For the test on small mat condition, this analysis yielded no significant main effect of location, *F* (1, 33) = 1.61, *ns*. In addition, there was no significant Age x Loc interaction, *F* (2, 33) = .15, *ns*, indicating that the pattern of directional bias for outer and inner locations did not differ by age group (see Figure A6).

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A6). No difference in error would be expected if participants neither biased locations inward or outward. Positive scores would reflect bias toward the midline of the task space and negative scores would reflect bias away from the midline of the task space. Four-year-olds exhibited significant inward bias for locations one/eight, t (23) = 2.31, $p < .05$, but not for locations four/five, t (23) = .35, *ns*. Likewise, five-year-olds showed significant inward bias for locations one/eight, t (23) = 3.66, $p < .01$, but not for locations four/five, t (23) = 1.09, *ns*. Adults exhibited marginally significant inward bias for locations one/eight, t (23) = 1.91, $p = .07$, and significant outward bias for locations four/five, t (23) = -2.64, $p < .05$.

<u>Test on extra large mat</u>

For the test on extra large mat condition, the overall ANOVA yielded a significant Age x Location interaction, F (2, 33) = 3.69, $p < .05$. Follow-up tests revealed a significant effect of Location for adults, F (1, 11) > 33.63, $p < .001$, but not for 4- or 5-year-olds, Fs (1, 11) ≥ .16, *ns*. As shown in Figure A7, adults' placements on locations one/eight were biased inward toward the midline of the task space (positive directional error scores) and locations four/five were biased outward away from the midline of the task space (negative directional error scores).

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A7). Four-year-olds did not show significant bias for locations one/eight, t (23) = -.72, *ns*, or for locations four/five, t (23) = .12, *ns*. Likewise, 5-year-olds did not show significant bias for locations one/eight, t (23) = -.99, *ns*, or for locations four/five, t (23) = -.85, *ns*. As in the test on small mat condition, adults showed significant inward bias for locations one/eight, *t* (23) = 2.39, *p* < .05, and significant outward bias for locations four/five, *t* (23) = -3.95, *p* < .001.

Discussion

The goal of this experiment was to investigate whether young children could accurately scale distance along a single dimension when the scale difference between two spaces was very large. Overall, children and adults were relatively good at remembering the locations of objects in both the memory task and the memory + scaling task. As expected, adults exhibited significantly less overall error than did 4- and 5-year-old children when reproducing locations on both the small and extra large mats. In addition, 5-year-olds showed significantly less error than 4-year-olds, but only when reproducing locations on the extra large mat, suggesting that 4-year-olds may have more difficulty reproducing locations on larger spaces than 5-year-olds. Moreover, when examining differences in error among locations, adults were no more accurate on some locations relative to others when reproducing locations on the small mat. In contrast, 4- and 5-year-olds' placements varied depending on where they were located on each mat. Overall, locations near the edge of the mats seemed to be most accurate. For the test on extra large mat condition, both children and adults reproduced locations near the edges of the mats more accurately than other locations. The findings from the directional error scores showed that children in the test on small mat condition exhibited inward bias for locations near the outermost edges of the mats but did not exhibit significant bias for locations near the middle of the mats. When reproducing locations on the extra large mats, children did not exhibit significant inward or outward bias. In contrast, adults exhibited inward bias for locations near the outermost edges of the mats and outward bias for locations near the middle of the mats when reproducing locations on the small and extra large test mats. This suggests that adults (and possibly some children) may have mentally subdivided the space into two equal halves (Huttenlocher, et al., 1994, Schutte

& Spencer, 2007). Subdividing the space (especially in the extra large mat condition) may make locations toward the midline more accurate.

Although children and adults scaled distance quite accurately, using relative distance was not an all-or-none process. Rather, children and adults exhibited more error on the memory + scaling task than on the memory task when reproducing locations on the extra large mat but not when reproducing locations on the small mat. Thus, *scaling up* appeared to be more difficult than *scaling down*. These results are puzzling given that the scale difference between the two mat sizes was the same regardless of whether participants reproduced locations on the extra large or small test mat. Thus, the absolute amount of size *difference* between the learning and test mats cannot account for why children and adults exhibited significantly more error when scaling up than when scaling down. Rather, something about the process of scaling from a small to a larger space seems to influence how children and adults scale.

We conducted a second experiment to further explore the phenomenon that scaling up was more difficult than scaling down. Specifically, in Preliminary Experiment B we examined whether decreasing the size of the extra large referent space would facilitate participants' ability to scale distance (especially when scaling up). Previous research suggests that decreasing the scale difference between learning and test spaces effects how children reproduce locations (DeLoache et al., 1991; Marsozf & DeLoache, 1994; Vasilyeva & Huttenlocher, 2004). DeLoache et al. (1991) found that 2.5-year-old children preformed significantly better in the model-room task when the model and the room were more similar in size. Likewise, Vasiyeva and Huttenlocher (2004) found that 4- and 5-year-old children were more accurate reproducing locations acquired from a map when the referent space was more similar in size. Together, these studies suggest that the size difference between two spaces may play an important role in scaling. This experiment investigated this issue by using large referent mats that were half the size of the extra large referent mats used in Preliminary Experiment A.

Preliminary Experiment B

The goal of Preliminary Experiment B was to examine if scaling up is more difficult than scaling down when the larger space is reduced in size.

Method

Participants

Seventy-two 4- and 5-year-old children and adults participated in this study. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 4 years and 7 months (range = 4 years 6 months to 4 years 8 months), 5 years and 4 months (range = 5 years 2 months to 5 years 11 months), and 19 years and 11 months (range = 18 years 10 months to 23 years 7 months). Two additional 4-year-olds and one additional 5-year-old were excluded because they did not complete the task. Children and adults were recruited in the same manner as in Preliminary Experiment A. Ninety-eight percent of the children were European American and 2% were Hispanic/Latino. Four percent of mothers had completed their high school education or less, 17% had completed some college education, and 79% had a 4-year-college education or beyond. Ninety-two percent of adult participants were European American and 8% were Asian American.

Apparatus and Materials

The same experimental room used in Preliminary Experiment A was used for this experiment. A large mat (64 in. long by 8 in. wide) and a small mat (8 in. long by 2 in. wide) were used as referent mats. The material of the mats and the features of the objects were identical to that used in the previous experiment. Objects placed on the large mats were 4 in. in diameter and objects placed on the small mats were 1 in. in diameter.

Design and Procedure

Participants were randomly assigned to one of two conditions: test on large mat or test on small mat. All aspects of this procedure were the same as the previous experiment except half the participants reproduced locations on a large mat rather than the extra large mat used in Preliminary Experiment A. Table A3 shows location values for practice and test trials.

Coding and Measures

The coding and measures were identical to those used in Preliminary Experiment A. As in the previous experiment, I corrected for mirror reversal errors (see Table A4). The number of reversals differed significantly across age groups, $F\ (2, 66) = 5.33, p < .01$. Four- and 5-year-olds made significantly more reversal errors than adults. In addition, the number of reversals differed significantly across task, $F\ (1, 66) = 5.37, p < .05$, indicating that there were significantly more reversal errors on the memory + scaling task than on the memory task.

After all reversals were corrected, I classified placement values that were larger than the mean ± 3*SD*s (rounded to the nearest .25 in.) for each age group, location, and condition as outliers and omitted these values from all analyses. I omitted 3.13% of locations for 4-year-olds (6 out of 192), 2.60% for 5-year-olds (5 out of 192), and .52% for adults (1 out of 192). In addition, I omitted one additional location for an adult because an experimenter error occurred during the experimental session.

Results

Absolute Error Scores

Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in error across the memory and memory + scaling tasks for each condition (test on large mat or test on small mat), absolute error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, two/seven, three/six, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat

For the test on small mat condition, this analysis yielded significant main effects of age, *F* (2, 33) = 17.85, *p* < .0001, and location, *F* (3, 99) = 11.37, *p* < .0001. Both 4-year-olds (*M* = 1.11 in., *SD* = .79) and 5-year-olds (*M* = 1.21 in., *SD* = .83) exhibited significantly greater overall error than adults (*M* = .48 in., *SD* = .30). Moreover, participants placed objects significantly more accurately on locations one/eight than on all other sets of locations. In addition, placements were significantly more accurate on locations two/seven than on locations three/six. The absolute mean error scores were .60 in. (*SD* = .43), .87 in. (*SD* = .58), 1.22 in. (*SD* = 1.00), and 1.05 in. (*SD* = .75) for locations one/eight, two/seven, three/six, and four/five, respectively. There was no main effect of task, *F* (1, 33) = .001, *ns*, indicating that children and adults reproduced locations similarly on the memory (*M* = .93 in., *SD* = .77) and the memory + scaling tasks (*M* = .93 in., *SD* = .74).

There was also a significant Age x Location interaction, *F* (6, 99) = 2.50, *p* < .05. As in the previous experiment, simple effects tests revealed a significant effect of location for the 4- and 5-year-olds, *F*s (3, 33) ≥ 5.33, *p*s < .01, but not for the adults, *F* (3, 33) = .69, *ns* (see Figure A8). Follow-up tests for the 4-year-olds indicated that placements were significantly more accurate for locations one/eight than for all other sets of locations. Similarly, follow-up tests for the 5-year-olds showed that placements were significantly more accurate for locations one/eight than for locations three/six and four/five. In addition, placements were more accurate for locations two/seven than for locations three/six. Again, children's placements varied depending on where locations were on each mat (i.e., locations near the edges of the mat were most accurate) whereas adults exhibited similar levels of accuracy across all locations.

Analyses also revealed a significant Age x Location x Task interaction, F (6, 99) = 2.93, $p < .05$. Simple effects tests revealed a significant Location x Task interaction for the 5-year-olds, F (3, 33) = 5.13, $p < .01$, but not for the 4-year-olds or adults, Fs (3, 33) > .08, *ns* (see Figure A9). For the 5-year-olds, there was a significant effect of task for locations one/eight, F (1, 11) = 9.79, $p < .01$, and locations three/six, F (1, 11) = 6.61, $p < .05$, but not for locations two/seven or four/five, Fs (1, 11) $\geq .01$, *ns*. Follow-up tests for locations one/eight showed that placements were significantly more accurate on the memory task than on the memory + scaling task. In contrast, follow-up tests for locations three/six indicated that placements were significantly more accurate on the memory + scaling task than on the memory task. Overall, the fact that 4-year-olds and adults did not exhibit a significant Location x Task interaction and that the task effect for the 5-year-olds was unsystematic, these findings illustrate that the memory + scaling task is not more difficult than the memory task when scaling locations from large to small.

Test on large mat

For the test on large mat condition, the overall analysis yielded significant main effects of age, F (2, 33) = 52.85, $p < .0001$, location, F (3, 99) = 17.88, $p < .0001$, and task, F (1, 33) = 8.39, $p < .01$. Both 4-year-olds (M = 6.34 in., SD = 5.18) and 5-year-olds (M = 4.76 in., SD = 3.38) exhibited significantly greater error than adults (M = 1.88 in., SD = 1.39). In addition, 4-year-olds exhibited significantly greater error than 5-year-olds. Moreover, participants placed objects significantly more accurately on locations one/eight than on all other sets of locations. The absolute mean error scores were 2.08 in. (SD = 1.81), 4.71 in. (SD = 4.67), 4.90 in. (SD = 3.93), and 5.61 in. (SD = 4.45) for locations one/eight, two/seven, three/six, and four/five, respectively. In contrast to performance with the small test mat, children and adults again had more difficulty remembering locations of objects in the memory + scaling task (*M* = 4.88 in., *SD* = 4.50) than in the memory task (*M* = 3.77 in., *SD* = 3.57). Thus, as in Preliminary Experiment A, participants had more difficulty scaling up than scaling down.

There was also a significant Age x Location interaction, *F* (6, 99) = 3.67, $p < .01$. Simple effects tests revealed a significant effect of location for the 4-year-olds, *F* (3, 33) = 6.77, $p < .01$, 5-year-olds, *F* (3, 33) = 12.96, $p < .0001$, and adults, *F* (3, 33) = 6.01, $p < .01$ (see Figure A10). However, the pattern of differences among the locations differed by age. Follow-up tests for the four-year-olds showed that placements were significantly more accurate for locations one/eight than for all other sets of locations. Similarly, follow-up tests for the five-year-olds indicated that placements were significantly more accurate for locations one/eight than for all other sets of locations. In addition, placements were significantly more accurate for locations two/seven than for locations four/five. Finally, follow-up test for adults revealed that placements were more accurate for locations one/eight than for locations three/six and four/five. In addition, adults' placements were more accurate for locations two/seven than for locations four/five. Thus, all ages exhibited less error on locations closest to the edges of the mats than on locations near the midline.

Directional Error Scores

To test for differences in directional error among locations near the midline (four/five) and locations far from the midline (one/eight) for each condition and task, mean directional error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat

For the test on small mat condition, this analysis yielded a significant main effect of age, *F* (2, 33) = 5.47, $p < .01$. Four-year-olds (*M* = .57 in., *SD* = .85) exhibited significantly greater directional error than adults (*M* = -.08 in., *SD* = .50), but not 5-year-olds (*M* = .21 in., *SD* = 1.15). In addition, there was also a significant Age x Location interaction, *F* (2, 33) = 14.03, $p < .0001$. Simple effects tests revealed a significant difference between locations one/eight and locations four/five for 4-year-olds, *F* (1, 11) = 10.71, $p < .01$, 5-year-olds, *F* (1, 11) = 8.62, $p < .05$, and the adults, *F* (1, 11) = 14.35, $p < .01$. Interestingly, the pattern of directional bias differed across age groups (see Figure A11). Thus, for the 4-year-olds, locations one/eight and locations four/five were biased inward toward the midline of the task space (positive directional error scores). For the 5-year-olds and adults, however, locations one/eight were biased inward toward the midline of the task space and locations four/five were biased outward away from the midline of the task space. Thus, 5-year-old children and adults seemed to subdivide the space whereas 4-year-old children did not.

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A11). Four-year-olds did not show significant bias for locations one/eight, *t* (23) = 1.75, *ns*, but did exhibit significant inward bias for locations four/five, *t* (23) = 4.85, $p < .0001$. Five-year-olds showed significant inward bias for locations one/eight, *t* (23) = 3.87, $p < .001$, but did not exhibited significant bias for locations four/five, *t* (23) = -.60, *ns*. Adults exhibited marginally significant inward bias for locations one/eight, *t* (23) = 1.98, *p* = .06, and significant outward bias for locations four/five, *t* (23) = -3.72, $p < .01$.

Test on large mat

For the test on large mat with boundary condition, the overall analysis yielded no significant effect of location, *F* (1, 33) = .10, *ns*. In addition, there was no significant Age x Location interaction, *F* (2, 33) = 1.88, *ns*, indicating that the pattern of directional bias for the inner and outer locations did not differ by age group (see Figure A12). There was a significant Age x Task interaction, *F* (2, 33) < 7.59, *p* > .01 (see Figure A13). Simple effects tests revealed a significant difference for directional error scores between the memory task the memory + scaling task for the 5-year-olds, *F* (1, 11) < 9.27, *p* > .05, but not for the 4-year-olds or adults, *F*s (1, 11) < 2.72, *ns*.

One-sample t-tests comparing directional error scores to 0 were also conducted for participants in each age group (see Figure A12). Four-year-olds did not exhibited significant bias for locations one/eight, *t* (23) = .01, *ns*, or for locations four/five, *t* (23) = .93, *ns*. Likewise, 5-year-olds did not show significant bias for locations one/eight, *t* (23) = -1.78, *ns*, or for locations four/five, *t* (23) = -.27, *ns*. Adults exhibited significant inward bias for locations one/eight, *t* (23) = 2.65, *p* < .05, and significant outward for locations four/five, *t* (23) = -2.93, *p* < .01.

Discussion

These results again show that using relative distance to scale location is affected by the direction of the scale translation. That is, children and adults exhibited more error on the memory + scaling task than on the memory task when scaling up than when scaling down. Similar to the previous experiment, adults exhibited significantly less error than 4- and 5-year-old children when reproducing locations on both the small and large mats. In addition, 5-year-olds showed significantly less error than 4-year-olds, but only when reproducing locations on the large mat. Moreover, adults exhibited no differences in accuracy across locations when reproducing locations on the small mat. In contrast, when reproducing locations on the large mat, adults were significantly more accurate on locations near the edges of the mat than on locations near the midline. Four- and 5-year-olds' placements varied depending on where locations were on each mat for both the small and large test mat conditions. Overall, locations near the edge of the mats seemed to be most accurate for both the test on small mat and test on large mat conditions.

Interestingly, the pattern of directional error scores differed across age groups. In the small test mat condition, 5-year-olds and adults exhibited a similar pattern to the pattern found among the adults in the previous experiment. That is, locations near the outermost edges of the mats were biased inward toward the midline of the task space and locations near the middle were biased outward away from the midline of the task space, suggesting that they may have subdivided the space into two equal halves. In contrast, for the 4-year-olds, the direction of error scores revealed that both sets of locations were biased inward toward the midline of the task space, suggesting that they may have treated the space as a whole instead of subdividing the space into two equal halves. In the large test mat condition, adults exhibited similar patterns of bias as seen in the small test mat condition, whereas the children did not exhibit significant bias in either direction for the outer or inner locations.

Why is scaling up more difficult than scaling down? These experiments revealed that locations near the edges of the mats (one/eight) were more accurate than locations farther from the edges. These findings illustrate the importance of using the edges of the task space when reproducing locations from memory. I argue that the use of the edges becomes even more important in the memory + scaling task than in the memory task. That is, a scaling task requires people to use a minimum of *two* landmarks (e.g., far edges of the mat) to code relative distance. When people are scaling up, they may have difficulty *mapping* relative distance from the small to the larger size space because the edges on the larger space are now farther apart and may not be viewable from a single vantage point. The inability to map corresponding edges on larger spaces, along with the process of making a scale translation, may make scaling up more difficult. By examining why scaling from a small to a larger space is more difficult than scaling from a large to a smaller space, we can begin to understand how people map relative distance from one space to another. That is, the differences in scaling up versus scaling down can be used as a tool to examine the processes underlying the ability to scale distance more generally.

In the thesis experiments that follow, I examine how absolute and relative size differences between learning and test spaces affect the ease with which children and adults scale up versus scale down. I predict that the difficulty children and adults have scaling up can be attributed to mapping relative distances onto spaces that are too large to be viewed from a single vantage point. Experiment 1 examined whether the presence of a midline boundary facilitates how children and adults use relative distance to scale. Using the relative distance between one edge of the mat and the midline boundary may make it easier to view two reference points simultaneously, facilitating how children and adults scale up. Experiments 2 directly examined the influence of absolute size on mapping relative distance by decreasing the absolute size of the test space. I would expect scaling up to be better when the absolute size of the test space is viewable from a single vantage point. In contrast, Experiment 3 examined how children and adults use relative distance to scale up and scale down when the size of the space is large. Again, if the absolute size of the space influences scaling, both scaling up and scaling down should be difficult when the edges of the mats cannot be viewed simultaneously, illustrating the importance of absolute size in using relative distance to scale.

CHAPTER 3: EXPERIMENT 1

Does a Midline Boundary Facilitate Scaling Up?

This experiment examined how children and adults scale locations when a midline boundary divided the task space in half during learning and test. The presence of the midline boundary provided participants with additional structure to help them map relative distance onto a different size space. Thus, the midline boundary could be used as one of two points of reference necessary in a scaling task. Participants could code the relative distance of a location between one edge of the mat and the midline boundary, reducing the distance between the two reference points. In turn, the midline boundary may make it easier to view two reference points simultaneously, facilitating how children and adults scale up.

Method

Participants

Seventy-two 4- and 5-year-old children and adults participated in this study. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 4 years and 7 months (range = 4 years 6 months to 4 years 10 months), 5 years and 4 months (range = 5 years 3 months to 5 years 7 months), and 19 years and 3 months (range = 18 years 3 months to 21 years 7 months). Three additional 4-year-olds were excluded because they did not complete the task. Children and adults were recruited in the same manner as used in the previous experiments. Eighty-four percent of the children were European American, 12% were Black, 2% were Asian American, and 2% were Hispanic/Latino. Two percent of mothers had completed their high school education or less, 13% had completed some college education, and 85% had a 4-year-college education or beyond. Ninety-six percent of adult participants were European American and 4% were Asian American.

Apparatus and Materials

The same experimental room used in the previous experiments was used for this experiment. The mats were identical to those used in Preliminary Experiment B, with the exception that a visible black boundary divided each mat into two equal sized halves. The boundary was .125 in. wide on the small mat and .5 in. wide on the large mat. The same objects used in Preliminary Experiment B were used in this experiment.

Design and Procedure

Participants were randomly assigned to one of two conditions: test on large mat with boundary or test on small mat with boundary. All aspects of this procedure were the same as in the previous experiments. Table A3 shows locations for the practice and test trials.

Coding and Measures

The coding and measures were identical to those used in the previous experiments. As in Preliminary Experiments A and B, I corrected for mirror reversal errors (see Table A5). The number of reversals differed significantly across age group, F (2, 66) = 10.08, $p < .001$. Four- and 5-year-olds made significantly more reversal errors than adults.

After all reversals were corrected, I classified placement values that were larger than the mean $\pm$ 3*SD*s (rounded to the neared .25 in.) for each age group, location, and condition as outliers and omitted these values from all analyses. I omitted 4.17% of locations for 4-year-olds (8 out of 192), 5.21% for 5-year-olds (10 out of 192), and 2.08% for adults (4 out of 192). In addition, for one 4-year-old and two 5-year-olds, I omitted a location because an experimenter error occurred during the experimental session.

Results

Absolute Error

Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in error across the memory and memory + scaling tasks for each condition (test on large mat with boundary and test on small mat with boundary), absolute error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, two/seven, three/six, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat with boundary

For the test on small mat with boundary condition, this analysis yielded significant main effects of age, F (2, 33) = 27.61, $p < .0001$, and location, F (3, 99) = 5.74, $p < .01$. Both 4-year-olds (M = 1.18 in., SD = .92) and 5-year-olds (M = .91 in., SD = .89) exhibited significantly greater overall error than adults (M = .34 in., SD = .22). In addition, 4-year-olds exhibited significantly greater error than 5-year-olds. Moreover, participants placed the objects significantly more accurately on locations one/eight than on locations two/seven and three/six. In addition, placements were significantly more accurate on locations four/five than on locations two/seven. The absolute mean error scores were .56 in. (SD = .42), 1.06 in. (SD = 1.15), .85 in. (SD = .59), and .76 in. (SD = .87) for locations one/eight, two/seven, three/six, and four/five, respectively. As before, there was no main effect of task, F (1, 33) = .23, *ns*, indicating that children and adults reproduced locations similarly in the memory (M = .83 in., SD = .91) and the memory + scaling tasks (M = .79 in., SD = .73).

There was also a significant Age x Location interaction, F (6, 99) = 2.80, $p < .05$, and a significant Task x Location interaction, F (3, 99) = 5.92, $p < .001$. These interactions were subsumed in a significant Age x Location x Task interaction, F (6, 99)

= 3.61, $p < .01$. Simple effects tests revealed a significant Location x Task interaction for the 5-year-olds, F (3, 33) = 8.40, $p < .001$, but not for the 4-year-olds or adults, Fs (3, 33) > 1.38, *ns* (see Figure A14). For the 5-year-olds, there was a significant effect of task for locations two/seven, F (1, 11) = 6.59, $p < .05$, but not for locations one/eight, three/six, or four/five, Fs (1, 11) $\geq$ .74, *ns*. Follow-up tests for locations two/seven showed that placements were significantly more accurate on the memory + scaling task than on the memory task. The fact that 4-year-olds and adults did not exhibit a significant Loc x Task interaction and that there was only a task effect for the 5-year-olds for locations two/seven supports the finding that levels of error on the memory and memory + scaling task are similar when children and adults reproduce locations on small sized mats.

<u>Test on large mat with boundary</u>

For the test on large mat with boundary condition, this analysis yielded significant main effects of age, F (2, 33) = 13.11, $p < .0001$, location, F (3, 99) = 11.42, $p < .0001$, and task, F (1, 33) = 8.31, $p < .01$. Both 4-year-olds (M = 4.62 in., SD = 5.12) and 5-year-olds (M = 3.28 in., SD = 2.78) exhibited significantly greater overall error than adults (M = 1.25 in., SD = .92). Moreover, participants placed the objects significantly more accurately on locations one/eight and locations four/five than on locations two/seven and three/six. Thus, accurate judgments of locations were found not only near the edges of the mats but also near the midline where the boundary was located. The absolute mean error scores were 1.98 in. (SD = 1.56), 3.84 in. (SD = 4.44), 4.34 in. (SD = 4.87), and 2.03 in. (SD = 1.97) for locations one/eight, two/seven, three/six, and four/five, respectively. As in the previous studies, children and adults had more difficulty remembering locations in the memory + scaling task (M = 3.35 in., SD = 3.88) than in the memory task (M = 2.75 in., SD = 3.42), indicating that they again had more difficulty scaling up than scaling down. Even though a midline boundary was present to provide additional structure, participants continued to have difficulty mapping relative distances onto larger spaces.

There was also a significant Age x Location interaction, *F* (6, 99) = 4.60, *p* < .001. Simple effects tests revealed a significant effect of location for the 4-year-olds, *F* (3, 33) = 8.86, *p* < .001, but not for the 5-year-olds or adults, *F*s (3, 33) > 1.61, *ns* (see Figure A15). Follow-up tests for the 4-year-olds showed that placements on locations one/eight and four/five were significantly more accurate than placements on locations two/seven and three/six. Thus, 4-year-old children's placements varied depending on where locations were on each mat whereas 5-year-olds children and adults' placements did not vary by location. Four-year-old children exhibited less error on locations near the edges of the mat (as seen in the previous experiments) and on locations near the midline where the boundary was visible.

Directional Error

To test for differences in directional error between locations near the midline (four/five) and locations far from the midline (one/eight) for each condition and task, mean directional error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat with boundary

For the test on small mat with boundary condition, this analysis yielded a significant main effect of location, *F* (1, 33) = 10.65, *p* < .01, but no significant Age x Location interaction, *F* (2, 33) = 2.18, *ns*, indicating that the pattern of directional bias was similar for all age groups (see Figure A16). Thus, for all age groups, locations one/eight (*M* = .26 in., *SD* = .56) were biased inward toward the midline of the task space (positive directional error scores) and locations four/five (*M* = -.22 in., *SD* = .79) were biased outward away from the midline of the task space (negative directional error scores).

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A16). Four-year-olds exhibited significant inward bias for locations one/eight, t (23) = 3.26, $p < .01$, and marginally significant outward bias for locations four/five, t (23) = -1.95, $p = .06$. Five-year-olds did not show significant bias for locations one/eight, t (23) = 1.72, *ns*, or for locations four/five, t (23) = -.193, *ns*. Adults exhibited significant inward bias for locations one/eight, t (23) = 2.22, $p < .05$, and significant outward bias for locations four/five, t (23) = -3.64, $p < .01$.

Test on large mat with boundary

For the test on large mat with boundary condition, the overall analysis yielded a significant Age x Location interaction, F (2, 33) = 7.55, $p < .01$. Simple effects tests revealed a significant effect of location for the 4-year-olds and adults, Fs (1, 11) > 10.85, ps < .01, but not for the 5-year-olds, F (1, 11) = .40, *ns* (see Figure A17). For the four-year-olds, locations one/eight were biased outward away from the midline of the task space and locations four/five were biased inward toward the midline of the task space. This pattern of bias was opposite of that exhibited for the 4-year-olds in the test on small mat with boundary condition. In contrast, adults continued to exhibit the pattern in which locations one/eight were biased inward toward the midline of the task space and locations four/five were biased outward away from the midline of the task space.

Separate one-sample t-tests for participants in each age group comparing directional error scores to 0 (see Figure A17) revealed that 4-year-olds exhibited significant outward bias for locations one/eight, t (23) = -2.21, $p < .05$, and significant inward bias for locations four/five, t (23) = 3.39, $p < .01$. Five-year-olds did not show significant bias for locations one/eight, t (23) = .73, *ns*, or for locations four/five, t (23) = -.317, *ns*. Adults exhibited significant inward bias for locations one/eight, t (23) = 2.43, $p < .05$, and significant outward bias for locations four/five, t (23) = -3.64, $p < .05$.

Discussion

With a midline boundary dividing the large mat in half, children and adults still exhibited more error on the memory + scaling task than on the memory task when scaling up than scaling down. Similar to the previous experiments, adults exhibited significantly less overall error than 4- and 5-year-old children when reproducing locations on both the small and large mats. In addition, 5-year-olds showed significantly less error than 4-year-olds when reproducing locations on the small mat. Moreover, when examining differences in error among locations, placements were significantly more accurate for locations near the edge of the mats and near the midline boundary of each test space (especially for the 4-year-olds on the large test mat). When reproducing locations on the large mat with boundary, adults' and 5-year-olds placements did not vary by location, indicating that the midline boundary may have provided enough structure for the older children and adults to accurately map relative distance, making error scores similar across locations.

In contrast to findings in Preliminary Experiment B, the pattern of directional error scores did not differ by age in the test on small mat with boundary condition. All age groups exhibited the pattern with locations near the outermost edges of the mats biased inward toward the midline of the task space and locations near the middle biased outward away from the midline of the task space. This suggests that the midline boundary influenced 4-year-olds, who previously were unable to mentally subdivide the space into two equal halves. In contrast, in the test on large mat with boundary condition, 5-year-olds and adults showed a similar pattern as before, whereas 4-year-olds biased locations near the edges outward and biased locations near the midline inward. Thus, younger children may have had more difficulty subdividing the larger than the smaller spaces even in the presence of a visible boundary dividing the space in half.

Together, these findings illustrate that children and adults continue to have more difficulty scaling up than scaling down even when a boundary divides the large mat in half. Why did scaling up continue to be more difficult than scaling down? One reason may be that children and adults did not consistently use the boundary to divide the space into two smaller parts. On the other hand, maybe half of the large mat is still too large to be viewed from a single vantage point. The next experiment examined whether decreasing the absolute size of the large mat erases the difference between scaling up and scaling down.

CHAPTER 4: EXPERIMENT 2

Does Reducing the Absolute Size of the Test Mat Facilitate Scaling Up?

This experiment examined how reducing the absolute size of a test space influences how children and adults use relative distance to scale. The previous experiment used small and large mats with midline boundaries on each mat. Thus, people could have viewed these spaces as two halves. For example, the large mat (64 in. long) could have been viewed as two side-by-side 32 in. long spaces. This experiment examined whether reducing the size of the large mat has the same effect as a visible boundary subdividing the large mat. Thus, this experiment examined how children and adults scaled locations when the size of the large mat was reduced in half.

Method

Participants

Seventy-two 4- and 5-year-old children and adults participated in this study. There were 24 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 4 years and 7 months (range = 4 years 2 months to 4 years 11 months), 5 years and 6 months (range = 5 years 3 months to 5 years 11 months), and 19 years (range = 18 years 2 months to 22 years 10 months). Two additional 4-year-olds were excluded because one child did not complete the task and there was an experimenter error during the other child's session. Children and adults were recruited in the same manner as used in the previous experiments. Ninety percent of the children were European American, 2% were Black, 4% were Asian American, and 4% were Hispanic/Latino. Four percent of mothers had completed their high school education or less, 21% had completed some college education, and 75% had a 4-year-college education or beyond. Eighty-three percent of adult participants were European American, 13% were Asian American, and 4% were Hispanic/Latino.

Apparatus and Materials

The experimental room was the same as that used in the previous experiments. A medium mat (32 in. long by 4 in. wide) and a small mat (8 in. long by 2 in. wide) were used as referent mats. The material for the mats and the features of the objects were identical to those used in the previous experiments. Objects placed on the medium mats were 2 in. in diameter and objects placed on the small mats were 1 in. in diameter.

Design and Procedure

Participants were randomly assigned to one of two conditions: test on medium mat or test on small mat. All aspects of this procedure were the same as the previous experiments. Table A6 shows the location values for practice and test trials.

Coding and Measures

The coding and measures were identical to those used in the previous experiments. As in those experiments, I corrected for mirror reversal errors (see Table A7). The number of reversals differed significantly across age group, F (2, 66) = 10.41, p = .0001. Four-year-olds made significantly more reversal errors than 5-year-olds or adults.

After all reversals were corrected, I classified placement values that were larger than the mean ± 3*SD*s (rounded to the nearest .25 in.) for each age group, location, and condition as outliers and omitted these values from all analyses. I omitted 4.17% of locations for 4-year-olds (8 out of 192), 1.56% for 5-year-olds (3 out of 192), and .52% for adults (1 out of 192).

Results

Absolute Error

Preliminary analyses revealed no significant effects of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in error across the memory and memory + scaling tasks for each condition (test on medium mat and test on small mat), absolute error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, two/seven, three/six, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat

For the test on small mat condition, the analysis yielded significant main effects of age, F (2, 33) = 46.00, $p < .0001$, and location, F (3, 99) = 13.95, $p < .0001$. Both 4-year-olds (M = 1.18 in., SD = .79) and 5-year-olds (M = 1.20 in., SD = .82) exhibited significantly greater overall error than adults (M = .37 in., SD = .22). Moreover, participants placed the objects significantly more accurately on locations one/eight than on all other sets of locations. In addition, placements were significantly more accurate on locations two/seven than on locations three/six and four/five. The absolute mean error scores were .56 in. (SD = .42), .84 in. (SD = .76), 1.12 in. (SD = .72), and 1.15 in. (SD = .95) for locations one/eight, two/seven, three/six, and four/five, respectively. There was no main effect of task, F (1, 33) = .004, *ns*, again indicating that children and adults reproduced locations similarly on the memory (M = .92 in., SD = .82) and the memory + scaling tasks (M = .92 in., SD = .72) when reproducing locations on small mats.

There was also a significant Age x Location interaction, F (6, 99) = 3.44, $p < .01$, and a significant Task x Location interaction, F (3, 99) = 6.90, $p < .001$. These interactions were subsumed by a significant Age x Location x Task interaction, F (6, 99) = 2.90, $p < .05$. Simple effects tests revealed a significant Location x Task interaction for the 5-year-olds, $F(3, 33) = 6.29$, $p < .01$, and adults, $F(3, 33) = 3.23$, $p < .05$, but not for the 4-year-olds, $F(3, 33) > 1.99$, *ns* (see Figure A18). For the 5-year-olds, there was a significant effect of task for locations two/seven, $F(1, 11) = 10.25$, $p < .01$, and locations four/five, $F(1, 11) = 6.96$, $p < .05$, but not for locations one/eight or three/six, Fs $(1, 11) \geq .002$, *ns*. Follow-up tests for locations two/seven showed that placements were significantly more accurate on the memory + scaling task than on the memory task. In contrast, follow-up tests for locations four/five indicated that placements were significantly more accurate on the memory task than on the memory + scaling task. For the adults, there was a significant effect of task for locations one/eight, $F(1, 11) = 5.50$, $p < .05$, but not for locations two/seven, three/six, or four/five, Fs $(1, 11) \geq .05$, *ns*. Follow-up tests for locations one/eight showed that placements were significantly more accurate on the memory + scaling task than on the memory task. Again, these results suggest that there are possible difference between the memory and memory + scaling tasks for the 5-year-olds and adults, but these differences are unsystematic and reveal an overall lack of difference between the memory task and the memory + scaling task.

Test on medium mat

For the test on medium mat condition, the analysis yielded significant main effects of age, $F(2, 33) = 38.65$, $p < .0001$, and location, $F(3, 99) = 13.40$, $p < .0001$. Both 4-year-olds ($M = 2.40$ in., $SD = 1.82$), and 5-year-olds ($M = 2.06$ in., $SD = 1.36$), exhibited significantly greater overall error than adults ($M = .87$ in., $SD = .60$). Moreover, participants placed the objects significantly more accurately on locations one/eight than on all other locations. In addition, locations two/seven were significantly more accurate than three/six. The absolute mean error scores were .90 in. ($SD = .69$), 1.82 in. ($SD = 1.49$), 2.31 in. ($SD = 1.49$), and 2.07 in. ($SD = 1.75$) for locations one/eight, two/seven, three/six, and four/five, respectively. Importantly, there was no difference in absolute error scores across the memory ($M = 1.75$ in., $SD = 1.60$) and the memory + scaling tasks

(*M* = 1.80 in., *SD* = 1.40), *F* (1, 33) = .25, *ns*. Scaling up was no longer more difficult than scaling down when the size of the test space was reduced to the medium size.

There was also a marginally significant Age x Location interaction, *F* (6, 99) = 2.13, *p* = .06. Simple effects tests revealed a significant effect of location for the 4-year-olds, *F* (3, 33) > 6.31, *p* < .01, 5-year-olds, *F* (3, 33) > 4.87, *p* < .01, and adults, *F* (3, 33) > 7.66, p < .001 (see Figure A19). However, the pattern of differences among locations differed by age. Follow-up tests for the 4- and 5-year-olds showed that placements were significantly more accurate for locations one/eight than for all other sets of locations. Follow-up tests for adults revealed that placements were more accurate for locations one/eight than for locations three/six and four/five. In addition, placements were significantly more accurate for locations two/seven and four/five than for locations three/six. Thus, all ages exhibited less error on locations closest to the edges of the mats than on other locations (especially the children).

Directional Error

To test for differences in directional error between locations near the midline (four/five) and locations far from the midline (one/eight) for each condition and task, mean directional error scores were entered into two separate Age (4 years, 5 years, adults) x Task (memory, memory + scaling) x Location (one/eight, four/five) repeated-measures ANOVAs with age as a between-participants factor and task and location as within-participants factors.

Test on small mat

For the test on small mat condition, this analysis yielded no significant main effect of location, *F* (1, 33) = 2.20, *ns*. In addition, there was no significant Age x Location interaction, *F* (2, 33) = 1.54, *ns*, indicating that the pattern of directional errors did not differ among the age groups (see Figure A20).

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A20). Four-year-olds exhibited significant inward bias for locations one/eight, *t* (23) = 3.71, *p* < .01, and exhibited marginally significant inward bias for locations four/five, *t* (23) = 1.89, *p* = .07. Five-year-olds showed significant inward bias for locations one/eight, *t* (23) = 3.55, *p* < .01, but did exhibit significant bias for locations four/five, *t* (23) = -.05, *ns*. Adults exhibited significant inward bias for locations one/eight, *t* (23) = 3.22, *p* < .01, and significant outward bias for locations four/five, *t* (23) = -2.55, *p* < .05. Again, adults exhibited a pattern of bias reflecting possible subdivision effects whereas 4-year-olds exhibited the opposite pattern of directional bias illustrating that they did not subdivide the space but rather treated the space as a whole.

Test on medium mat

For the medium mat condition, this analysis revealed a significant Age x Location interaction, *F* (2, 33) = 5.27, *p* < .05. Simple effects tests revealed a significant effect of location for the adults, *F* (1, 11) = 14.88, *p* < .01, and a marginally significant effect of location for the 4-year-olds, *F* (1, 11) = 4.22, *p* = .06, but not for the 5-year-olds, *F* (1, 11) = 1.79, *ns* (see Figure A21). For the adults, locations one/eight were biased inward toward the midline of the task space (positive directional error scores) and locations four/five were biased outward away from the midline of the task space (negative directional error scores). For the 4-year-olds, however, locations one/eight were biased outward away from the midline of the task space and locations four/five were biased inward toward the midline of the task space.

There was also a significant Task x Location interaction, *F* (1, 33) = 5.16, *p* < .05. Simple effects tests revealed a significant difference between locations one/eight and four/five for the memory task, *F* (1, 35) = 6.14, *p* < .05, but not for the memory + scaling task, *F* (1, 35) = .40, *ns*. As shown in Figure A22, for the memory task, locations one/eight were biased inward toward the midline of the task space and locations four/five were biased outward away from the midline of the task space.

To examine whether the magnitude of directional error scores was significantly greater than 0, we conducted separate one-sample t-tests for participants in each age group (see Figure A21). Four-year-olds did not exhibit significant bias for locations one/eight, t (23) = -1.57, *ns*, or for locations four/five, t (23) = 1.69, *ns*. Five-year-olds showed significant inward bias for locations one/eight, t (23) = 2.97, $p < .01$, but did not exhibit significant bias for locations four/five, t (23) = -3.33, *ns*. Adults exhibited significant inward bias for locations one/eight, t (23) = 2.96, $p < .01$, and significant outward bias for locations four/five, t (23) = -2.55, $p < .05$.

Discussion

Unlike the previous experiments, this experiment revealed that children and adults no longer exhibited more error on the memory + scaling task than on the memory task when scaling up than scaling down. Thus, when the size of the larger mat was reduced, scaling up is no longer more difficult than scaling down. Similar to the previous experiment, adults exhibited significantly less error than 4- and 5-year-old children when reproducing locations on both the small and medium mats. Overall, when examining differences in error among locations, placements near the edges of the mats seemed to be the most accurate (especially for the 4- and 5-year-old children on the medium mats).

The pattern of directional error scores did not differ by age in the test on small mat condition. All age groups exhibited significant inward bias toward the midline of the task space for the outer locations (one/eight). Adults exhibited significant outward bias for inner locations (four/five) and 4-year-olds exhibited marginally significant inward bias for locations four/five. In the test on medium mat condition, 5-year-olds and adults showed a similar pattern as before, whereas 4-year-olds biased locations near the midline inward and biased locations near the edges outward.

These findings illustrate that reducing the size of the larger space made scaling up easier. The question that still remains is why does reducing the size of the larger space eliminate the difference between scaling up and scaling down?

CHAPTER 5: EXPERIMENT 3

Why is Scaling Up More Difficult than Scaling Down?

The previous experiment illustrates the importance of reducing the absolute size of the test mat on children and adults' ability to scale up. Specifically, when the size of the test mat was reduced to half the size of the large mat used in the two previous experiments, scaling up was no longer more difficult than scaling down. This suggests that when people can more easily view both edges of the mat simultaneously, they find it easier to map relative distance from a smaller space to a larger space. Note, however, that the previous experiments involved incrementally reducing the size of the larger mat while keeping the size of the small mat constant across the set of experiments. In doing so, I in turn reduced the scale difference between the learning and test mats. That is, reducing the absolute size of the larger mat also lead to a reduction in the scale difference between the smaller and larger mat. Experiment 3 examined if the absolute size of the mat or the similarity in scale ratio influenced the lack of task effect in Experiment 2. If the absolute size of the test mat influences how people map distances from one space to another, then children and adults should perform similarly on tasks that use the same size test mat. Thus, if children and adults have difficulty mapping distances onto larger sized spaces, they should have problems scaling up and scaling down when large test mats are used for both tasks. If similarity in the scale ratio influenced the lack of task effect in Experiment 2, then children and adults should not have difficulty scaling distance on the large test mat when the scale difference between the learning and test mats are similar.

The absolute size of the test space in both the memory and memory + scaling tasks was held constant for all participants (i.e., 64 in.). One scaling up condition and two scaling down conditions were used to disentangle the effect of absolute size and scale similarity on children and adults ability to scale. For the scaling up condition, a 32 in. mat was used for the learning mat. The absolute size difference between this mat and the 64 in. test mat was 32 in. In addition, the scale ratio was 1:2 from learning to test. To control for the absolute size difference and scale ratio from learning to test, two scaling down conditions were used. For one scaling down condition, a 96 in. mat was used for the learning mat. The absolute size difference between the learning and test mat was identical in this condition as in the scaling up condition (i.e., 32 in.) but the scale ratio varied between the conditions (i.e., 1:2 versus 1.5:2). In contrast, for the other scaling down condition, a 128 in. mat was used for the learning mat. For this condition, the absolute size difference between the learning and test mat differed from the scaling up condition (i.e., 64 in. versus 32 in.), however, the scale ratio between the learning and test mats were the same for scaling up and scaling down (i.e., 1:2). I would predict that children and adults would exhibit more error on the memory + scaling task than on the memory task for all three conditions, illustrating that the absolute size of the test space accounts for the difficulties children and adults have scaling up in the previous experiments. Both scaling up and scaling down should be more difficult on the larger mat that cannot be viewed simultaneously.

Method

Participants

One hundred and eight 4- and 5-year-old children and adults participated in this study. There were 36 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 4 years and 4 months (range = 4 years 3 months to 4 years 10 months), 5 years and 6 months (range = 5 years 5 months to 5 years 8 months), and 19 years and 9 months (range = 18 years 8 months to 22 years 5 months). Five additional 4-year-olds and two additional 5-year-olds were excluded because they did not complete the task. Children and adults were recruited in the same manner as used in the previous experiments. Ninety-two percent of the children were European American, 3% were Asian American, 2% were Black, 2% were American

Indian, and 1% was Pacific Islander. Six percent of mothers had completed their high school education or less, 14% had completed some college education, and 80% had a 4-year-college education or beyond. Ninety-two percent of adult participants were European American and 8% were Asian American.

Apparatus and Materials

The same experimental room was used as in the previous experiments. Four different sized mats were used in this experiment (32 in. long x 4 in. wide, 64 in. long x 8 in. wide, 96 in. long x 12 in. wide, and 128 in. long x 24 in. wide). The material of the mats and features of the objects were the same as those used in the previous experiments. Objects placed on the 32 in. mats were 2 in. in diameter, objects placed on the 64 in. mats were 4 in. in diameter, objects placed on the 96 in. mats were 6 in. in diameter, and objects placed on the 128 in. mats were 8 in. in diameter.

Design and Procedure

Participants were randomly assigned to one of three conditions: scaling up-32 in. learning mat, scaling down-96 in. learning mat, or scaling down-128 in. learning mat. As in the previous experiments, participants completed two tasks: memory and memory + scaling (see Table A8). All participants reproduced locations on a 64 in. long mat. Thus, all memory trials consisted of learning locations on a 64 in. mat and reproducing locations on another 64 in. mat. In addition, for the memory + scaling task, one-third of the participants scaled up (learned locations on a 32 in. mat and reproduced those locations on a 64 in. mat), one-third scaled down the same absolute distance as the scaling up condition (learned locations on a 96 in. mat and reproduce those locations on a 64 in. mat) and the other third scaled down the same scale ratio as the scaling up condition (learned locations on an 128 in. mat and reproduced those locations on a 64 in. mat). These conditions allowed us to directly examine possible differences between scaling up and scaling down when either the absolute or ratio scale difference was the same. All other aspects of the experiment were identical to the previous experiments. Table A9 shows location values for practice and test trials.

Coding and Measures

The coding and measures were identical to those used in the previous experiments. As in those experiments, I corrected for mirror reversal errors (see Table A10). The number of reversals differed significantly across age groups, F, (2, 99) = 7.66, *p* < .001. Four- and 5-year-olds made significantly more reversal error than adults.

After all reversal errors were corrected, I classified placement values that were larger than the mean ±3*SD*s (rounded to the nearest .25 in.) for each age group and location as outliers and omitted these values from all analyses. I omitted 1.74% of locations for 4-year-olds (5 out of 288), 1.74% for 5-year-olds (5 out of 288), and .69% for adults (2 out of 288). In addition, for one 4-year-old and two 5-year-olds, I omitted one location because an experimenter error occurred during the experimental session.

Results

Absolute Error Scores

Preliminary analyses revealed no significant effect of gender, so the data were collapsed across this factor in the analyses reported below. To test for differences in error across the memory and memory + scaling tasks when scaling up versus scaling down, absolute error scores were entered into an Age (4 years, 5 years, adults) x Condition (scaling up- 32 in. learning mat, scaling down-96 in. learning mat, scaling down-128 in. learning mat) x Task (memory, memory + scaling) x Location (one/eight, two/seven, three/six, four/five) repeated measures ANOVA with age and condition as between-participants factors and task and location as within-participant factors.

This analysis yielded significant main effects of age, *F* (2, 99) = 69.47, *p* < .0001, location, *F* (3, 297) = 39.92, *p* < .0001, task, *F* (1, 99) = 10.98, *p* < .01, and condition, *F*

(2, 99) = 3.16, $p < .05$. Both 4-year-olds (*M* = 4.20 in., *SD* = 2.98) and 5-year-olds (*M* = 3.69 in., *SD* = 2.41) exhibited significantly greater overall error than adults (*M* = 1.63 in., *SD* = 1.10). In addition, 4-year-olds exhibited significantly greater error than 5-year-olds. Moreover, participants placed objects significantly more accurately on locations one/eight than on all other sets of locations. In addition, placements were significantly more accurate on locations two/seven than on locations three/six and four/five. The absolute mean error scores were 1.90 in. (*SD* = 2.12), 3.16 in. (*SD* = 2.23), 3.76 in. (*SD* = 2.66), and 3.87 in. (*SD* = 2.68) for locations one/eight, two/seven, three/six, and four/five, respectively.

Importantly, children and adults had more difficulty remembering locations in the memory + scaling task (*M* = 3.40 in., *SD* = 2.79) than in the memory task (*M* = 2.95 in., *SD* = 2.27), but there was no significant Task x Condition interaction, *F* (2, 99) = .39, *ns*. Thus, children and adults exhibited more error on the memory + scaling task than on the memory task for both the scaling up and scaling down conditions. Overall, the ability to scale up and scale down was difficult when the absolute size of the test space large, and it did not matter whether the absolute size difference or scale ratio difference was the same from learning to test.

Follow-up tests of the main effect of condition revealed that placements were significantly more accurate in the Scaling down-96 in. learning mat condition (*M* = 2.86 in., *SD* = 2.15) than in the Scaling up-32 in. learning mat condition (*M* = 3.44 in., *SD* = 2.70). The absolute mean error scores for the Scaling down-128 in. learning mat condition (*M* = 3.21 in., *SD* = 2.74) did not differ from either of the other two conditions. Recall that the memory task is the same for all conditions (i.e., learning and test on 64 in. long mats). Thus, this overall difference between the Scaling down-96 in. mat condition and Scaling up-32 in. mat condition could indicate that scaling down may be easier than scaling up if the absolute size difference between the two spaces is similar. It is important to note, however, that there was no interaction between task and condition. Thus, the overall effect of condition does not show direct evidence that there is a difference between the memory + scaling task in these two conditions since the means in this analysis reflect performance on both the memory and the memory + scaling tasks. Rather, the important finding is that children and adults exhibited more error on the memory + scaling task than on the memory task for all scaling up and scaling down conditions (see Figure A23).

There was also a significant Age x Location interaction, F (6, 297) = 2.89, $p <$ .01. Simple effects tests revealed a significant effect of location for the 4-year-olds, F (3, 99) > 11.88, $p < .0001$, 5-year-olds, F (3, 99) > 21.75, $p < .0001$, and adults, F (3, 99) = 10.65, p < .0001 (see Figure A24). However, the pattern of differences among locations differed by age. Follow-up tests for the 4-year-olds showed that placements were significantly more accurate for locations one/eight than for all other sets of locations. Likewise, follow-up tests for the 5-year-olds indicated that placements were significantly more accurate for locations one/eight than for all other sets of locations. In addition, locations two/seven were significantly more accurate than locations three/six and four/five. Finally, follow-up tests for adults revealed that placements were more accurate for locations one/eight than for all other sets of locations. In addition, locations two/seven were significantly more accurate than locations four/five. Thus, all ages exhibited less error on locations closest to the edges of the mats than on locations near the midline of the task space.

Directional Error Scores

To test for differences in directional error among the locations when scaling up versus scaling down, mean directional error scores were entered into an Age (4 years, 5 years, adults) x Condition (scaling up-32 in. learning mat, scaling down-96 in. learning condition, scaling down-128 in. learning condition) x Task (memory, memory + scaling) x Location (one/eight, four/five) repeated measures ANOVA with age and condition as between-participants factors and task and location as within-participants factors.

This analysis revealed a significant main effects of Age, *F* (2, 99) = 10.63, *p* < .0001, and a significant Age x Location interaction, *F* (2, 99) = 9.95, *p* < .001. Simple effects tests revealed a significant effect of location for the adults, *F* (1, 33) = 70.23, *p* < .0001, but not for the 4- or 5-year-olds, *F*s (1, 33) > .29, *ns* (see Figure A25). For the adults, locations one/eight were biased inward toward the midline of the task space (positive directional error scores) and locations four/five were biased outward away from the midline of the task space (negative directional error scores).

Separate one-sample t-tests comparing directional error scores to 0 were also conducted for participants in each age group (see Figure A25). Four-year-olds did not exhibited significant bias for locations one/eight, *t* (71) = 1.38, *ns*, but did show significant inward bias for locations four/five, *t* (71) = 3.86, *p* < .001. Five-year-olds showed significant inward bias for locations one/eight, *t* (71) = 1.99, *p* <= .05, but did exhibit significant bias for locations four/five, *t* (71) = .33, *ns*. Adults exhibited significant inward bias for locations one/eight, *t* (71) = 4.12, *p* = .0001, and significant outward bias for locations four/five, *t* (71) = -10.87, *p* < .0001.

Discussion

As predicted, when the absolute size of the test mat was large (64 in. long), scaling up *and* scaling down were more difficult than the memory task. Consistent with the results of Preliminary Experiment 1, children and adults have difficulty mapping a relative distance on the large mat size because the space is too large to be viewed from a single vantage point, thus highlighting the importance of being able to simultaneously view multiple edges for scaling distances. Similar to the previous experiments, adults exhibited significantly less overall error than 4- and 5-year-old children when reproducing locations on both the small and large mats. In addition, 5-year-olds showed significantly less error than 4-year-olds. Moreover, when examining differences in error among locations, placements were significantly more accurate for locations near the edges of the mats than for locations near the midline (especially for the 4-year-olds).

Overall, placements were significantly more accurate for scaling down-96 in. mat condition than for the scaling up-32 in. mat condition. The absolute size difference and the memory task were the same across these two conditions, suggesting that the difference between these conditions must be related to scaling up versus scaling down. However, I argue that the overall effect of task and lack of a Condition x Task interaction makes this interpretation unlikely (see Figure A23). Rather, the difference between the scaling up-32 in. learning mat condition and the scaling down-96 in. learning mat condition reflects small differences in the memory and memory + scaling tasks, or both. Regardless, the important finding is that overall, scaling up and scaling down were more difficult when a large mat was used as the referent space.

The pattern of directional error scores differed by age. Adults exhibited the pattern with locations near the outermost edges of the mats biased inward toward the midline of the task space and locations near the middle biased outward away from the midline of the task space. In contrast, children biased locations near the edges and near the midline inward (although 5-year-olds exhibited relatively little directional bias overall). These findings (along with those from the previous experiments) illustrate the strong tendency for adults to bias outer and inner locations toward the center of the two halves of the space. Children, on the other hand, show more variability in the direction of bias that they exhibit.

Together these findings illustrate that the difficulty children and adults had scaling up in the previous experiments is linked to the difficulty children and adults have mapping relative distance onto large spaces with edges that cannot be viewed simultaneously.

CHAPTER 6: GENERAL DISCUSSION

Using Relative Distance to Scale Location

The goal of the present investigation was to further understand the processes by which children and adults use relative distance to scale location. Preliminary Experiments A and B provided new information about how children and adults scale remembered locations along a single dimension (i.e., length). These experiments revealed that both 4- and 5-year-old children and adults were relatively good at scaling location when the magnitude of scale difference was very large (e.g., 16 in. long versus 128 in. long in Preliminary Experiment A). However, the ability to scale distance was not an all-or-none phenomenon. Namely, using relative distance to scale location was more difficult when going from a smaller to a larger space (scaling up) than when going from a larger to a smaller space (scaling down). Importantly, the scale difference between the learning and test mat was the same regardless of whether participants scaled up or scaled down. This dissertation expanded on the findings from these studies and used the phenomenon that scaling up is more difficult than scaling down as a tool to gain insight on how children and adults scale distance. In the paragraphs below, I discuss the general processes underlying how children and adults use relative distance to scale location and how these processes predict why scaling up may be more difficult than scaling down.

How Do Children and Adults Scale Distance?

Findings from the present investigation, as well as others, have indicated that the ability to use relative distance to scale develops at a very young age (Huttenlocher et al., 1999; Uttal et al., 2006; Vasilyeva & Huttenlocher, 2004). These findings support the hypothesis that spatial scaling involves carrying out a perceptual strategy in the absence of formal proportional reasoning. To scale distance along a single dimension, one must visually code distance relative to two or more landmarks or edges. This relation must then be maintained and accurately mapped onto another space using the corresponding landmarks or edges. The importance of the edges of the mats in the present investigation was apparent when examining differences among locations. Children and adults placed objects near the edges of the mats (i.e., locations one and eight) more accurately than locations near the midline (i.e., locations four and five). In addition, Experiment 1 revealed that the when a midline boundary was present to provide additional structure, locations near the boundary were very accurate. These differences in accuracy among locations suggest that children and adults are using the edges of the mats to scale distance. The edges of the mats act as a perceptual standard to help ground estimates of location after a scale transformation. Specifically, the edges of the mat provide a standard that can be used to guide children through the process of coding and mapping relative distance.

These findings are consistent with previous research highlighting the importance of a continuous perceptual standard on young children's (and animals) ability to encode relative information (Duffy, Huttenlocher, & Levine, 2005; Duffy, Huttenlocher, Levine, & Duffy, 2005; Gray, Spetch, Kelly, & Nguyen, 2004; Huttenlocher, Duffy, & Levine, 2002; Jeong, Levine, & Huttenlocher, 2007; Sophian, 2000; Spinillo & Bryant, 1991; Tommasi & Vallortigara, 2000). For example, Sophian (2000) presented 4- and 5-year-old children and adults with a piece of paper that displayed three colored rectangles. One rectangle was located on the top half of the page and was used as the sample stimulus. The other two rectangles were located beneath the sample stimulus and were used as choice stimuli. One choice stimulus was proportionally the same as the sample stimulus but larger, whereas the other choice stimulus was changed only along a single dimension (i.e., height). Findings revealed that both children and adults chose the proportionally correct choice stimulus when asked to pick the one that was the same as the sample stimulus. These findings illustrate that young children are able to use the shape of a stimulus as a perceptual standard to maintain the overall shape relative to size after a scale transformation.

Although the present investigation does not provide conclusive evidence as to exactly how children and adults use the edges of the mats to map relative distance, I discuss two possibilities in turn below. The first possibility is that children and adults may code and reproduce distances by comparing relations within a space. One way to do this is to code the distance of an object from one edge of the mat and compare that distance to the distance between both edges of the mat (the object is a quarter of the way across the length of the mat). When mapping relative distance onto the test mat, one could place the object the same distance (a quarter of the way across the length of the mat) relative to the distance between both edges of the test mat. Another way to do this is to mentally impose a boundary to subdivide a space into two or more parts. One can then use one edge of the mat along with the imagined boundary to code and map relative distance. The findings from the directional error scores in the present investigation could be used to determine whether children and adults compared distances relative to the whole space or relative to two or more parts. Adults always exhibited the same pattern of bias with outer locations (one/eight) biased inward toward the midline of the task space and inner locations (four/five) biased outward away from the midline of the task space. This pattern of bias suggests that adults may have mentally subdivided the space into two equal halves, making locations near the midline more accurate. These subdivision effects suggest that adults do not perceptually scale distances relative to a whole but rather are more likely to compare distances between parts of the space. Interestingly, there may be developmental changes in children’s use of perceptually strategies to scale distance. In the present investigation, directional error scores indicated that 4-year-old children did not show evidence of mental subdivision but rather coded distances relative to the whole space (except when reproducing distances on the small mat with boundary). On the other hand, 5-year-olds exhibited bias reflecting mental subdivision when a midline boundary was visible (Experiment 1) and when the absolute size of space was reduced (Experiment 2). These differences in how children and adults impose mental boundaries to subdivide a space could indicate that younger children are using a different perceptual strategy to code and map distances than are older children and adults. When the large mat was divided by a midline boundary, younger children did not find it easy to treat each half as a separate entity. Rather, they seem compelled to scale distance relative to the whole mat. It is possible that young children rely heavily on scaling both dimensions of the space and would have difficulty scaling distance in the absence of this information (e.g., if mats were replaced by thin lines).

A second possible way that children and adults can use the edges of the space to scale relative distance is through a mental transformation of expanding or contracting the image of the original space. These mental transformations could be carried out with the use of time (e.g., it takes more time to map relative distance when spaces are more different in size) or by matching a relative distances (e.g., mentally expanding or contracting distances until they look the same). As discussed earlier, the edges of the mats in the present experiment play a vital role in these types of mental transformations by acting as a perceptual standard that can be used to guide estimates after scale transformations.

Regardless of the exact strategy used in these experiments, evidence does suggest that children and adults visually scale distances. The question that remains is how do these processes of visually scaling explain the difficulty children and adults have scaling up versus scaling down. Interestingly, results from the present investigation highlight that children and adults do not have difficulty *coding* relative distance, but rather have trouble *mapping* relative distance onto larger space. For example, in Preliminary Experiment A, there was no significant difference between how children and adults remembered locations and scaled remembered locations in the small test mat condition. Thus, coding relative distance on a larger space and mapping the distance onto a smaller space did not pose to be a problem. However, there was a significant difference between how children and adults remembered locations and scaled remembered locations in the test on extra large mat condition. Children and adults had more difficulty going from the small mat (16 in. long) to the extra large mat (64 in. long) than from the extra large mat to an identical extra large mat, illustrating that mapping relative distance onto larger spaces seems to be associated with the difficulty children and adults have scaling up.

Scaling Up Versus Scaling Down

The first step in understanding why scaling up is more difficult than scaling down requires one to examine key differences between these tasks. In the present investigation, I focused on the idea that scaling up often requires people to map relative distance onto spaces that are too large to be viewed from a single vantage point, whereas scaling down often involves mapping relative distance onto smaller spaces that can easily be viewed from a single vantage point. Recall that visual scaling requires one to code a distance relative to two or more landmarks or edges and then map this distance relative to the corresponding landmarks or edges in the other space. The inability to view the edges of a larger space simultaneously may interfere with one's ability to judge spatial relations and could help explain why children often have difficulty scaling with larger referent spaces (Blades, 1989; Uttal, 2000; Uttal, Fisher, & Taylor, 2006; Vasilyeva & Huttenlocher, 2004).

Findings from the present investigation highlight the difficulty that children and adults have mapping relative distance onto larger referent spaces (see Table A11). For example, the two preliminary experiments and Experiment 1 are consistent with the idea that absolute size rather than size similarity influences how children and adults scale relative distance. For these experiments, the extra large and large mats were too large to be viewed from a single vantage point. When these mats were used during test, findings across these experiments consistently revealed that the memory + scaling task was significantly more difficult than the memory task. Importantly, the magnitude of size difference between the learning and test mat was equivalent for the scaling up and scaling down conditions (e.g., small to extra large and extra large to small). Thus, scale similarity cannot account for the difference between scaling up versus scaling down. Rather, the differences that were found between the scaling up and scaling down tasks point to the importance of absolute size in scaling distance. Likewise, the finding that scaling up was more difficult than scaling down when children and adults placed objects on extra large and large mats demonstrating that making the mats more similar in size (i.e., small to large) did not effect how children and adults used relative distance to scale.

Experiment 2 further explored why children and adults may have more difficulty scaling distance onto larger spaces by decreasing the absolute size of the larger mat. In this experiment, children and adults no longer exhibited more difficulty scaling up than scaling down when the absolute size of the larger space was reduced to a medium sized mat. Thus, when the size of the larger space was reduced, the ability to simultaneously view the space facilitated how children and adults used relative distance to scale. This experiment was inconclusive, however, as to whether reducing the absolute size of the mat helped children and adults scale distance or whether the smaller size difference between the learning and test mats could explain these findings.

As you can recall, Experiment 3 was designed to separate the effects of the absolute size of the test space and the similarity in size difference between the learning and test mats. In this experiment, the absolute size of the test mat was held constant for all participants (64 in. long). The size difference between the learning and test mats was identical in the scaling up-32 in. learning mat condition and in the scaling down-96 in. learning mat condition (both differed by 32 in.). Alternatively, the size difference between the learning and test mats was smaller in the scaling up-32 in. learning mat condition (32 in.) than in the scaling down-128 in. learning mat condition (64 in.). If high similarity between learning and test mats influences accuracy in how children and adults scale, it would be predicted that scaling distance would be more accurate in the 32 in. learning mat condition than in the 128 in. learning mat conditions. In contrast, if the absolute size of the test space influences how children and adults scale distance, no difference between the scaling up-32 in. and scaling down-128 in. learning mat conditions would be found. This experiment revealed no differences among the conditions, illustrating that similarity does not account for our previous finding that reducing the absolute size of the space facilitated how children and adults scale distance. Rather, larger sized test spaces make scaling relative distance difficult for both scaling up and scaling down.

Previous research has attempted to study how reducing the absolute size of a space influences how children scale (DeLoache et al, 1991; Vasilyeva & Huttenlocher, 2004). These studies have largely focused, however, on how similarity (not absolute size) affects scaling. For example, Vasilyeva and Huttenlocher (2004) had 4- and 5-year-old children use a small map to find a location on a space that was similar in size or one that was much larger in size. Both 4- and 5-year-old children exhibited significantly more error when scaling from the map to the larger space than when scaling from the map to the smaller space. These researchers conclude that scaling distance is more difficult when two spaces were more different in size. However, in this experiment, scaling from the map to the large mat not only decreased the similarity between the map and mat but also increased the absolute size of the test space. Thus, it is unclear whether scaling is more difficult when mapping distance onto larger spaces or more difficult when spaces are less similar in size. The results from the present investigation clarify these findings by suggesting that it is the absolute size of the test space, not similarity of size that accounts for their results. Thus, mapping relative distance onto larger sized spaces is more difficult than mapping relative distance onto small sized spaces because the edges of larger sized spaces cannot be viewed simultaneously.

Limitations

As noted previously, the processes underlying how children and adults scale involves the use of a perceptual strategy (Huttenlocher et al., 1999; Huttenlocher et al., 2002; Jeong et al., 2007; Vasilyeva & Huttenlocher, 2004). Although the exact perceptual strategy used by children and adults is unknown, the present investigation suggests that people must first visually code distance relative to two or more landmarks or edges. This relation must then be maintained and accurately mapped onto another space using the corresponding landmarks or edges. In turn, mapping relative distances onto larger sized spaces interferes with one's ability to scale because larger sized spaces cannot be viewed from a single vantage point. One limitation of this research is that the direction and length of gaze was not monitored for participants. Thus, in the present investigation it is difficult to know whether children and adults did in fact have difficulty simultaneously viewing two edges of the extra large and large mat sizes. Further work is necessary to examine how the inability to view the contents of a large sized space from a single vantage point affects how people scale distance.

This investigation examined how young children and adults scale distance along a single dimension (i.e., length) in a laboratory study. Previous research has suggested that children and adults treat small-scale spaces differently than large-scale spaces (Acredolo, 1981; Siegel & White, 1975; Uttal, 2000; Weatherford, 1982). Thus, another limitation of this work is how applicable it is to how children and adults scale distance in larger sized spaces in the real world. Our findings suggest that children and adults would have difficulty mapping relative distance in the real world because mapping relative distance onto larger sized space is difficult. Additionally, the present research could add insight as to why older children seem to have difficulty in mapping tasks that require mapping relative distances in the real world (Liben et al, 1982; Liben & Yekel, 1996; Siegel et al., 1979). However, examining how larger spaces influence how children scale distance in the real world is necessary.

Future Directions

As noted above, an important claim in this thesis is that scaling distance on larger sized spaces is more difficult because two or more edges cannot be viewed from a single vantage point. An important next step in this research would be to track where children and adults are looking as they scale relative distance. Our findings indicate that *mapping* relative distances is more difficult on larger than smaller sized spaces but *coding* relative distances is not. By tracking patterns of looking behavior when children and adults are coding relative distance versus mapping relative distance, we may be able to further explain why mapping relative distances onto larger spaces is difficult. Patterns of looking behavior toward the edges of the space may differ between coding and mapping relative distances.

Another way to examine how simultaneously viewing the edges of the mats influences how children and adults scale would be to remove other cues providing information that could be used to scale. In the present investigation the size of the objects were proportionally scaled to correspond to each mat size. An important question is how the size of the objects themselves help children and adults scale? It may be possible that adults were able to use the boundary surrounding each object as a perceptual standard to guide their estimate of relative distance in the present investigation. Using the objects would make the task of mapping locations onto larger sized spaces easier because the size of the objects were small enough to be viewed from a single vantage point. Whether children and adults use the objects to help guide their estimates of relative distance requires further research. As discussed above, 4-year-olds did not show evidence of using the midline boundary to subdivide the large test mat in Experiment 1, suggesting that young children may rely on whole objects when scaling. The fact that both the mats and objects were scaled in these experiments probably helped young children scale in the present investigation. An important question that remains is whether the processes involved in scaling distance are similar (if not the same) to the processes involved in scaling objects.

Finally, an important component of these studies was the comparison between how children and adults remembered locations (memory task) and scaled remembered locations (memory + scaling task). The results of these studies revealed that scaling up *and* scaling down was difficult on larger spaces. An important question is whether the same difficulties would occur with a minimal memory requirement. Can children and adults scale distance on larger sized spaces when they do not have to remember previously learned distances? Understanding how the memory component of the task influences children and adults ability to scale distance can further provide insight as to why scaling distance may be more difficult in some tasks relative to others.

Summary and Conclusions

This investigation is one of the first to systematically explore how children and adults use relative distance to scale. My preliminary experiments demonstrated that young children and adults accurately scale locations along a single dimension between spaces that vary in size. However, they had more difficulty going from a smaller to a larger space than from a larger to a smaller space. Experiment 1 demonstrated that although a visible boundary dividing a large space influenced how children and adults remember locations, scaling up was still more difficult than scaling down. Experiment 2 further examined the influence of the absolute size on mapping relative distance. When the absolute size of the test space was reduced, scaling up was no longer more difficult than scaling down. Finally, to further examine why reducing the absolute size of the test space influenced scaling up, Experiment 3 examined how children and adults scale up and scale down when the size of the test space was large. Findings revealed that both scaling up and scaling down were more difficult, illustrating the importance of absolute size in using relative distance to scale.

In conclusion, children and adults can use relative distance to scale location. However, when the absolute size of the space is large, children and adults have more difficulty using multiple edges of the space to accurately scale distance. These findings provide valuable insights into underlying processes used to scale distance. First, they underscore the idea that scaling distance is not an all-or-none process but rather an emergent ability that combines multiple cues available in particular task structures. Second, these findings are among the first to systematically examine why some scaling tasks may be more difficult than others. The overall finding that mapping distances onto larger spaces is more difficult than mapping distances onto smaller spaces is an important first step toward understanding how children and adults use relative distance to scale. As such, these experiments provide information as to how the cognitive system (i.e., visual scaling processes) and task structure (i.e., absolute size of test space) interact to give rise to the ability to use relative distance to scale.

APPENDIX

TABLES AND FIGURES

Table A1. Corresponding practice and test locations on the small and extra large mats used in Preliminary Experiment A.

	One	Two	Three	Four	Five	Six	Seven	Eight
Practice Trials								
Small mat	2.75	4.5	6.25	8	9.75	11.5	13.25	
Extra large mat	22	36	50	64	78	92	106	
Test Trials								
Small mat	1.875	3.625	5.375	7.125	8.875	10.625	12.375	14.125
Extra large mat	15	29	43	57	71	85	99	113

Note: For each mat, distance is indicated in inches, starting from the left edge of the mat.

Table A2. Number of reversals for each age group and reversal type in Preliminary Experiment A.

Age and Reversal Type	Memory Task	Memory + Scaling Task	Total
4-year-olds			
1/8 Between	1	0	1
2/7 Between	1	2	3
3/6 Between	2	3	5
Far Within	4	2	6
Double	3	6	9
Total	11	13	24
5-year-olds			
1/8 Between	2	3	5
2/7 Between	1	1	2
3/6 Between	1	2	3
Far Within	0	3	3
Double	0	1	1
Total	4	10	14
Adults			
1/8 Between	0	0	0
2/7 Between	0	0	0
3/6 Between	0	0	0
Far Within	0	0	0
Double	0	0	0
Total	0	0	0

Table A3. Corresponding practice and test locations on the small and large mats used in Preliminary Experiment B and Experiment 1.

	One	Two	Three	Four	Five	Six	Seven	Eight
Practice Trials								
Small mat	2.75	4.5	6.25	8	9.75	11.5	13.25	
Large mat	11	18	25	32	39	46	53	
Test Trials								
Small mat	1.875	3.625	5.375	7.125	8.875	10.625	12.375	14.125
Large mat	7.5	14.5	21.5	28.5	35.5	42.5	49.5	56.5

Note: For each mat, distance is indicated in inches, starting from the left edge of the mat.

Table A4. Number of reversals for each age group and reversal type in Preliminary Experiment B.

Age and Reversal Type	Memory Task	Memory + Scaling Task	Total
4-year-olds			
1/8 Between	2	3	5
2/7 Between	1	3	4
3/6 Between	1	3	4
Far Within	0	1	1
Double	3	5	8
Total	7	15	22
5-year-olds			
1/8 Between	1	0	1
2/7 Between	4	4	8
3/6 Between	0	6	6
Far Within	2	3	5
Double	2	4	6
Total	9	17	26
Adults			
1/8 Between	0	0	0
2/7 Between	0	0	0
3/6 Between	0	0	0
Far Within	1	0	1
Double	0	1	1
Total	1	1	2

Table A5. Number of reversals for each age group and reversal type in Experiment 1.

Age and Reversal Type	Memory Task	Memory + Scaling Task	Total
4-year-olds			
1/8 Between	3	3	6
2/7 Between	3	3	6
3/6 Between	3	6	9
Far Within	1	3	4
Double	6	8	14
Total	16	23	39
5-year-olds			
1/8 Between	2	1	3
2/7 Between	0	4	4
3/6 Between	3	2	5
Far Within	4	2	6
Double	4	5	9
Total	13	14	27
Adults			
1/8 Between	0	0	0
2/7 Between	0	0	0
3/6 Between	0	0	0
Far Within	0	0	0
Double	0	0	0
Total	0	0	0

Table A6. Corresponding practice and test locations on the small and medium mats used in Experiment 2.

	One	Two	Three	Four	Five	Six	Seven	Eight
Practice Trials								
Small mat	2.75	4.5	6.25	8	9.75	11.5	13.25	
Medium mat	5.5	9	12.5	16	19.5	23	26.5	
Test Trials								
Small mat	1.875	3.625	5.375	7.125	8.875	10.625	12.375	14.125
Medium mat	3.75	7.25	10.75	14.25	17.75	21.25	24.75	28.25

Note: For each mat, distance is indicated in inches, starting from the left edge of the mat.

Table A7. Number of reversals for each age group and reversal type in Experiment 2.

Age and Reversal Type	Memory Task	Memory + Scaling Task	Total
4-year-olds			
1/8 Between	1	4	5
2/7 Between	4	3	7
3/6 Between	2	2	4
Far Within	1	1	2
Double	3	2	5
Total	11	12	23
5-year-olds			
1/8 Between	0	0	0
2/7 Between	3	2	5
3/6 Between	0	1	1
Far Within	3	0	3
Double	0	0	0
Total	6	3	9
Adults			
1/8 Between	0	0	0
2/7 Between	0	0	0
3/6 Between	0	0	0
Far Within	0	0	0
Double	0	0	0
Total	0	0	0

Table A8: Size of learning and test mats for the memory and memory + scaling tasks for each condition in Experiment 3.

	Learning Mat	Test Mat
Scaling up-32 in. learning mat		
Memory	64 in.	64 in.
Memory + Scaling	32 in.	64 in.
Scaling down-96 in. learning mat		
Memory	64 in.	64 in.
Memory + Scaling	96 in.	64 in.
Scaling down-128 in. learning mat		
Memory	64 in.	64 in.
Memory + Scaling	128 in.	64 in.

Table A9. Corresponding practice and test locations on the 32 in., 64 in., 96 in., and 128 in. mats used in Experiment 3.

	One	Two	Three	Four	Five	Six	Seven	Eight
Practice Trials								
32 in. mat	5.5	9	12.5	16	19.5	23	26.5	
64 in. mat	11	18	25	32	39	46	53	
96 in. mat	16.5	27	37.5	48	58.5	69	79.5	
128 in. mat	22	36	50	64	78	92	106	
Test Trials								
32 in. mat	3.75	7.25	10.75	14.25	17.75	21.25	24.75	28.25
64 in. mat	7.5	14.5	21.5	28.5	35.5	42.5	49.5	56.5
96 in. mat	11.25	21.75	32.25	42.75	53.25	63.75	74.25	84.75
128 in. mat	15	29	43	57	71	85	99	113

Note: For each mat, distance is indicated in inches, starting from the left edge of the mat. Also note that the 32 in. mat was identical to the medium mat used in Experiment 2, the 64 in. mat was identical to the large mat used in Preliminary Experiment B and Experiment 1, and the 128 in. mat was identical to the extra large mat used in Preliminary Experiment A.

Table A10. Number of reversals for each age group and reversal type in Experiment 3.

Age and Reversal Type	Memory Task	Memory + Scaling Task	Total
4-year-olds			
1/8 Between	2	3	5
2/7 Between	1	3	4
3/6 Between	6	3	9
Far Within	0	0	0
Double	3	1	4
Total	12	10	22
5-year-olds			
1/8 Between	2	2	4
2/7 Between	0	0	0
3/6 Between	2	3	5
Far Within	0	0	0
Double	4	0	4
Total	8	5	13
Adults			
1/8 Between	0	0	0
2/7 Between	0	0	0
3/6 Between	0	0	0
Far Within	0	0	0
Double	0	0	0
Total	0	0	0

Table A11: Summary of results indicating whether scaling up was more difficult than scaling down for each experiment.

	Size of mat during learning and test trials		Was scaling up more difficult than scaling down?
	Scaling Up	Scaling Down	
Experiment A			
Learning mat	Small (16”)	Extra Large (128”)	Yes
Test mat	Extra Large (128”)	Small (16”)	
Experiment B			
Learning mat	Small (16”)	Large (64”)	Yes
Test mat	Large (64”)	Small (16”)	
Experiment 1			
Learning mat	Small (16”) with boundary	Large (64”) with boundary	Yes
Test mat	Large (64”) with boundary	Small (16”) with boundary	
Experiment 2			
Learning mat	Small (16”)	Medium (32”)	No
Test mat	Medium (32”)	Small (16”)	
Experiment 3			
Learning mat	32”	128” or 96”	No
Test mat	64”	64”	

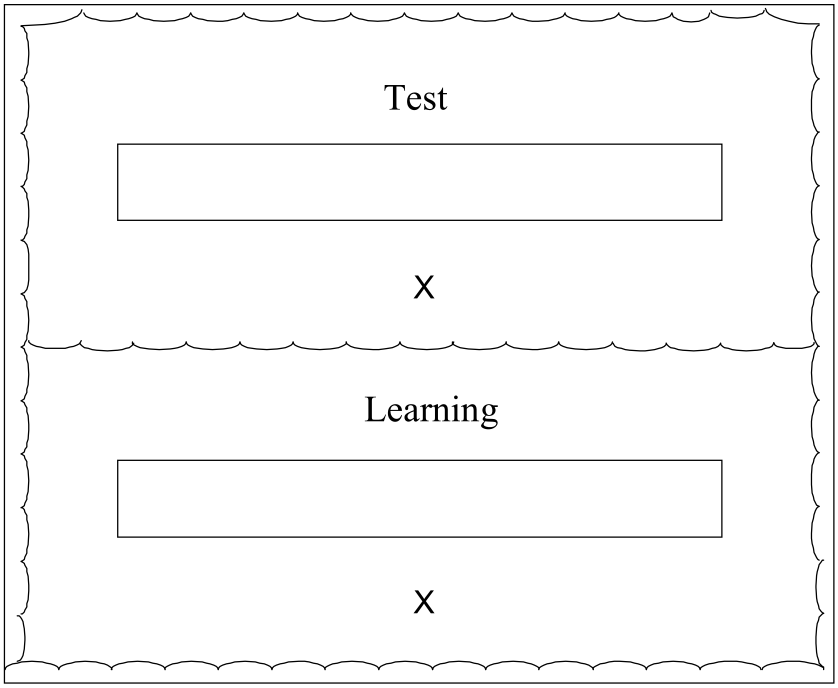

Figure A1. An aerial view of the experimental room used in all experiments.

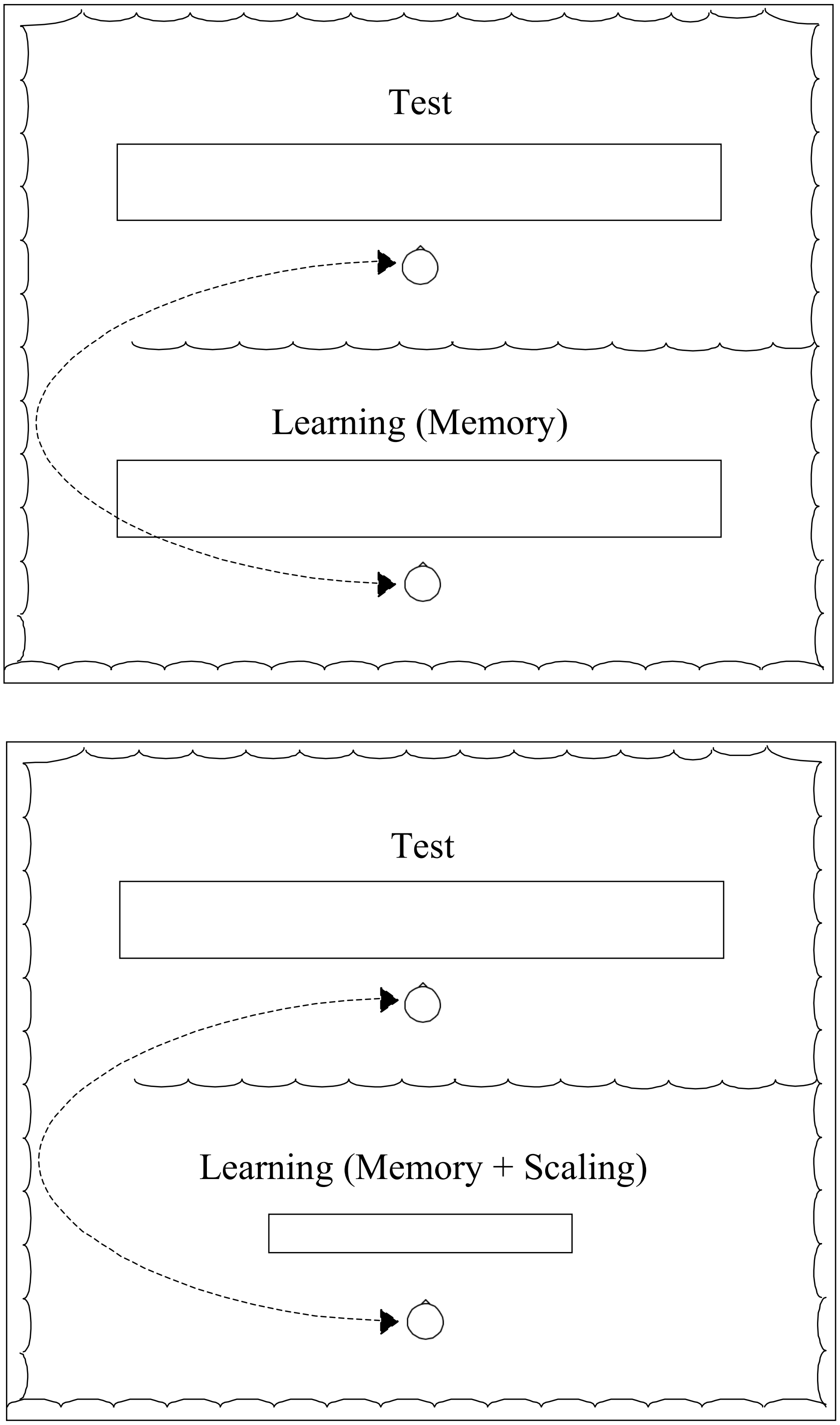

Figure A2. An aerial view of the experimental room depicting learning and test trials for the memory and memory + scaling tasks.

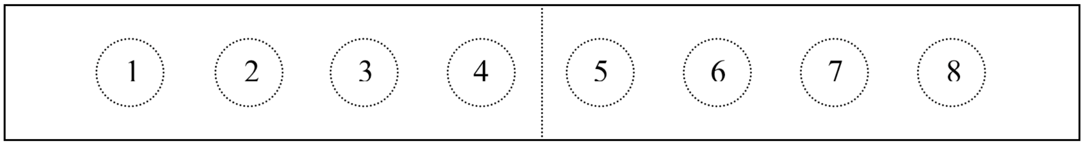

Figure A3. Diagram illustrating the layout of locations on each mat.

Note: Locations and midline boundary were not visible on the mats (see Experiment 1 for an exception).

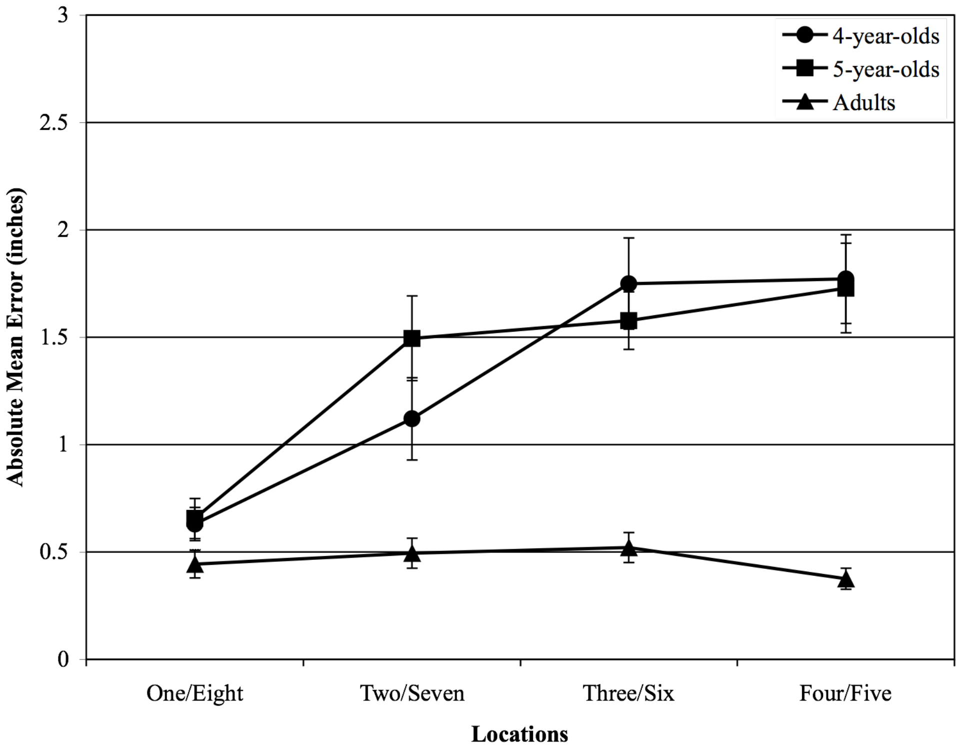

Figure A4. Absolute mean error for each age group and location in the test on small mat condition in Preliminary Experiment A.

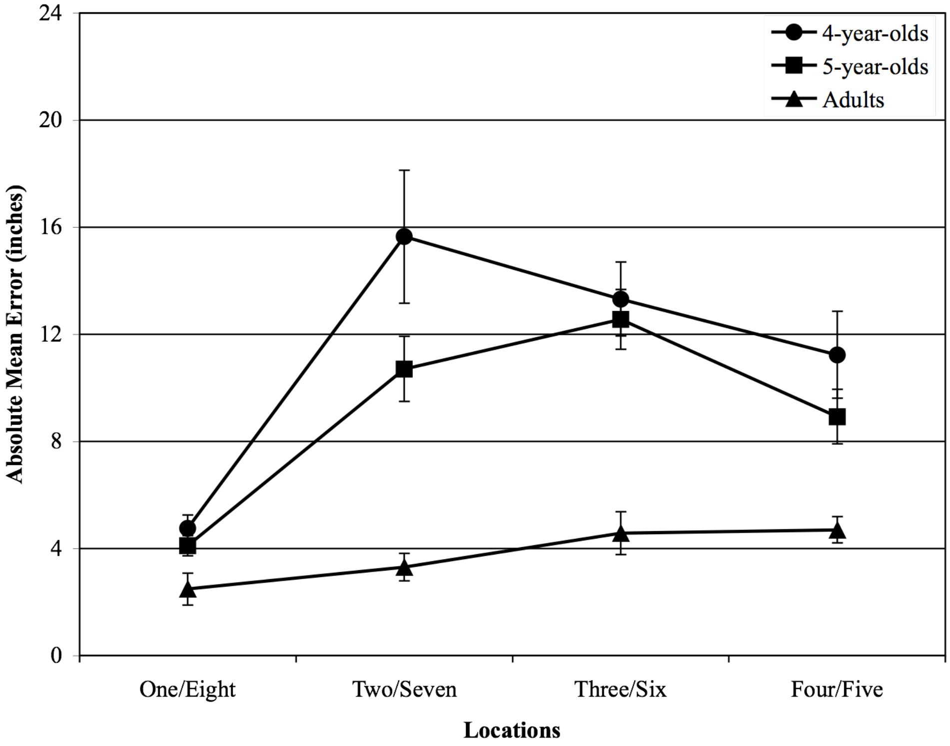

Figure A5. Absolute mean error for each age group and location in the test on extra large mat condition in Preliminary Experiment A.

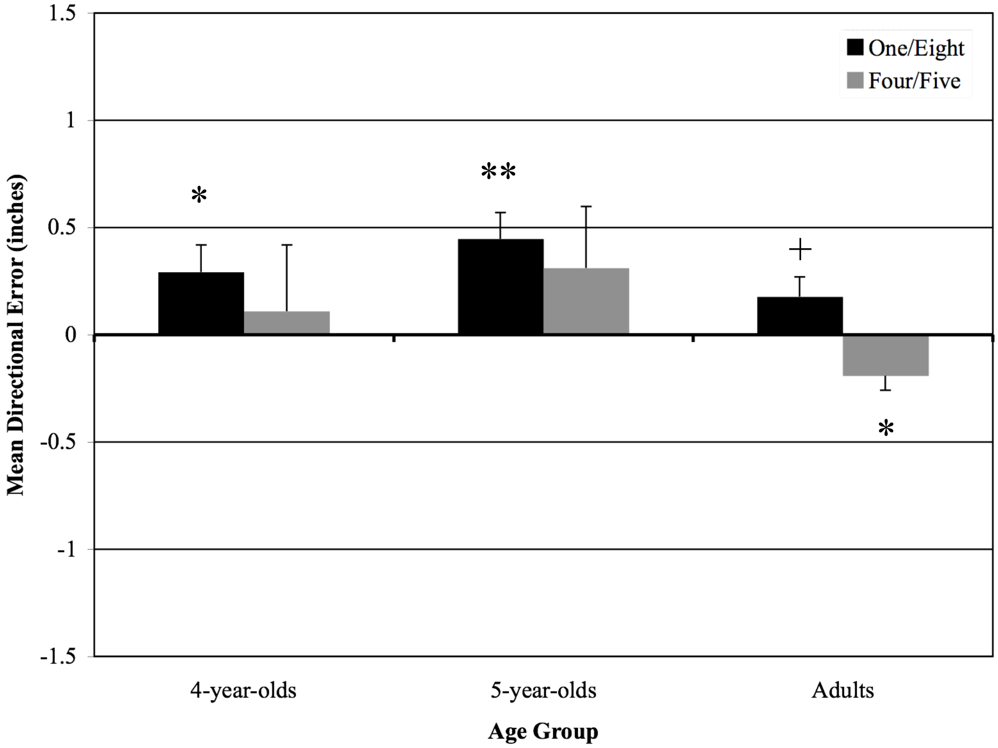

Figure A6. Mean directional error scores for each age group and location in the test on small mat condition in Preliminary Experiment A.

Note: Asterisks denote significant results (* $p < .05$, ** $p < .01$) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). The plus sign denotes a marginally significant result ($p < .07$) from a one-sample *t*-test.

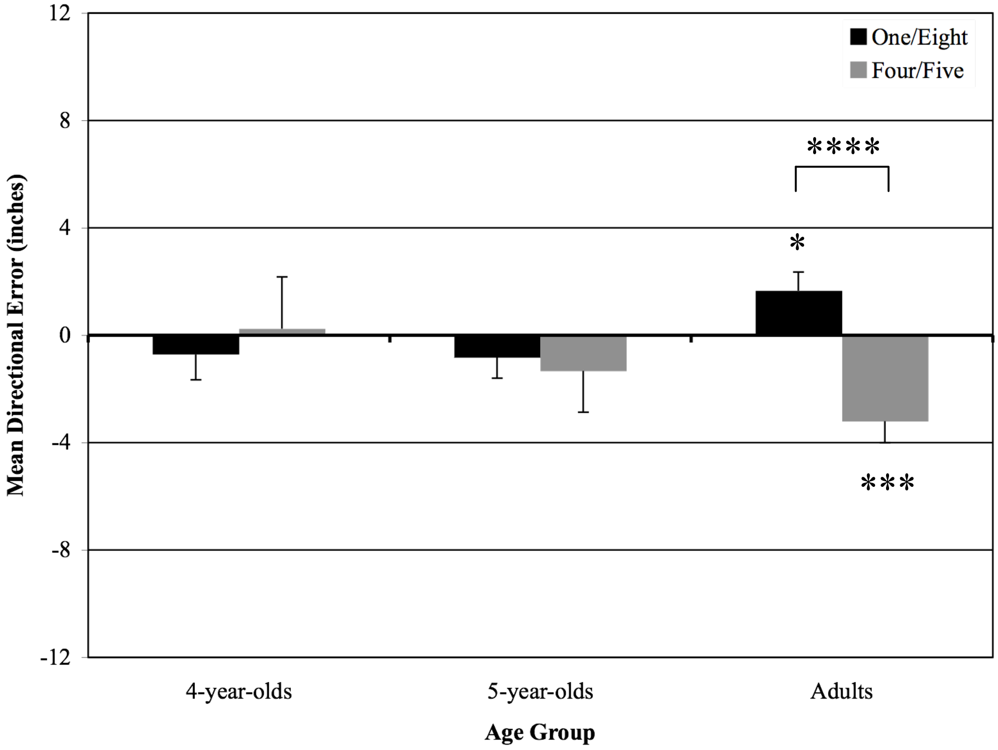

Figure A7. Mean directional error scores for each age group and location in the test on extra large mat condition in Preliminary Experiment A.

Note: Asterisks denote significant results (* $p < .05$, *** $p < .001$) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). In addition, directional error scores for locations were compared to one another and those that are significantly different are indicated by **** ($p = .0001$).

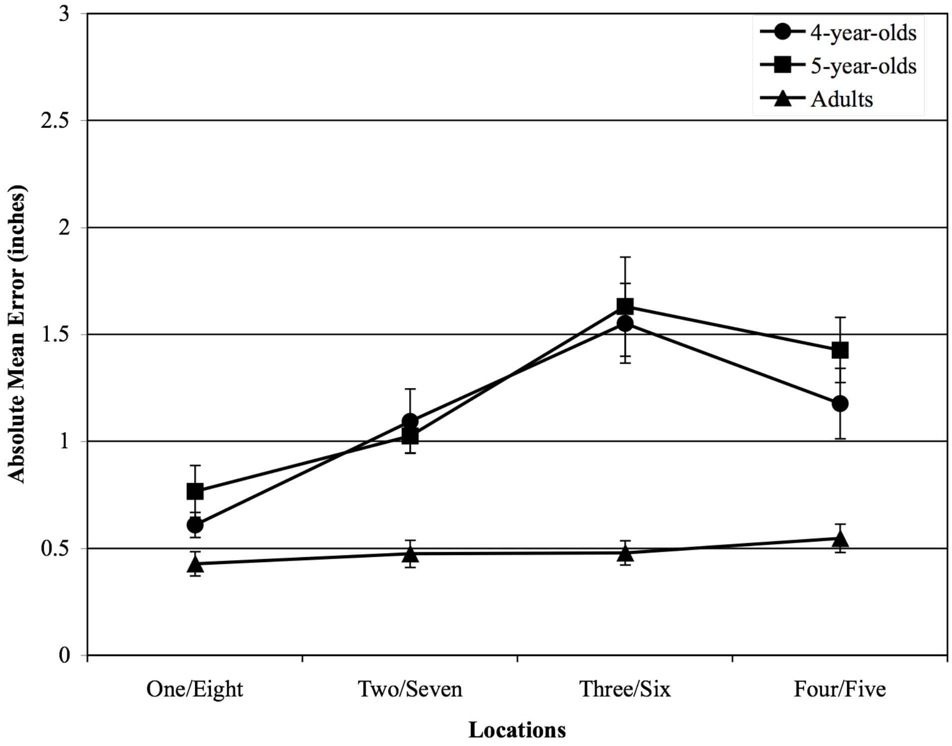

Figure A8. Absolute mean error for each age group and location in the test on small mat condition in Preliminary Experiment B.

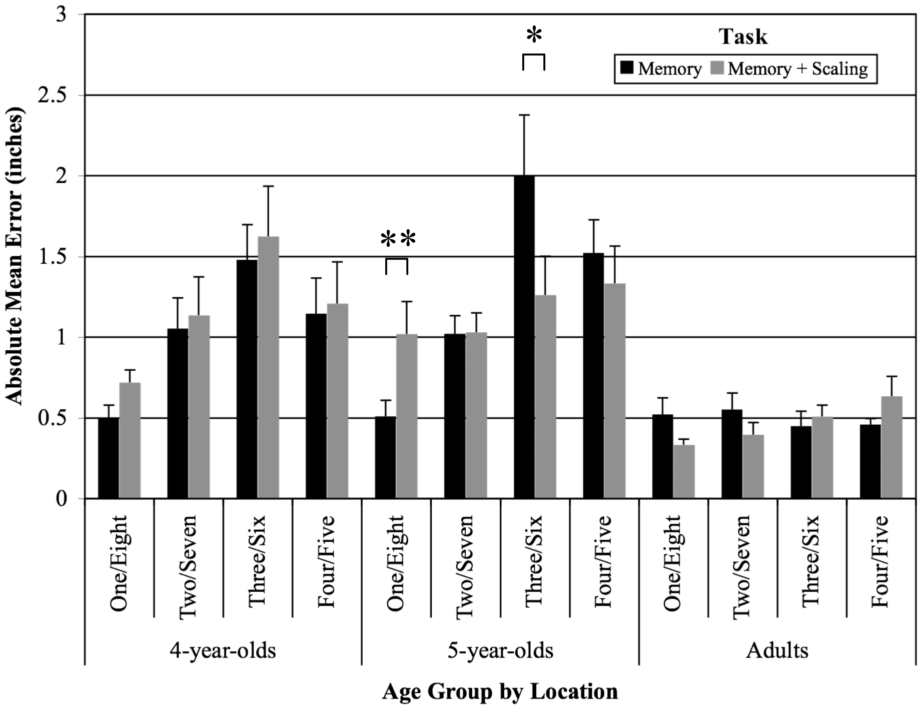

Figure A9. Absolute mean error in the test on small mat condition in Preliminary Experiment B: Age by location by task interaction.

Note: Asterisks denote significant results (* $p < .05$, ** $p < .01$).

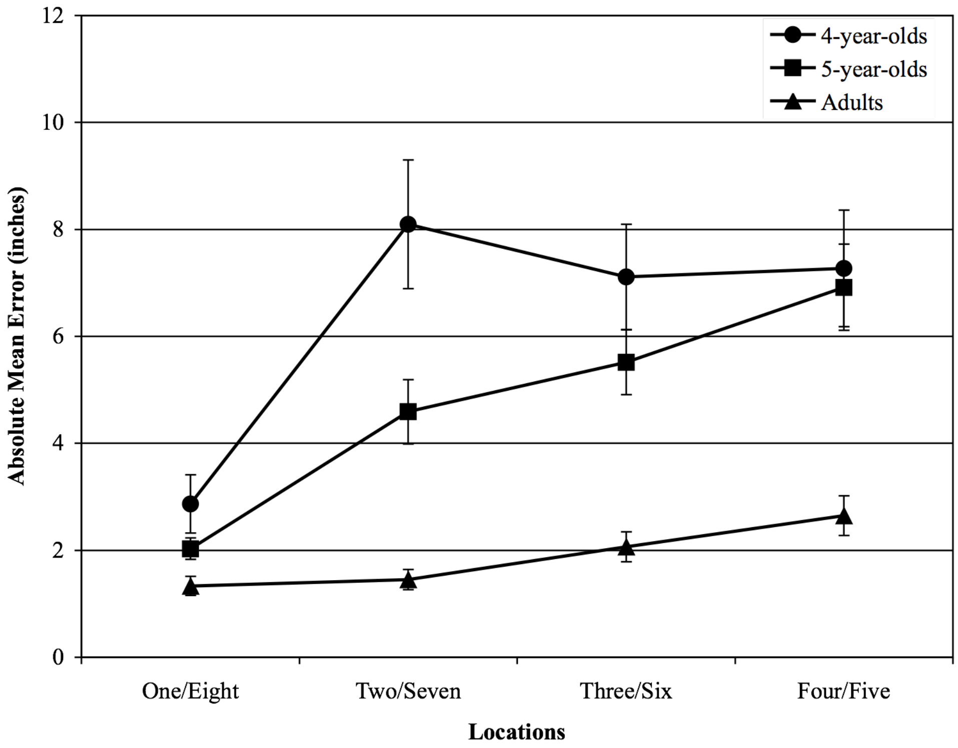

Figure A10. Absolute mean error for each age group and location in the test on large mat condition in Preliminary Experiment B.

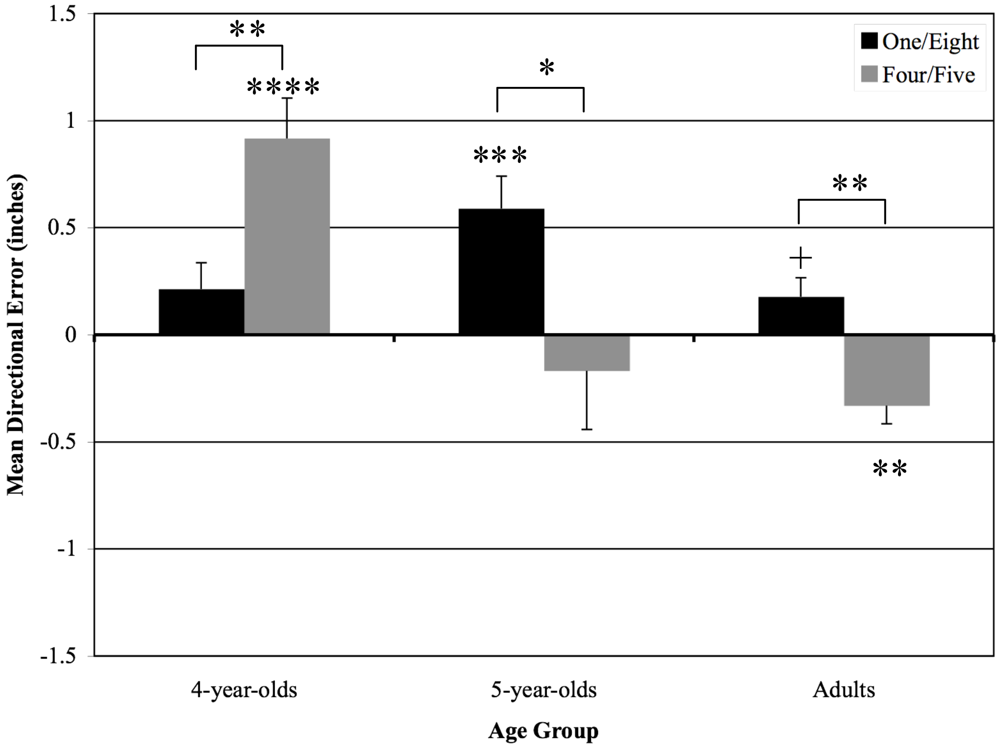

Figure A11. Mean directional error scores for each age group and location in the test on small mat condition in Preliminary Experiment B.

Note: Asterisks denote significant results (** $p < .01$, *** $p < .001$, **** $p < .0001$) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). The plus sign denotes a marginally significant result ($p \leq .06$) for a one-sample *t*-test. In addition, directional error scores for locations were compared to one another and those that are significantly different are indicated by * ($p < .05$) or ** ($p < .01$).

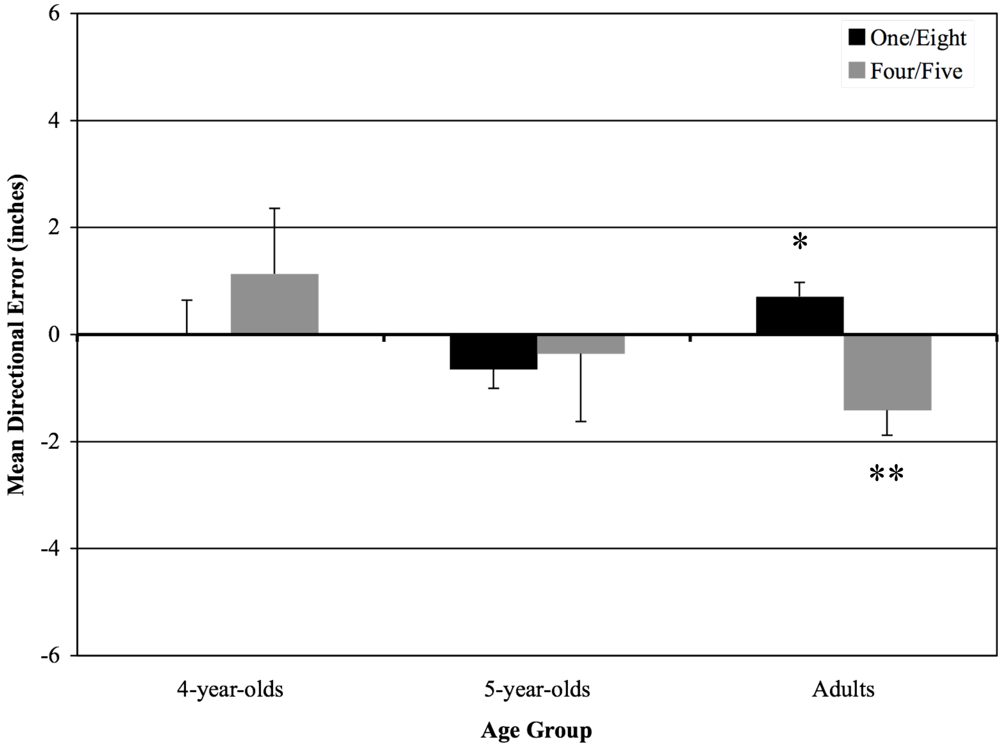

Figure A12. Mean directional error scores for each age group and location in the test on large mat condition in Preliminary Experiment B.

Note: Asterisks denote significant results (* $p < .05$, ** $p < .01$) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.).

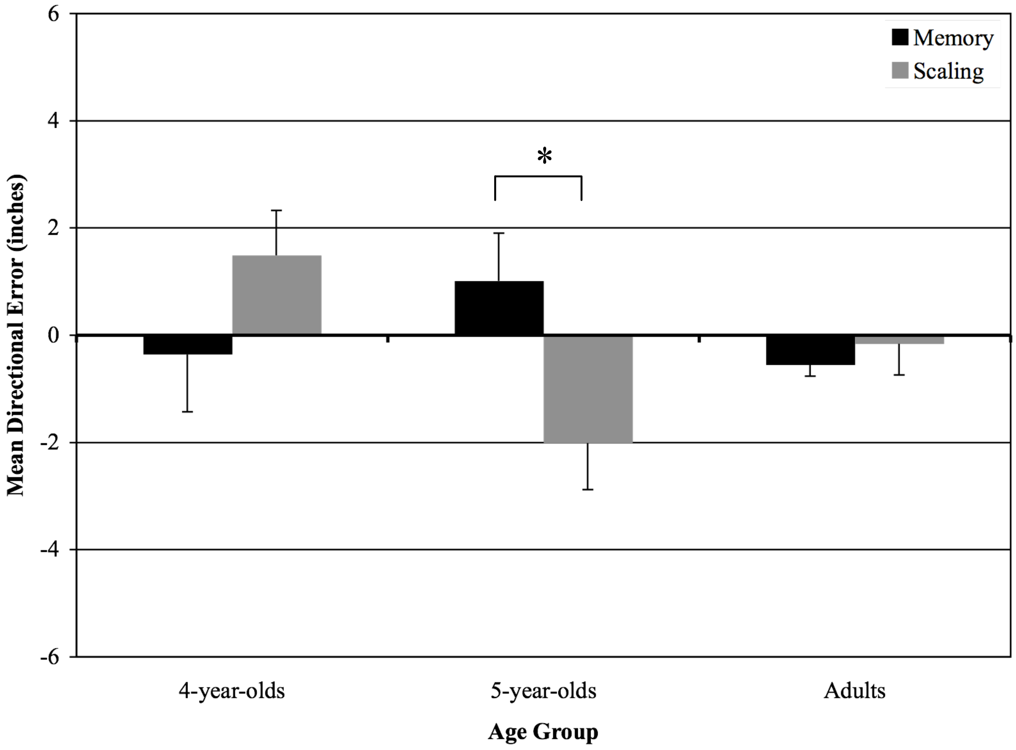

Figure A13. Mean directional error scores for each age group and task in the test on large mat condition in Preliminary Experiment B.

Note: Asterisks denote significant results (*p* < .05).

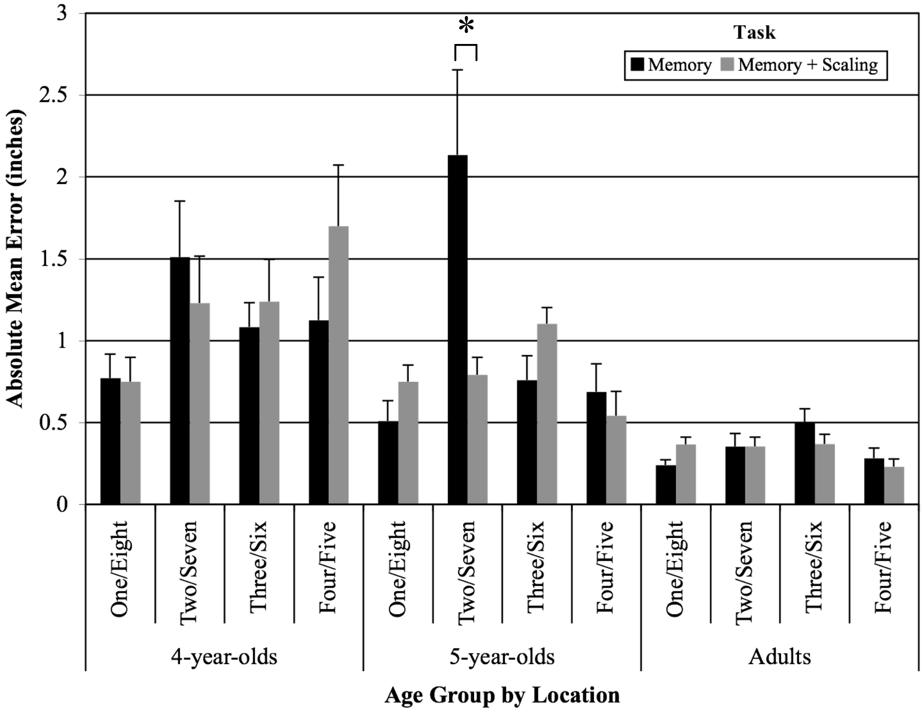

Figure A14. Absolute mean error in the test on small mat with boundary condition in Experiment 1: Age by location by task interaction.

Note: Asterisks denote significant results (*p* < .05).

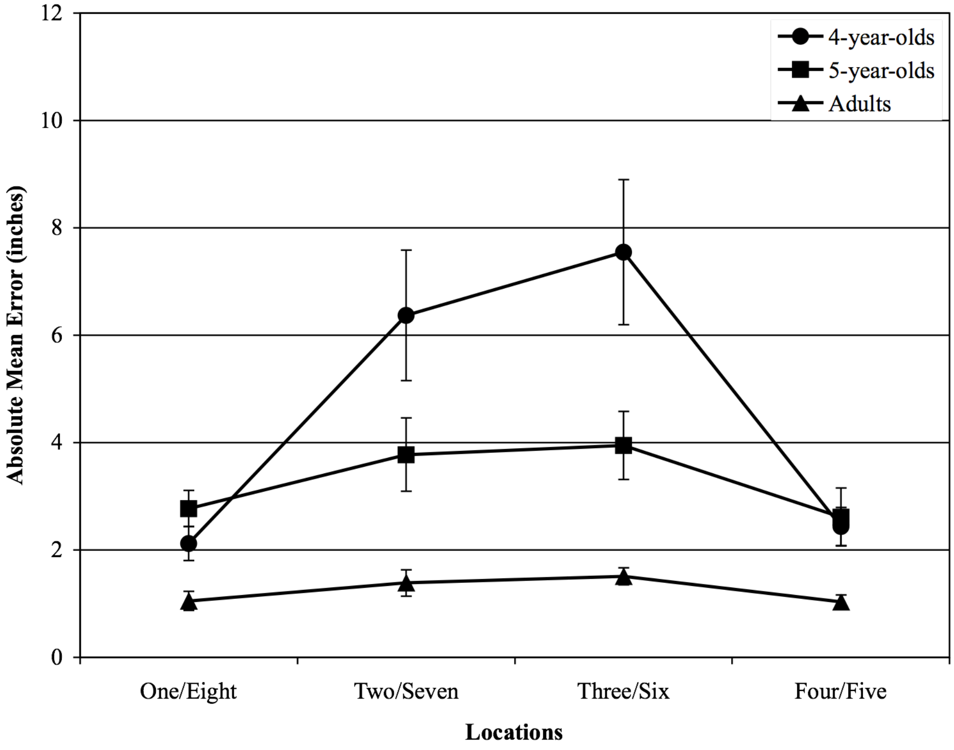

Figure A15. Absolute mean error for each age group and location in the test on large mat with boundary condition in Experiment 1.

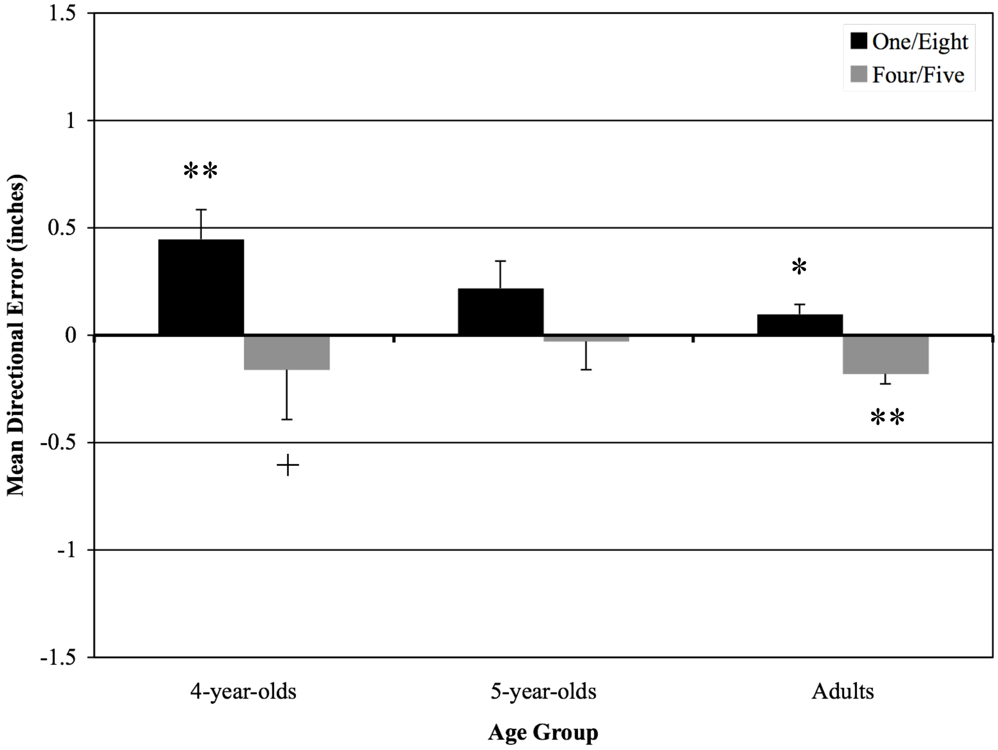

Figure A16. Mean directional error scores for each age group and location in the test on small mat with boundary condition in Experiment 1.

Note: Asterisks denote significant results (* $p < .05$, ** $p < .01$) of one-sample t-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). The plus sign denotes a marginally significant result ($p = .06$) from a one-sample t-test.

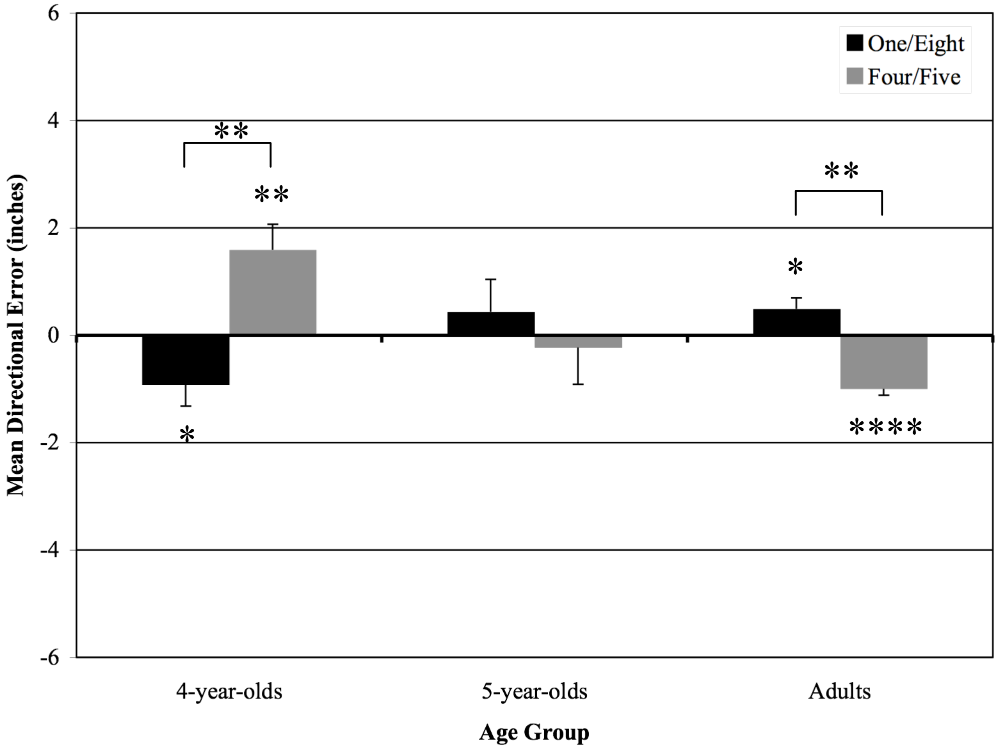

Figure A17. Mean directional error scores for each age group and location in the test on large mat with boundary condition in Experiment 1.

Note: Asterisks denote significant results (* $p < .05$, ** $p < .01$, **** $p < .0001$) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). In addition, directional error scores for locations were compared to one another and those that are significantly different are indicated by ** ($p < .01$).

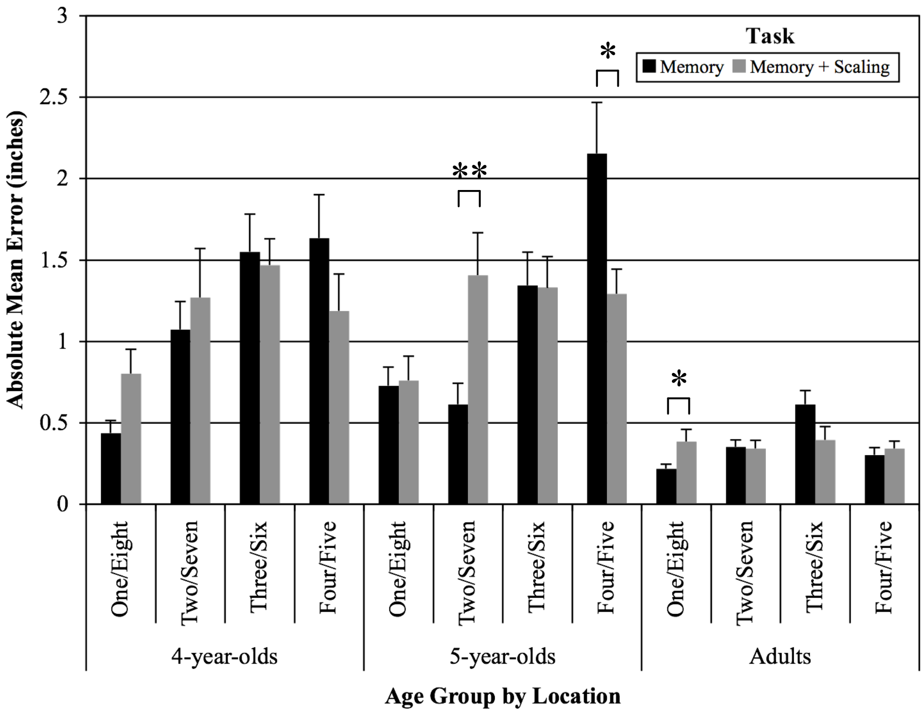

Figure A18. Absolute mean error in the test on small mat condition in Experiment 2: Age by location by task interaction.

Note: Asterisks denote significant results (* *p* < .05, ** *p* < .01)

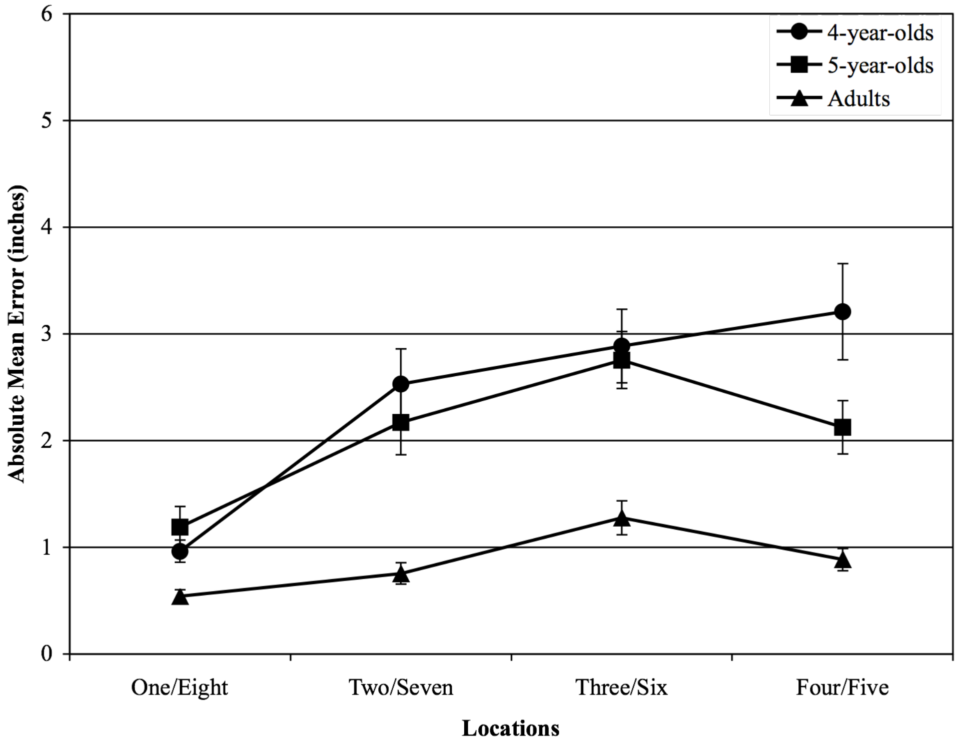

Figure A19. Absolute mean error for each age group and location in the test on medium mat condition in Experiment 2.

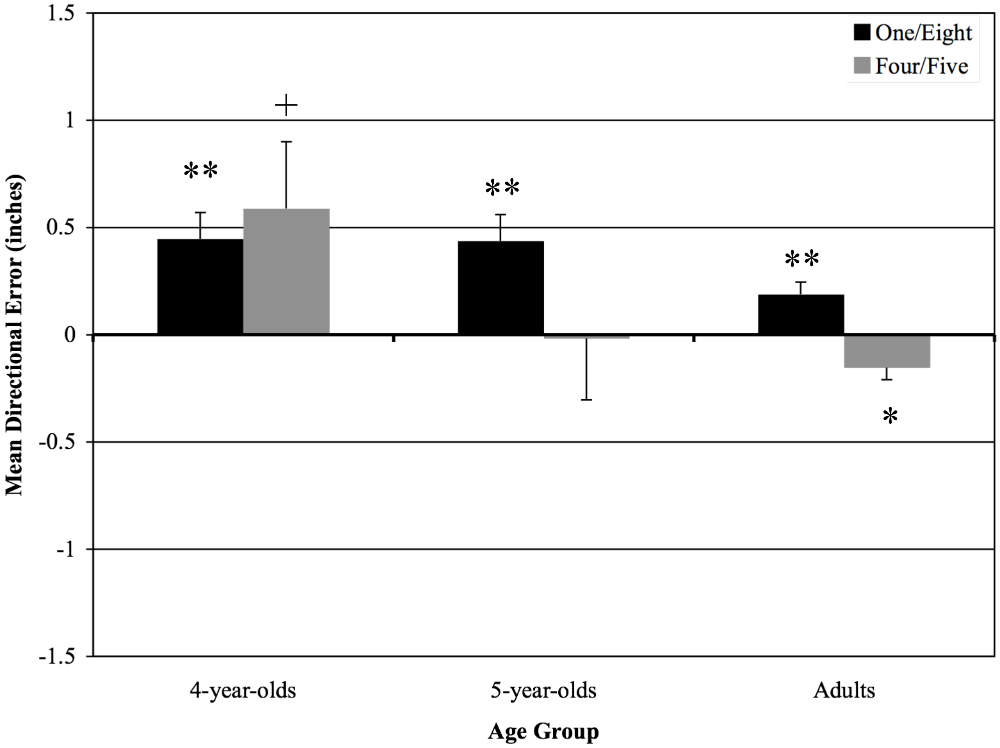

Figure A20. Mean directional error scores for each age group and location in the test on small mat condition in Experiment 2.

Note: Asterisks denote significant results (* *p* < .05, ** *p* < .01) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). The plus sign denotes a marginally significant result (*p* = .07) from a one-sample *t*-test.

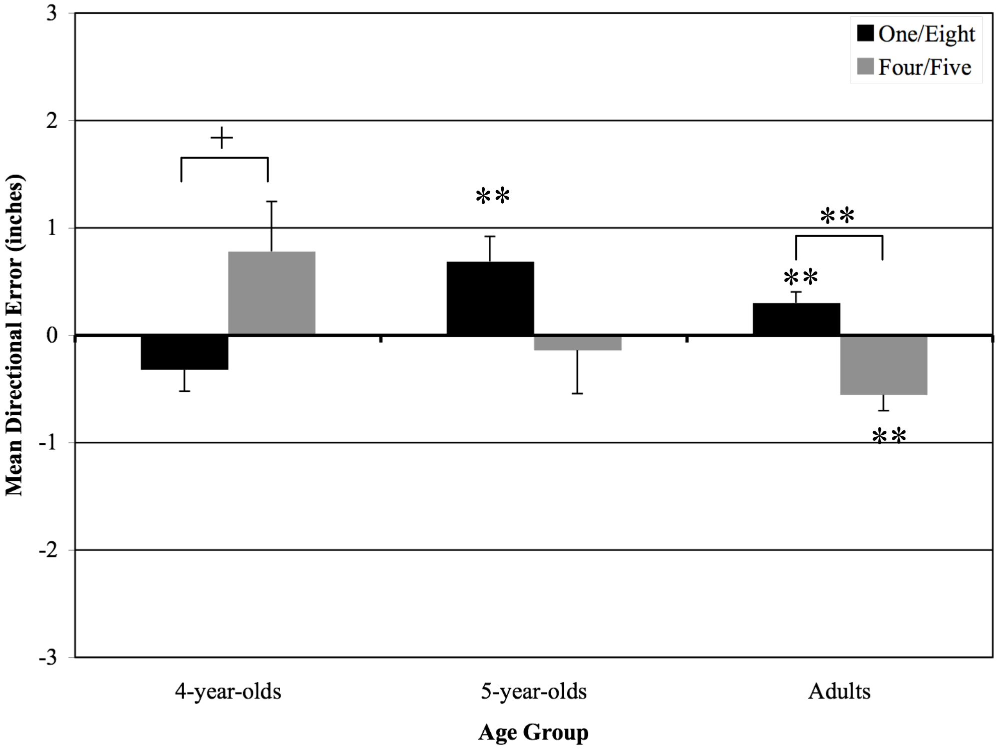

Figure A21. Mean directional error scores for each age group and location in the test on medium mat condition in Experiment 2.

Note: Asterisks denote significant results (** *p* < .01) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). In addition, directional error scores for locations were compared to one another and those that are significantly different are indicated by ** (*p* < .01) and those that are marginally significant are indicated by + (*p* = .06).

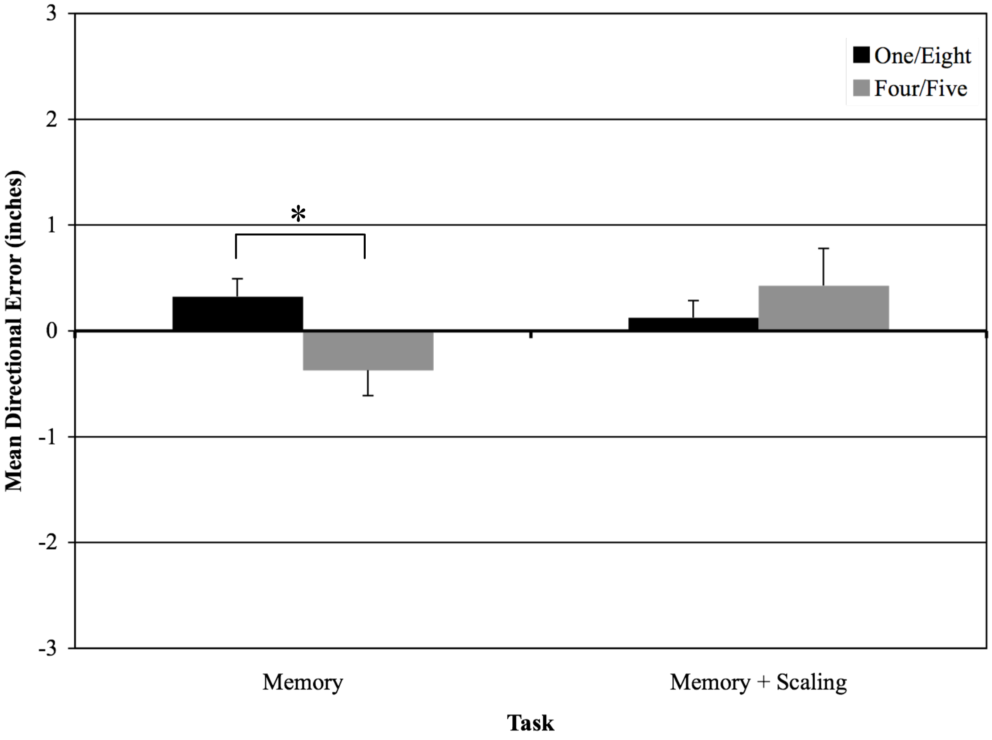

Figure A22. Mean directional error scores for each task and location set in the test on medium mat condition in Experiment 2.

Note: Asterisks denote significant results ($p < .05$).

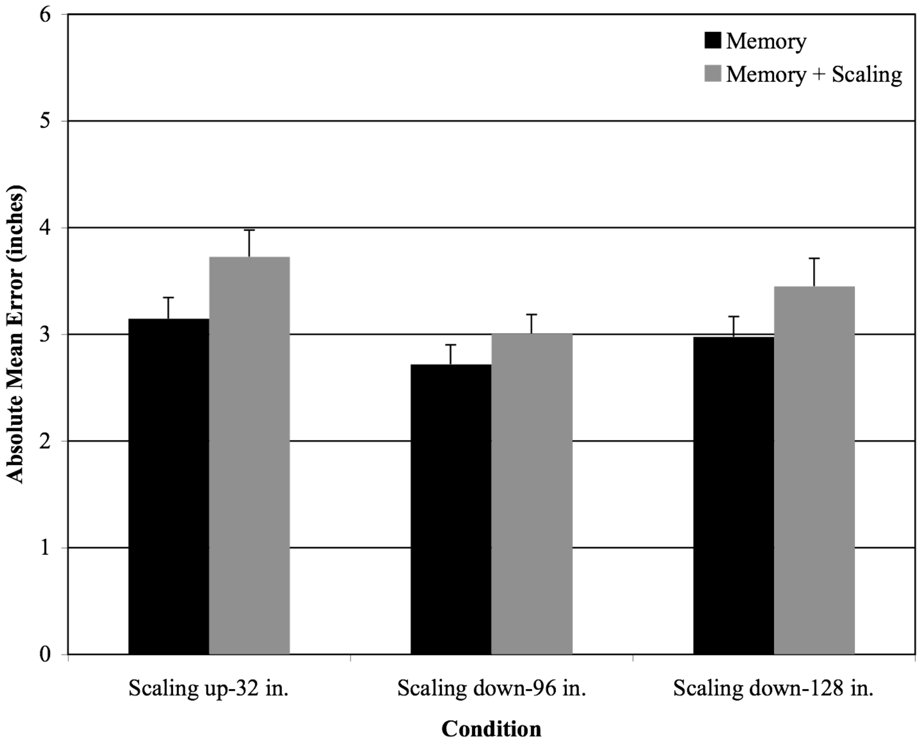

Figure A23. Absolute mean error for each condition and task in Experiment 3.

Note: Results from this experiment did not reveal a significant interaction between task and condition.

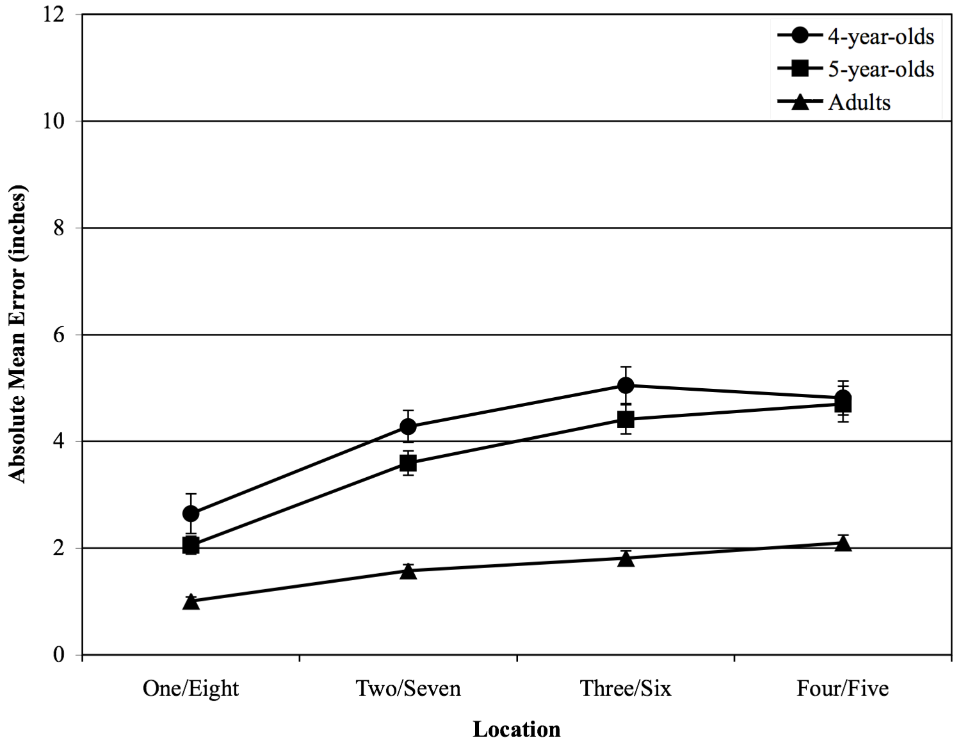

Figure A24. Absolute mean error for each age group and location in Experiment 3.

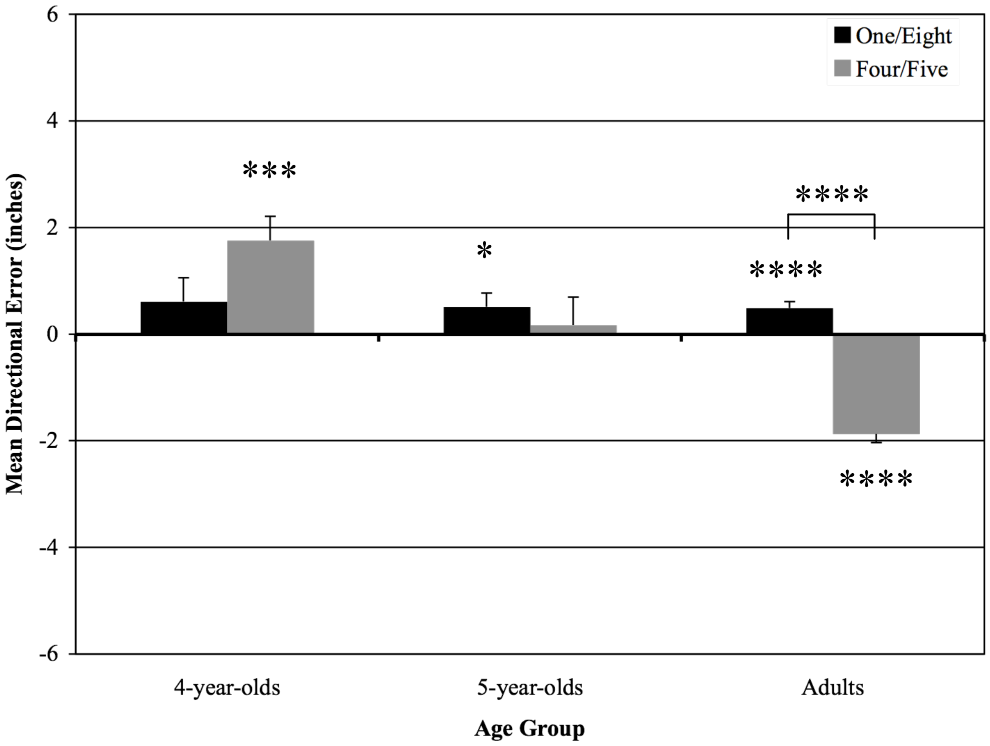

Figure A25. Mean directional error scores for each age group and location set in Experiment 3.

Note: Asterisks denote significant results (* *p* < .05, *** *p* < .001, *p* ≤ .0001) of one-sample *t*-tests (df = 23) comparing directional error scores to the expected score with no bias (i.e., 0 in.). In addition, directional error scores for locations were compared to one another and those that are significantly different are indicated by **** (*p* < .0001).

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