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The stability and flexibility of spatial categories☆

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Abstract

Four experiments examined the flexibility and stability with which children and adults organize locations into categories based on their spatiotemporal experience with locations. Seven-, 9-, 11-year-olds, and adults learned the locations of 20 objects in an open, square box. During learning, participants experienced the locations in four spatiotemporally defined groups (i.e., four sets of nearby locations learned together in time). At test, participants attempted to place the objects in the correct locations without the aid of the dots marking the locations. Children and adults displaced the objects toward the corners of the box consistent with the organization they experienced during learning, suggesting that they used spatiotemporal experience to organize the locations into groups. Importantly, the pattern of organization remained the same following a long delay for all four age groups, demonstrating stability. For adults, this organization shifted after a new pattern of spatiotemporal experience was introduced, suggesting that adults' categories based on spatiotemporal experience are quite flexible. Children only exhibited flexibility when the new pattern of spatiotemporal organization was consistent with available perceptual cues, demonstrating that the flexibility with which children organize locations into categories is intimately tied to both remembered and perceptual sources of information.

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1. Introduction

Stability and flexibility are two hallmarks of human cognition. Stability enables people to respond similarly when faced with similar situations or goals. For example, we tend to think of our pet dog, Rover, as a dog regardless of the situation in which we encounter him. Obviously, stability is critical for interacting successfully with items in the environment. Knowing that Rover is a dog allows us to make important predictions about how he will behave and how we should behave in response. In contrast, flexibility enables people to respond in different ways when faced with differing situations or goals. For example, we might categorize Rover with wolves and Great Danes when thinking about dogs. However, we might categorize our dog with family members, photo albums, and jewelry when thinking about things to remove from our burning home. As these examples illustrate, flexibility allows us to tailor our responses to the task at hand. Clearly, the ability to group items in the same way (i.e., stability) and in different ways (i.e., flexibility) is necessary for adaptive functioning. At present, relatively little is known about how people form categories that are both stable and flexible. Even less is known about how stability and flexibility operate across development. The goal of this investigation was to examine the stability and flexibility with which children and adults form categories.

1.1. Stability and flexibility in categorization

What processes give rise to categories that are both stable and flexible? In recent years, there has been a shift from viewing categories as static representations with inherent structures (e.g., Mandler, 1993; Mandler & McDonough, 1993; Mervis, 1985) toward viewing them as emergent products of cognitive processes (e.g., Barsalou, 1983, 1987, 2003; Jones & Smith, 1993; Madole & Oakes, 1999; Oakes & Madole, 2000; Smith, 2000; Smith & Heise, 1992; Smith & Samuelson, 1997; Thelen & Smith, 1994). According to this view, categories are created on-line from multiple sources of information for the purpose of solving specific tasks. Thus, remembered information, perceptually available information, and task goals all constrain the formation of on-line categories. Stability results from the repeated combination of the same cues in many task contexts, leading to similarities in emergent categories over time. In contrast, flexibility results from the combination of different pieces of information and from differences in the task at hand (e.g., making judgments about similarity vs. naming instances of a category).

Examining the stability and flexibility of categories enables researchers to understand the on-line dynamics of categorization processes. For example, repeatedly assessing category formation in the same situation provides details regarding the stability of category formation, thereby providing information about the emergence and maintenance of categories over time. Assessing category formation following different experiences provides information regarding the flexibility with which people form categories (Goldstone, 1995; Madole & Oakes, 1999; Oakes & Madole, 2000; Ross, 1996; Schyns & Murphy, 1994; Schyns & Rodet, 1997). Such investigations of category flexibility provide insights into how people combine remembered information, perceptually available information, and task goals to create on-line categories.

One common approach to studying category flexibility is to present the same items, but to provide different experiences with the items for people in different experimental conditions (e.g., Goldstone, 1995; Schyns & Murphy, 1994; Schyns & Rodet, 1997). Differences in performance across conditions would suggest that people can organize the items into different categories, depending on their experience with the items. For example, Goldstone (1995) investigated how classification experience with symbols influenced people's perception of the symbols. On each trial, adults viewed a symbol (e.g., a letter or number) that varied in redness and violetness. The participants' task was to adjust the color of another symbol to match the standard. The stimuli were constructed so that the letters were always redder than were the numbers. In general, people thought that the letters were redder than they really were and that the numbers were more violet than they really were. In particular, one letter and number were actually the same color, but people thought that their colors were different (e.g., they thought the letter was redder and the number was more violet). These differences across conditions revealed that experience with the symbols influenced color perception, demonstrating flexibility in perceptual processes.

In a similar set of studies, Schyns and Rodet (1997) examined whether people's experience with particular perceptual features influenced later classification performance. During training, participants learned to categorize Martian cells (e.g., circles containing various shapes). The order of experience with category members differed across conditions. At test, people were presented with new items and asked to categorize them. Categorization of these new items was consistent with their experience during the training phase, demonstrating flexibility in category formation. Similarly, Schyns and Murphy (1994) found not only flexibility in categorization based on particular experience, but stability across repeated testing experiences. Together, these findings show that experience with items influences the way people form categories, demonstrating flexibility and stability in categorization. One limitation of this work, however, is that conclusions about category flexibility were drawn from between-subjects comparisons (e.g., Goldstone, 1995; Schyns & Murphy, 1994; Schyns & Rodet, 1997). That is, flexibility in categorization was inferred when *different* groups of people categorized the same items in different ways following differing experiences with the items. An important next step in understanding the dynamics of categorization processes is to examine category flexibility by assessing categorization in the *same people* following differing experiences with the items to be categorized.

Our approach to studying category stability and flexibility focused on how children and adults organize locations into groups, or categories. We used the following research strategy to address these issues. The first step was to establish that children and adults could use a particular cue to form spatial categories. The cue we chose to use was spatiotemporal contiguity (i.e., experiencing nearby locations close together in time). Spatiotemporal contiguity is an ideal cue for investigating category stability and flexibility in the spatial domain because it is relatively easy to create different groupings of the same set of locations by manipulating which locations are experienced together in time. The second step was to examine whether *different* sets of participants formed different spatial categories when given different patterns of spatiotemporal experience. The final step was to examine whether the *same* participants could form spatial categories based on one pattern of spatiotemporal experience with a set of locations and then shift to new spatial categories based on a new pattern of spatiotemporal experience with the same set of locations. This research strategy allowed us to examine the stability and flexibility of spatial categories in a systematic fashion.

Why study spatial categorization? First, spatial categories are ideally suited for investigations of on-line categorization because it is relatively easy to teach people sets of locations and monitor their categorization over time. Second, exploring spatial categorization provides critical information regarding the domain-general nature of categorization processes. According to Madole and Oakes (1999), the processes by which people stably and flexibly organize items into categories are similar across various domains, despite differences in the content of the domains themselves. Although researchers have begun to investigate stability and flexibility in object categorization (Goldstone, 1995; Schyns & Murphy, 1994; Schyns & Rodet, 1997), relatively little is known about how stability and flexibility operate outside the domain of object categorization. Understanding what sorts of similarities and differences might exist across domains is critical for determining the extent to which the dynamic processes underlying category formation are in fact domain general.

1.2. Developmental changes in category stability and flexibility

Results from numerous studies document changes in children's categorization (e.g., Bauer & Mandler, 1989; Gelman & Markman, 1986; Madole & Cohen, 1995). Many of these studies have focused on developmental changes in children's reliance on thematic and taxonomic information (e.g., Baldwin, 1992; Bauer & Mandler, 1989; Imai, Gentner, & Uchida, 1994; Inhelder & Piaget, 1969; Smiley & Brown, 1979; Waxman & Namy, 1997). For example, Imai et al. (1994) found that 3-year-olds categorized based on thematic relations when asked to make similarity judgments, deciding that a birthday hat goes with a birthday cake. In contrast, older children tended to categorize based on taxonomic relations in these types of task (e.g., Inhelder & Piaget, 1969; Smiley & Brown, 1979).

What might account for these developmental changes in categorization? According to traditional accounts, differences in categorization result from qualitative changes in the underlying processes of categorization (Gelman & Markman, 1986, 1987; Keil, 1981, 1991; Mandler, 1988, 1992, 1993; Murphy & Medin, 1985; Wellman & Gelman, 1988). Mandler (1988, 1992, 1993) has proposed, for example, that early perceptual categorization gives way to later conceptual categorization. An alternative explanation is that the underlying process of categorization remains the same across development, but that the types of information children rely on to form categories (and the relative weighting of information) changes across development (Jones & Smith, 1993; Madole & Oakes, 1999; Murphy, 2002; Oakes & Madole, 2000; Quinn & Eimas, 1996; Smith & Heise, 1992; Smith & Samuelson, 1997). From this perspective, it is critical to understand how children and adults use available cues to form categories that meet the goals of their current task. Previous research has focused on documenting the types of cues infants and children use when forming categories. For example, young infants use highly visible cues such as color and shape to form object categories (Colombo, McCollam, Coldren, Mitchell, & Rash, 1990; Younger & Cohen, 1986). Not until the second year of life, however, do infants use less obvious cues such as function to form categories of objects (Madole & Cohen, 1995; Madole, Oakes, & Cohen, 1993). An important next step is to understand the circumstances in which children use cues to form categories. One way to address this issue is to examine developmental changes in category stability and flexibility.

How might stability and flexibility operate across development? From an on-line categorization perspective, developmental increases in stability result from an increasing ability to repeatedly extract the same cues across situations and note similarities in task structures, whereas developmental increases in flexibility result from an increasing ability to extract new cues across situations and note differences in task structures. One might expect that children more easily capitalize on real-time experiences with category cues and task goals that point to a consistent organization of locations than they capitalize on category cues and task goals that suggest a new organization of those same locations. In other words, children should demonstrate the ability to form stable organizations of locations before they demonstrate the ability to flexibly shift to new organizations of those same locations. In support of this view, Plumert (1994) found that when 10- and 12-year-olds were asked to recall the names of objects that were previously placed in four rooms, both age groups organized their recall by object category (i.e., vehicles, animals, clothing, and furniture). When subsequently asked to recall *both* the names and the locations of those same objects, however, only the 12-year-olds organized their recall by spatial category (i.e., room). Ten-year-olds continued to organize their recall by object category. These results suggest that there are developmental increases in the flexibility of spatial categorization.

1.3. Spatiotemporal contiguity as a cue for forming spatial categories

One cue that people use to form spatial categories is spatiotemporal experience. For example, suppose a child and parent spend Saturday morning shopping at several downtown shops and stop for lunch at a nearby restaurant. This spatiotemporal experience (and similar experiences on other days) may lead the child (and parent) to create a spatial category that includes downtown businesses. According to McNamara, Halpin, and Hardy (1992), this kind of spatiotemporal experience facilitates spatial categorization by highlighting relations among locations. That is, experiencing several nearby locations close together in time may create a cohesive spatial group. As the previous example demonstrates, spatiotemporal contiguity might be particularly important in situations where clearly defined spatial boundaries are lacking. In these cases, people might rely on their experience with individual locations to decide which locations go together, thereby forming a spatial category (see McNamara, Hardy, & Hirtle, 1989 for related ideas).

Several researchers have investigated whether spatiotemporal contiguity influences how adults remember locations (e.g., Clayton & Habibi, 1991; Curiel & Radvansky, 1998; McNamara et al., 1992; Sherman & Lim, 1991). Clayton and Habibi (1991), for example, used a spatial priming task to examine whether spatial and temporal contiguity plays a role in how people organize locations into groups. First, adults learned the locations of several cities on a fictitious map. In the correlated condition, nearby locations were presented contiguously in time, and distant locations were separated in time. In the uncorrelated condition, nearby and distant locations were presented contiguously in time. Following learning, participants completed a recognition task that involved judging whether or not city names had appeared during learning. Participants in the correlated condition were faster to recognize a city name when it was preceded by a nearby city than when it was preceded by a distant city (i.e., a spatiotemporal priming effect). Thus, when people learned the locations of nearby cities close together in time, they organized these locations into groups. These findings suggest that spatiotemporal contiguity plays an important role in adults' ability to form spatial groups.

Recently, we investigated whether children could use spatiotemporal contiguity and visible boundaries to organize locations into groups (Hund, Plumert, & Benney, 2002). Seven-, 9-, and 11-year-old children and adults learned the locations of 20 objects in an open, square box. Opaque walls or lines divided the box into four identical regions. The locations were marked by 20 dots on the floor of the box. Participants learned the locations either region by region or in a random order. During test, participants attempted to place the objects in the correct locations without the presence of the dots and the boundaries. In the random learning condition, only the adults significantly underestimated distances between locations in the same group. In the contiguous learning condition, however, 9- and 11-year-olds and adults significantly underestimated distances between locations in the same grouping, suggesting that they formed spatial groups following spatiotemporally contiguous experience with nearby locations. Overall, these findings indicate that 9- and 11-year-olds and adults can use spatiotemporal experience and visible boundaries to form spatial categories (for related results, see Hund & Spencer, 2003; Schutte & Spencer, 2002; Schutte, Spencer, & Schöner, 2003; Spencer & Hund, 2002, 2003; Spencer, Smith, & Thelen, 2001). These findings provide preliminary support for the notion that children can use spatiotemporal cues to form spatial categories when these cues are presented in combination with visible boundary cues. Nonetheless, it is necessary to assess the effects of spatiotemporal contiguity in the absence of visible boundaries to clearly determine the role of spatiotemporal contiguity in spatial category formation.

2. Experiment 1

The primary goal of Experiment 1 was to establish that children and adults could use spatiotemporal contiguity alone (e.g., in the absence of visible boundaries) to organize locations into groups. The second goal of Experiment 1 was to examine the degree of spatiotemporal contiguity needed to form spatial categories in our task. In previous studies that have directly manipulated spatiotemporal experience, researchers have compared an experimental condition in which spatial and temporal contiguity are *perfectly* correlated to a control condition in which spatial and temporal orders are randomly determined (e.g., Hund et al., 2002; Sherman & Lim, 1991). Although these studies have found clear differences between conditions, it is not yet known whether a less consistent relation between spatial and temporal contiguity would also facilitate category formation. This is an important issue because very little is known about children's ability to exploit statistical regularities that are less than perfect. For example, studies of infants' use of statistical information to detect word boundaries have examined infants' ability to exploit transitional probabilities between words of 1.0 (e.g., Saffran, Aslin, & Newport, 1996). To investigate children's ability to use less than perfect statistical regularities, we varied the magnitude of the correlation between spatial and temporal contiguity during the learning phase of Experiment 1. In addition to the randomly ordered and perfectly correlated conditions included in previous studies, we included another condition in which participants experienced 75% of the locations in the same region together in time during learning. This allowed us to examine how the strength of the correlation between spatial and temporal contiguity affects whether children and adults organize locations into groups.

As in previous work, 7-, 9-, and 11-year-old children and adults learned the locations of 20 objects in an open, square box. To investigate the influence of spatiotemporal experience, participants experienced four sets of nearby locations in a completely contiguous order, a partially contiguous order, or a random order during learning. The locations experienced together in time were inconsistent with the perceptual structure of the task space (e.g., the axes of symmetry dividing the box into four quadrants), providing a *strong test* of people's ability to use spatiotemporal cues alone (i.e., in the absence of visible boundaries and perceptual symmetry axes) to form spatial groups. Based on previous findings, we expected that the older children and adults in the completely contiguous condition would organize the locations into groups based on their spatiotemporal experience. In contrast, we predicted that the younger children would have difficulty using spatiotemporal cues alone to organize locations into groups. We expected that only the adults in the partially contiguous condition would organize the locations into groups. These findings would suggest that children require highly consistent spatiotemporal organization to form spatial groups, whereas adults can use less consistent spatiotemporal organization to form spatial groups.

2.1. Method

2.1.1. Participants

One hundred forty-four 7-, 9-, and 11-year-old children and adults participated. There were 36 participants in each age group, with approximately equal numbers of males and females in each group. The mean ages were 7 years 8 months (range = 7 years 4 months to 7 years 11 months), 9 years 4 months (range = 9 years 0 months to

10 years 3 months), 11 years 4 months (range = 10 years 9 months to 12 years 0 months), and 18 years 11 months (range = 18 years 0 months to 21 years 5 months), respectively. Five additional 7-year-olds were excluded because they did not reach the learning criterion. One additional 9-year-old was excluded because he did not finish the testing session. One additional adult was excluded due to an experimenter error. Children were recruited from a child research participant database maintained by the Department of Psychology at the University of Iowa, announcements in university publications, and referrals from other participants. Parents received a letter describing the study followed by a telephone call inviting children to participate. Most children were from middle- to upper-middle-class European American families. Adults participated to fulfill research credit in their introductory psychology course at the University of Iowa.

2.1.2. Apparatus and materials

A 32-in. long × 32-in. wide × 13-in. high open square box with white exterior walls was used as the experimental space. The floor of the box consisted of a layer of Plexiglas and a layer of plywood separated by a 1/2-in. space. Removable boards could be inserted between the plywood and the Plexiglas to change the appearance of the floor. Three floors were used in this experiment: (a) a blue carpeted floor with yellow dots on it, (b) a blue carpeted floor with no dots, and (c) a grid of *x*- and *y*-coordinates at 1/2-in. intervals.

The box contained 20 locations marked by 3/4 in. yellow dots (see Fig. 1). These locations were arranged so that they could be organized in two specific ways—each forming four groups of five locations. In one case, the groups were along the sides of

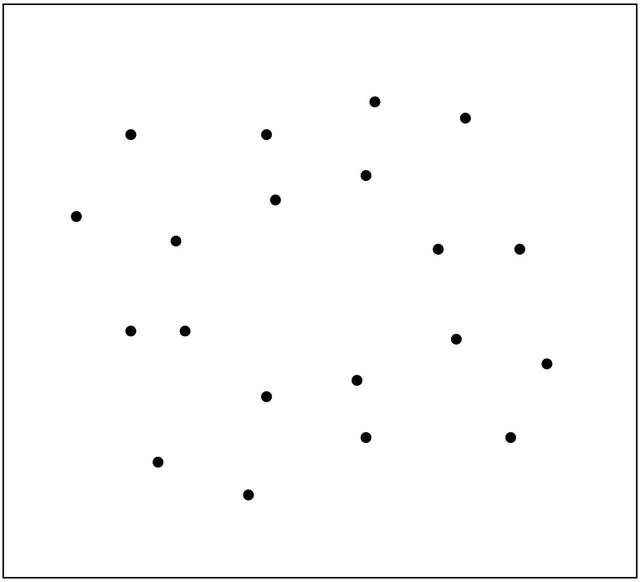

Fig. 1. Diagram of the experimental apparatus and locations.

the box (i.e., the side-defined groups, see Fig. 2A), and in the other case, the groups were defined by the quadrants of the box (i.e., the quadrant-defined groups, see Fig. 2B). To ensure that these different patterns of organization were equated in terms of distance between locations, both the average distance between locations in each group (side-defined group: $M = 5.68$ in., quadrant-defined group: $M = 5.71$ in.) and the average perimeter of the groups (side-defined group: $M = 28.41$ in., quadrant-defined group: $M = 28.54$ in.) were identical across organization types. Both patterns of organization resulted in groups of locations that were irregularly shaped, unlike the "circular" configurations of locations used in our previous work (Hund & Plumert, 2002, 2003; Hund et al., 2002; Plumert & Hund, 2001).

Eight target locations differentiated between the two patterns of organization. As can be seen in Fig. 2, the target locations were included in different groups depending on whether the side-defined or quadrant-defined groups were highlighted. Note that the target locations were physically closer to the corners corresponding to the quadrant-defined groups than to the corners corresponding to the side-defined groups. That is, for each side-defined group of locations, the target locations were on the opposite side of the quadrant boundary relative to the non-target locations. This design was intentional because it meant that the side-defined groups were inconsistent with the perceptual structure of the task space (e.g., the axes of symmetry dividing the box into four quadrants) and therefore provided a strong test of people's ability to use spatiotemporal cues alone to form spatial groups.

Twenty miniature objects were used during the experiment to help participants learn the locations in the box: a pot, a bear, a birdhouse, a pie, an iron, a paint can, a picture, a book, a purse, a watering can, a present, a fishbowl, an apple, a trashcan, a

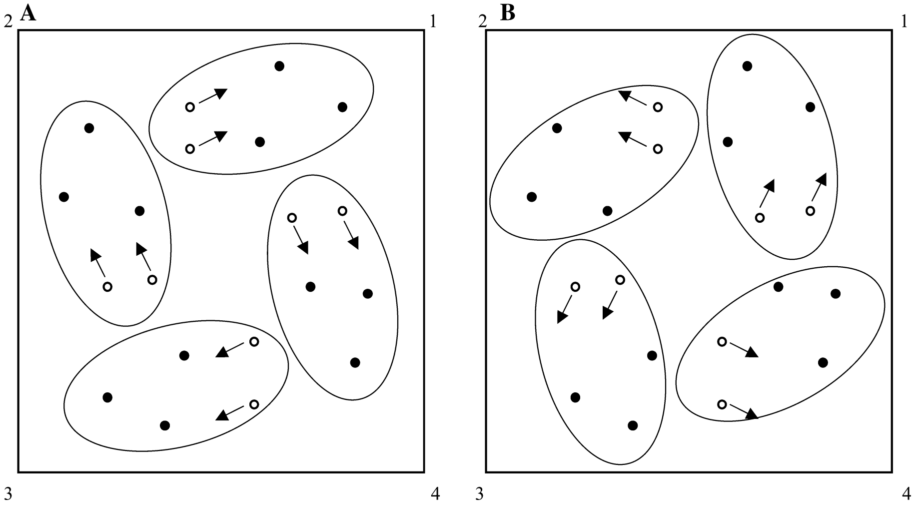

Fig. 2. Diagram of the experimental apparatus and locations. Open circles mark the eight target locations. Arrows show the predicted pattern of displacement for the target locations. (A) The locations experienced together in the side experience condition. (B) The locations experienced together in the quadrant experience condition. The arrows, ovals, and numbers are for illustration only.

hat, a pail, a toy plastic person, a bag of chips, a jar of honey, and a beverage carton. The average length and width of the objects was .71 and .63 in., respectively.

2.1.3. Design and procedure

Participants were randomly assigned to one of three conditions: random learning, partially contiguous learning, or completely contiguous learning. These conditions differed based on the magnitude of the correlation between spatial and temporal contiguity during the learning phase. Participants in the random learning condition experienced the locations in different random orders throughout learning. Participants in the partially contiguous learning condition experienced 75% of the locations belonging to each side-defined group together in time during each learning trial. Participants in the completely contiguous learning condition experienced all locations belonging to each side-defined group together in time during each learning trial. Only the side-defined groups were used in this experiment. As mentioned above, these groups provided a strong test of people's ability to use spatiotemporal cues alone because the groups were inconsistent with the perceptual structure of the task space. (The quadrant-defined groups served as an alternative pattern of organization here and were experienced together in time in the subsequent experiments.)

Participants were tested individually in a laboratory room at the Department of Psychology. The open, square box was placed on the floor of the experimental room. At the beginning of the experiment, the experimenter stood in front of the box, and participants were seated to the right of the experimenter facing an adjacent side of the box (see Fig. 1).

The experiment was divided into a learning phase and a test phase. During the learning phase, participants learned the locations of the 20 objects in the open, square box. At the beginning of the session, the experimenter told participants that 20 objects would be placed in the box and that they should try to remember the locations of the objects because they would be asked to replace the objects later. The locations corresponded to the 20 yellow dots on the floor of the box. Participants watched as the experimenter named the objects and placed them in the box one at a time. In the random learning condition, the experimenter placed the objects in a random order. In the partially contiguous learning condition, the experimenter placed 75% of the objects belonging to each group contiguously in time, whereas the remaining 25% were placed in a random order. In the completely contiguous learning condition, the experimenter placed all five objects belonging to one side-defined group before placing all of the objects belonging to another group. Both the order of groups and the order of locations within each group were randomized for participants in the completely contiguous learning condition. The order of groups and remaining "random" locations, the order of locations within each group, and the order of the random locations were randomized for participants in the partially contiguous learning condition. The order of locations was randomized for participants in the random learning condition. In addition, the pairings of objects and locations were randomized for each participant, regardless of learning condition.

Immediately after the experimenter placed all 20 objects, participants turned around while the experimenter removed the objects from the box. Then, the experimenter gave the objects to participants one at a time and asked them to place them in the correct locations. The order of placement differed depending on learning condition. Participants in the random learning condition placed the objects in a new random order. Participants in the partially contiguous learning condition placed 75% of objects belonging to the same side-defined group together in time, providing a moderate correlation between spatial and temporal contiguity. The objects placed together in time varied on each trial. Participants in the completely contiguous learning condition placed all objects from one side-defined group before placing those belonging to another group, providing a perfect correlation between spatial and temporal contiguity. The experimenter presented the objects in a new order on each trial. Thus, the order of groups and locations within each group were randomized for each learning trial for the completely contiguous learning condition. The order of groups and random locations, the locations within each group, and the remaining random locations were randomized for each learning trial for the partially contiguous learning condition. The order of locations was also randomized for each learning trial for the random learning condition. Participants were allowed to move around the outside of the box to place the objects during learning trials. The experimenter immediately corrected any placement errors. The objects were removed immediately after the last one had been placed.

Learning trials continued until participants could correctly place all 20 objects (i.e., on the corresponding yellow dots) in a single trial. The mean number of trials to criterion for 7-, 9-, 11-year-olds, and adults were 4.22 ($SD = 1.64$), 4.11 ($SD = 1.89$), 2.92 ($SD = 1.05$), and 2.72 ($SD = 1.19$), respectively. The mean number of learning trials did not differ across conditions (completely contiguous: $M = 3.33$, $SD = 1.55$; partially contiguous: $M = 3.65$, $SD = 1.64$; random: $M = 3.50$, $SD = 1.68$).

The test phase began immediately following the learning phase. First, the experimenter asked the participants to turn away from the box while the objects were removed. The experimenter also removed the floor with the yellow dots and replaced it with a plain blue floor. Participants then were asked to face the box and try to replace the objects in the correct locations. Thus, participants attempted to place the objects in the correct locations without the aid of the yellow dots marking the locations. Participants replaced the objects in any order they chose. After participants left, the experimenter removed the blue floor and replaced it with the grid floor of x- and y-coordinates. Then, the experimenter recorded the position of each object (i.e., x- and y-coordinates) to the nearest 1/2 in.

2.1.4. Coding

A placement was considered "correct" if it was in the correct position relative to the other objects. The experimenter decided which object was in each location immediately following each test session. Occasionally, participants preserved the overall configurations of objects, but incorrectly paired objects and locations. As in previous studies (e.g., Hund & Plumert, 2002, 2003; Hund et al., 2002; Plumert & Hund, 2001), we used the x- and y-coordinates for these locations, regardless of whether the correct objects were placed in the locations. We substituted 0.56% of the locations for 7-year-olds (4 out of 720), 1.67% for 9-year-olds (12 out of 720), 0.56% for 11-year-olds

(4 out of 720), and 0.56% for adults (4 out of 720). These substituted locations were used in all analyses. As in previous experiments, objects placed in a completely wrong configuration were omitted from analyses. We omitted 0.28% of locations for 7-year-olds (2 out of 720), 0.83% for 9-year-olds (6 out of 720), 0.69% for 11-year-olds (5 out of 720), and 0.42% for adults (3 out of 720).

Inter-coder reliability estimates of object placement were calculated for 25 randomly selected participants (17% of the sample) using exact percentage agreement. For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 100% of the 500 locations coded.

2.1.5. Measures

2.1.5.1. Error score. Participants received a single *error score* reflecting the degree to which they placed objects near their actual locations in the memory task. This score was calculated by determining the distance between each remembered location and the corresponding actual location and then averaging these distances over all locations to obtain a single error score.

2.1.5.2. Displacement scores. Two displacement scores were calculated: a *side displacement score* and a *quadrant displacement score.* These scores were based on eight target locations, which were arranged so that side-defined organization (consistent with spatiotemporal experience) and quadrant-defined organization (consistent with perceptual cues) would lead to different patterns of displacement. Thus, examining displacement for these target locations differentiated between two potential patterns of organization (see Fig. 2). The side displacement score reflected the degree to which participants systematically placed the eight target objects closer to the corners corresponding to the side-defined groups than they actually were. Conversely, the quadrant displacement score reflected the degree to which participants systematically placed the eight target objects closer to the corners corresponding to the quadrant-defined group than they actually were.[1] To calculate the displacement scores, we first subtracted the distance between each remembered location and the corner from the distance between the corresponding actual location and the corner. We then averaged these differences across the eight target locations to obtain one side displacement score and one quadrant displacement score for each participant. These scores reflected the degree to which participants displaced locations toward the corners of the box (see Plumert & Hund, 2001 for a similar corner displacement score).

Conceptually, these displacement scores indirectly captured the *degree of separation between different categories* (i.e., between-category differentiation). This differentiation between categories is a common measure of categorical organization (e.g., Cohen, Baldwin, & Sherman, 1978; Cohen & Weatherford, 1980; Hartley & Homa, 1981; Homa, Rhoads, & Chambliss, 1979; Markman & Ross, 2003; Newcombe &

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[1] For example, consider the target locations at the top of Fig. 2. Corner 1 was used in calculating the side displacement score. In contrast, Corner 2 was used in calculating the quadrant displacement score.

Liben, 1982; Plumert & Hund, 2001; Tversky, 1977), capturing the tendency to think that things belonging to different categories are more different (or less similar) than they really are. One alternative to our focus on between-category differentiation is to focus on within-category similarity (i.e., the tendency to think that items belonging to the same category are more similar than they really are). For example, we could examine whether people displaced the target locations toward the centers of the groups of locations, suggesting that they remembered the category members as more similar than they really were. Preliminary analyses revealed that both children and adults displaced the target locations toward the corners of the box corresponding to the groups of locations rather than toward the centers of the groups of locations. At present, it is not known why people sometimes show bias consistent with between-category differentiation effects and sometimes show bias consistent with within-category similarity effects. We suspect that when people are confronted with irregularly shaped configurations of locations, they find it easier to anchor the groups to salient perceptual features of the space (e.g., the corners) than to the centers of the groups themselves. Further research is needed to address this issue.

2.2. Results

2.2.1. Error

To investigate possible differences in overall error among the age groups and experimental conditions, error scores were entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Condition (random learning, partially contiguous learning, and completely contiguous learning) Analysis of Variance (ANOVA) with two between-subjects factors. This analysis yielded a significant effect of age, $F(3, 132) = 12.30$, $p < .001$. Fisher's Protected Least Significant Difference (PLSD) follow-up tests indicated that 7-year-olds exhibited significantly greater error than did the other age groups. In addition, 9-year-olds showed significantly greater error than did the adults. The mean distance from correct locations was 2.82 in. ($SD = .60$) for 7-year-olds, 2.52 in. ($SD = .55$) for 9-year-olds, 2.32 in. ($SD = .50$) for 11-year-olds, and 2.11 in. ($SD = .41$) for adults.

2.2.2. Patterns of displacement

The primary question of interest was whether children and adults used spatiotemporally contiguous experience with the locations to organize the locations into groups. To address this question, displacement scores were analyzed in two ways. First, to examine whether participants in each age group and condition significantly displaced target locations toward the corners of the box, side and quadrant displacement scores for the target locations were compared to the expected score with no displacement (i.e., 0 in.) using one-sample t tests. If children and adults used spatiotemporal experience to form spatial categories, then side scores should be significantly greater than 0, and quadrant scores should not be significantly greater than 0. If, however, participants did not use spatiotemporal experience to organize the locations into groups, then side scores should not be significantly greater than 0. Displacement scores for each age group and condition can be seen in Table 1. In the

Table 1
Displacement scores (in inches) for each age group and condition in Experiment 1

Age	Score type	
	Side	Quadrant
7-year-olds		
Completely contiguous	.91 (.80)*	.33 (.78)
Partially contiguous	.60 (1.28)	.57 (.97)
Random	.21 (.86)	.74 (.57)*
9-year-olds		
Completely contiguous	.59 (1.21)	.13 (1.13)
Partially Contiguous	.53 (.81)*	.27 (.91)
Random	.78 (.81)*	.22 (.68)
11-year-olds		
Completely contiguous	1.15 (1.08)*	−.20 (1.06)
Partially contiguous	.29 (.87)	.42 (1.03)
Random	.42 (.83)	.43 (.72)
Adults		
Completely contiguous	.84 (1.02)*	−.13 (1.18)
Partially contiguous	.72 (.76)*	−.06 (.86)
Random	.15 (.78)	.27 (.74)
Overall		
Completely contiguous	.87 (1.03)	.03 (1.03)
Partially contiguous	.53 (.93)	.30 (.94)
Random	.39 (.83)	.41 (.69)

Note. Standard deviations are listed in parentheses. Asterisks denote significance ($p < .05$) on one-sample t tests comparing displacement scores to the expected score with no displacement (i.e., 0).

completely contiguous condition, 7- and 11-year-olds and adults placed the target objects significantly closer to the side-defined corners than they really were, ts(11) > 2.82, ps < .05. Displacement scores for 9-year-olds were in the predicted direction, but failed to reach statistical significance, $t(11) = 1.68, p < .13$. None of the groups placed the objects significantly closer to the quadrant-defined corners than they really were, ts(11) < 1.49, *ns*. These findings suggest that participants organized the locations into groups based on their spatiotemporal experience during learning. In the partially contiguous condition, 9-year-olds and adults placed the target objects closer to the side-defined corners than they really were, suggesting that they used the less consistent spatiotemporal cues to organize the locations into groups, ts(11) > 2.25, ps < .05. Again, none of the groups placed the objects significantly closer to the quadrant-defined corners than they really were, ts(11) < 2.05, *ns*. In the random condition, 9-year-olds placed the target objects closer to the side-defined corners than they really were, $t(11) = 3.34$, $p < .01$, and 7-year-olds placed the target objects significantly closer to the quadrant-defined corners than they really were, $t(11) = 4.49, p < .001$.

Second, side and quadrant displacement scores for the target locations were entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Condition (random learning, partially contiguous learning, and completely contiguous learning) × Score Type (side, quadrant) repeated-measures ANOVA with the first two factors as between-subjects factors and the third factor as a within-subjects factor.[2] This analysis yielded a significant effect of age, $F(3, 132) = 4.80, p < .005$. Follow-up tests indicated that, in general, 7-year-olds displaced the objects toward the corners significantly more than did the other three age groups. Displacement scores were .56 in. ($SD = .90$) for 7-year-olds,. 42 in. ($SD = .94$) for 9-year-olds, .42 in. ($SD = .99$) for 11-year-olds, and .30 in. ($SD = .95$) for adults.

More importantly, the analyses also yielded a significant effect of score type, $F(1, 132) = 5.78$, $p < .05$, and a significant Score Type × Condition interaction, $F(2, 132) = 3.08, p < .05$. Simple effects tests revealed that side and quadrant displacement differed significantly in the completely contiguous condition, $F(1,47) = 8.75$, $p < .005$, but not in the partially contiguous condition, $F(1,47) = .81$, *ns*, and not in the random condition, $F(1,47) = .01$, *ns*. Participants in the completely contiguous learning condition placed the objects significantly closer to the side-defined corners ($M = .87$ in., $SD = 1.03$) than to the quadrant-defined corners ($M = .03$ in., $SD = 1.03$), suggesting that they used their experience during learning to organize the locations into groups (see Table 1).

2.3. Discussion

The primary goal of this experiment was to investigate whether children and adults can use spatiotemporal experience with locations during learning to organize locations into groups. Although previous findings revealed that the combination of spatiotemporal contiguity and visible boundaries helped 9- and 11-year-old children and adults organize locations into groups (Hund et al., 2002), this study was the first to examine whether children and adults can use spatiotemporal experience alone to create spatial categories. Moreover, this experiment explored whether the strength of the correlation between spatial and temporal contiguity influenced the ease with which children and adults formed spatial categories. To address these issues, we examined whether people placed eight target objects closer to the side-defined corners than to the quadrant-defined corners of the box, suggesting that they displaced the objects in ways consistent with their experience during learning. Seven- and 11-year-old children and adults in the completely contiguous learning condition placed the target objects closer to the side-defined corners than they really were, consistent with their spatiotemporal experience during learning. Nine-year-olds showed a similar pattern, though the magnitude of the effect did not reach significance. These findings suggest that children and adults who experienced all of the locations belonging to one group before experiencing those belonging to another group during the

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[2] Although the side and quadrant scores are not completely independent, we analyzed these scores using a repeated measures design because this design allowed us to directly compare the scores, as well as to compare performance across the age groups and conditions. These comparisons are important to our understanding of how children and adults use spatiotemporal cues to organize locations into groups. Therefore, results from the repeated measures ANOVA are presented to complement results from the one-sample t tests.

learning phase used this experience to organize the locations into groups. Nine-year-olds and adults in the partially contiguous learning condition also placed the target objects closer to the side-defined corners than they really were, suggesting that experiencing most of the locations belonging to the groups together in time during learning enabled them to organize the locations into groups.

The fact that children and adults tended to think that the locations experienced together in time during learning were closer to the corners of the box consistent with this experience than they really were is strong evidence that spatiotemporal experience serves as an important cue for forming spatial categories because the target locations were actually closer to the quadrant-defined corners than to the side-defined corners. As in previous experiments (e.g., Clayton & Habibi, 1991; Curiel & Radvansky, 1998; Hund et al., 2002; McNamara et al., 1992; Sherman & Lim, 1991), providing completely contiguous spatiotemporal experience was particularly beneficial. However, results also showed that adults can organize objects based on partially contiguous spatiotemporal experience. Together, these findings suggest that a moderate correlation between spatial and temporal contiguity might be influential, though a perfect correlation is particularly beneficial.

3. Experiment 2

Experiment 1 demonstrated that people can use spatiotemporal contiguity as a cue to organize locations into groups. The remaining experiments explored the flexibility and stability with which children and adults form spatial categories using this cue. In particular, the goal of Experiment 2 was to determine whether children and adults who experience different spatiotemporal patterns of organization can organize the same locations into different groups. That is, if different groups of people experience the same locations in one of two ways (e.g., with one of two patterns of spatiotemporal organization), do they organize the locations into different groups? This experiment was similar to several recent studies in the object categorization domain (e.g., Goldstone, 1995; Schyns & Murphy, 1994; Schyns & Rodet, 1997). As such, it provided important information regarding the domain-generality of category flexibility. Moreover, it was a necessary step toward examining the stability and flexibility with which the *same* people organize locations into groups based on spatiotemporal cues.

As in Experiment 1, children and adults learned the locations of 20 objects in an open, square box. As before, they experienced the locations belonging to one group before experiencing those belonging to the next group during learning. Although all participants learned the same locations, they experienced different patterns of organization depending on their learning condition. Participants in the side experience condition experienced the locations belonging to the side-defined groups together in time during learning. In the quadrant experience condition, however, participants experienced the locations belonging to the quadrant-defined groups together in time during the learning phase. Following learning, participants attempted to replace the objects without the aid of the dots that had marked the locations. If children and adults can use spatiotemporal experience to organize locations into groups based on their particular experience in the task, then displacement should be consistent with spatiotemporal experience during learning, thereby leading to differences in the overall pattern of displacement across conditions. In particular, children and adults in the side experience condition should displace the objects toward the side-defined corners of the box, consistent with the side-defined experience. Conversely, people in the quadrant experience condition should displace the objects toward the quadrant-defined corners, consistent with the quadrant-defined experience.

3.1. Method

3.1.1. Participants

Ninety-six 7-, 9-, and 11-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 7 years 4 months (range = 7 years 1 month to 7 years 11 months), 9 years 2 months (range = 9 years 0 months to 10 years 0 months), 11 years 3 months (range = 10 years 9 months to 11 years 11 months), and 19 years 8 months (range = 18 years 8 months to 21 years 11 months), respectively. Six additional 7-year-olds and one additional 11-year-old were excluded because they did not reach the learning criterion. Two additional 7-year-olds were excluded because their experimental sessions were interrupted. One additional 9-year-old was excluded due to an experimenter error. Children and adults were recruited in the same manner as in Experiment 1.

3.1.2. Apparatus and materials

The box, locations, and miniature objects were identical to those used in Experiment 1.

3.1.3. Design and procedure

Participants were randomly assigned to one of two conditions: side experience or quadrant experience. Participants in both conditions experienced the locations group by group during learning; however, the locations constituting a spatiotemporally defined group differed across conditions. In the side experience condition, the locations along each side of the box constituted a group. (These groups were identical to those used in the spatiotemporally contiguous learning conditions in Experiment 1.) In the quadrant experience condition, the locations in each quadrant of the box were experienced together during learning (see Fig. 2).

As described above, the experiment was divided into a learning phase and a test phase. The learning phase was identical to that used in the completely contiguous learning condition of Experiment 1 except that participants continued with learning trials until they could correctly replace the objects on two learning trials (rather than the one correct trial used as the learning criterion in Experiment 1). This change was meant to ensure that participants had sufficient experience with the locations during learning to provide salient spatiotemporal information. To avoid unnecessarily prolonging the learning phase, participants were allowed to incorrectly place one item following a correct learning trial. Seven participants incorrectly placed one item following a correct learning trial. If participants missed more than one item following a correct learning trial, they were asked to complete additional learning trials until they could correctly replace the items once more. Only one 7-year-old required additional learning trials (two trials) following the first correct trial because two locations were missed. The mean number of trials to criterion for 7-, 9-, 11-year-olds, and adults were 5.67 ($SD = 1.49$), 4.38 ($SD = 1.58$), 4.13 ($SD = 1.30$), and 3.25 ($SD = 1.23$), respectively. The mean number of learning trials did not differ across conditions (side experience: $M = 4.40$, $SD = 1.61$; quadrant experience: $M = 4.31$, $SD = 1.68$). The test phase began immediately following the learning phase. It was identical to the test phase used during Experiment 1.

3.1.4. Coding and measures

The coding and measures were identical to those used in Experiment 1. As in Experiment 1, we used the x- and y-coordinates for the locations, regardless of whether the correct objects were placed in the locations. We substituted 0.21% of the locations for 7-year-olds (1 out of 480), 0% for 9-year-olds (0 out of 480), 0.42% for 11-year-olds (2 out of 480), and 0% for adults (0 out of 480). These substituted locations were used in all analyses. As in Experiment 1, objects placed in a completely wrong configuration were omitted from analyses. We omitted 0.83% of locations for 7-year-olds (4 out of 480), 0.42% for 9-year-olds (2 out of 480), 0.21% for 11-year-olds (1 out of 480), and 0.21% for adults (1 out of 480).

Inter-coder reliability estimates of object placement were calculated for 16 randomly selected participants (17% of the sample) using exact percentage agreement. For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 100% of the 320 locations coded.

3.2. Results

3.2.1. Error

To investigate possible differences in overall error during the test phase among the age groups and experimental conditions, error scores were entered into Age (7 yrs., 9 yrs., 11 yrs., and adult) × Condition (side experience, quadrant experience) ANOVA with two between-subjects factors. This analysis did not yield any significant effects, suggesting that error was similar across age groups and conditions. The mean distance from correct locations was 2.46 in. ($SD = .47$) for 7-year-olds, 2.40 in. ($SD = .49$) for 9-year-olds, 2.47 in. ($SD = .65$) for 11-year-olds, and 2.15 in. ($SD = .49$) for adults. This lack of age differences in error may have resulted from the inclusion of an additional learning trial in this experiment.

3.2.2. Patterns of displacement

The primary question of interest was whether children and adults use spatiotemporally contiguous experience with locations to organize locations into groups based on their particular experience during learning. As in Experiment 1, this question was addressed using two sets of analyses. First, to examine whether participants in each age group and condition significantly displaced target locations toward the corners of the box, side and quadrant displacement scores were compared to the expected score with no displacement (i.e., 0 in.) using one-sample *t* tests. Displacement scores for each age group and condition can be seen in Table 2. In the side experience condition, 7- and 9-year-olds and adults placed the target objects significantly closer to the side-defined corners than they really were, $ts(11) > 2.70$, $ps < .05$. Eleven-year-olds also placed the target objects closer to the side-defined corners than they really were, $t(11) = 2.18, p < .055$. None of the groups placed the objects significantly closer to the quadrant-defined corners than they really were, $ts(11) < .88$, *ns*. These results suggest that participants used their spatiotemporal experience with the locations during learning to organize the locations into categories. In the quadrant experience condition, all age groups placed the target objects significantly closer to the quadrant-defined corners than they really were, $ts(11) > 2.29, ps < .05$. In addition, none of the groups placed the objects significantly closer to the side-defined corners than they really were, $ts(11) < 1.67$, *ns*. Again, these findings support the conclusion that participants organized the locations into groups based on their spatiotemporal experience during the learning phase.

Second, side and quadrant displacement scores for target locations were entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Condition (side experience, quadrant experience) × Score Type (side, quadrant) repeated-measures ANOVA with the first two factors as between-subjects factors and the last factor as a within-subjects factor. As predicted, this analysis yielded a significant Score Type × Condition interaction,

Table 2
Displacement scores (in inches) for each age group and condition in Experiment 2

Age	Score type	
	Side	Quadrant
7-year-olds		
Side experience	.70 (.89)*	.18 (.91)
Quadrant experience	.27 (.57)	.74 (.79)*
9-year-olds		
Side experience	.82 (.95)*	.10 (.78)
Quadrant experience	.27 (.64)	.67 (.82)*
11-year-olds		
Side experience	.65 (1.03)+	.27 (1.05)
Quadrant experience	.25 (1.06)	.70 (.96)*
Adults		
Side experience	.74 (.82)*	.08 (.97)
Quadrant experience	−.22 (1.13)	.73 (1.10)*
Overall		
Side experience	.73 (.90)	.16 (.91)
Quadrant experience	.14 (.88)	.71 (.89)

Note. Standard deviations are listed in parentheses. Asterisks denote significance ($p < .05$) on one-sample *t* tests comparing displacement scores to the expected score with no displacement (i.e., 0). The plus sign denotes a marginally significant result ($p < .08$) from a one-sample *t* test.

$F(1, 88) = 10.54, p < .005$. Simple effects tests revealed that side displacement was significantly greater than quadrant displacement in the side experience condition, $F(1, 47) = 5.61, p < .05$, and that quadrant displacement was significantly greater than side displacement in the quadrant experience condition, $F(1, 47) = 5.52$, $p < .05$. Participants placed the target objects closer to the corners that were consistent with the organization they experienced during learning, again demonstrating that they can use spatiotemporal cues to organize the same locations into different groups based on their particular experience (see Table 2).

3.3. Discussion

The goal of this experiment was to investigate whether children and adults can use particular patterns of spatiotemporal experience with locations during learning to organize locations into groups. Participants who experienced the side-defined locations together in time during learning placed the objects significantly closer to the side-defined corners than to the quadrant-defined corners. Similarly, participants who experienced the quadrant-defined locations together in time during the learning phase placed the objects closer to quadrant-defined corners than to the side-defined corners. Thus, as in Experiment 1, participants placed the objects closer to the corners that were consistent with the organization they experienced during learning. These findings clearly demonstrate that children and adults can use particular patterns of spatiotemporal experience with locations during learning to organize the locations into groups. Moreover, they parallel results from the object categorization domain (e.g., Goldstone, 1995; Schyns & Murphy, 1994; Schyns & Rodet, 1997), suggesting that the ability to tailor categories to specific experiences is a domain-general aspect of categorization.

Although the present findings demonstrate that people can differentiate locations in different ways depending on their particular experience with the items, it is not clear whether the *same people* can flexibly organize the same items differently when given different experiences. The primary goal of the final experiments was to examine the flexibility with which the same people organize locations into groups. That is, if the same people are given different spatiotemporal experiences with the same set of locations, do they organize the locations into different groups? A second goal was to examine the stability of spatial category formation based on spatiotemporal cues over a relatively long delay. A final goal was to investigate how category stability and flexibility might change across development.

4. Experiment 3

Examining the stability and flexibility with which people form spatial categories provides information about the on-line dynamics of categorization processes. In particular, assessing categorization at multiple time points illuminates the formation, maintenance, and decay of categorical organization. The experimental task used in Experiments 3 and 4 included two testing sessions separated by approximately

5 days. The first session was identical to that of Experiment 2. At the beginning of the second session, participants were asked to replace the original objects in the correct locations without the aid of the dots. This repeated assessment following a long delay provided an index of the stability of categories based on spatiotemporal cues. After this initial test, participants learned the locations of a new set of objects using a new spatiotemporal organization. The locations were identical to those learned at the first session; however, the objects and spatiotemporal organization differed across sessions. In Experiment 3, participants first experienced the locations belonging to the quadrant-defined groups together in time during learning. Later, they learned a second set of objects such that the locations belonging to the side-defined groups were experienced together in time. Experiment 4 was identical, except that participants first experienced the locations belonging to the side-defined groups together in time and later experienced the locations belonging to the quadrant-defined groups together in time during learning. In both experiments, comparison across sessions provided an index of flexibility in category formation.

The design of Experiments 3 and 4 allowed us to address an important issue in online category formation. Namely, how does the relative strength of remembered and perceptual information influence category flexibility? Note that in Experiment 3, the initial organization (during Session 1) was relatively strong because it was consistent with participants' spatiotemporal experience with the locations to be learned and with the perceptual structure of the task space (i.e., the axes of symmetry). The subsequent organization (during Session 2) was not as strong because it was consistent with participants' spatiotemporal experience with the locations, but it was inconsistent with the perceptual structure of the task space. In contrast, in Experiment 4, the initial organization (during Session 1) was consistent with spatiotemporal experience and inconsistent with the perceptual structure of the task space, whereas the subsequent organization (during Session 2) was consistent both with people's experience with the locations and with the perceptual structure of the task space.

Because we expected that the relative strength of the initial and subsequent organizations would influence category flexibility, we predicted age differences in the overall pattern of flexibility across experiments. In particular, we expected that both children and adults would demonstrate flexibility in Experiment 4, when the new organization to be learned (at Session 2) was consistent with spatiotemporal experience and with the perceptual structure of the task space. In contrast, we predicted that only the adults would demonstrate flexibility in Experiment 3, when the new organization was consistent with spatiotemporal experience and inconsistent with perceptual structure. In general, we expected that flexibility would increase across development (Oakes, Plumert, Lansink, & Merryman, 1996; Plumert, 1994), though the increase would depend on the relative strength of the initial and subsequent organizations of locations.

In contrast, we expected that stability would not be affected by the relative strength of organizational cues in this task. The results of the first experiments demonstrated clear evidence of organization using these cues. Moreover, our general developmental expectations were that stability would emerge prior to flexibility. Thus, we predicted that the pattern of category stability would be similar across experiments and across development. That is, we expected that children and adults would organize the locations into groups based on their spatiotemporal experience during the learning phase at the first session. Moreover, we expected that this organization would be relatively stable across a long delay for all age groups.

4.1. Method

4.1.1. Participants

Forty-eight 7-, 9-, and 11-year-old children and adults participated in the study. There were 12 participants in each age group, with approximately equal numbers of males and females. The mean ages were 7 years 3 months (range = 7 years 2 months to 7 years 4 months), 9 years 5 months (range = 9 years 1 month to 9 years 10 months), 11 years 4 months (range = 10 years 11 months to 11 years 11 months), and 22 years 6 months (range = 18 years 1 month to 36 years 10 months), respectively. Two additional 7-year-olds were excluded because their sessions were interrupted. Two additional 11-year-olds were excluded because they were unable to return for the second testing session. Children and adults were recruited in the same manner as in the previous experiments. Children received a small gift and $4 as compensation for each experimental session. Adults were compensated in the same manner used in the previous experiments.

4.1.2. Apparatus and materials

The box and locations were the same as those used in Experiments 1 and 2 (see Fig. 1). In addition to the 20 objects used in the previous studies (Set A), a second set of 20 objects was used (Set B). Set B included a cat, a doughnut, a tape measure, a van, a bag, a shirt, a plant, a block, a shoe, a teapot, a basket, a frog, a plate, a watermelon, a rabbit, a cake, a box of tissues, a jack-o-lantern, a milk bottle, and a box of laundry detergent. The average length and width of the objects was .77 and .58 in., respectively.

4.1.3. Design and procedure

Participants completed two testing sessions. The first session was identical to that used in Experiment 2. As in Experiment 2, participants experienced locations belonging to each quadrant-defined group together in time during learning at Session 1. Half of the participants learned the locations of the objects used in the previous experiments (Set A), whereas the remaining participants learned the locations of a different set of objects (Set B).

Session 1 was divided into a learning phase and a test phase as described above. The learning phase was identical to that used in Experiment 2. Participants were allowed to incorrectly place one item following a correct learning trial. Nine participants incorrectly placed one item following a correct learning trial. If participants missed more than one item following a correct learning trial, they were asked to complete additional learning trials until they could correctly replace the items once more. Only one 7-year-old required additional learning trials (three trials) following the first correct trial because two locations were missed. The mean number of trials to criterion during Session 1 was 5.00 ($SD = 1.13$) for 7-year-olds, 4.25 ($SD = 1.71$) for 9-year-olds, 3.83 ($SD = 1.59$) for 11-year-olds, and 3.67 ($SD = 1.23$) for adults. The test phase began immediately following the learning phase. It was identical to the test phase used during Experiments 1 and 2.

Participants completed a second testing session approximately 5 days following the completion of Session 1 ($M = 4.65$ days; $SD = 2.35$ days; range = 1–13 days). The number of days between sessions did not differ significantly across age groups, $F(3, 44) = 1.69$, *ns* (7 years: $M = 3.50$, $SD = 1.83$; 9 years: $M = 4.83$, $SD = 2.25$; 11 years: $M = 4.67$, $SD = 1.67$; and Adults: $M = 5.58$, $SD = 3.14$). First, participants attempted to replace the *original* objects in the box without the dots marking the locations. Then, they learned a *new* set of objects paired with the (same) locations in the box. This time, participants experienced the locations belonging to the side-defined groups together in time during the learning phase. Participants continued with learning trials until they could correctly replace the new objects on two learning trials. Again, participants were allowed to incorrectly place one item following a correct learning trial. Eleven participants placed one item incorrectly following a correct learning trial. No participants missed more than one item following a correct learning trial. The mean number of trials to criterion during Session 2 was 4.33 ($SD = 1.30$) for 7-year-olds, 4.17 ($SD = 1.19$) for 9-year-olds, 3.33 ($SD = .65$) for 11-year-olds, and 2.75 ($SD = .62$) for adults. Following learning, participants completed a test phase in which they attempted to replace the new objects without the aid of the yellow dots. The mean number of learning trials did not differ significantly across age groups or sessions.

4.1.4. Coding and measures

The coding and measures were identical to those used in Experiment 2. In this experiment, however, object locations were coded from digital pictures of the objects in the box taken from directly above the box. After each test phase, the experimenter replaced the plain blue floor with the floor containing a grid of x- and y-coordinates. The experimenter then took a picture of the objects in the box (containing the grid floor) using a remote-control operated Olympus C-3040Z digital camera mounted on the ceiling directly above the apparatus. Later, the digital pictures were viewed on a 21-in. Samsung monitor, and the object locations were coded to the nearest 1/2-in. using the digital image of the grid of x- and y-coordinates.

As in Experiments 1 and 2, we used the x- and y-coordinates for the locations, regardless of whether the correct objects were placed in the locations. These substituted locations were used in all analyses. As in Experiments 1 and 2, objects placed in a completely wrong configuration were omitted from analyses. The mean percentage of substituted locations for each age group and session was between 0 and 7.50%. The mean percentage of omitted locations for each age group and session was between 0 and 7.50% (see Table 3).

Inter-coder reliability estimates of object placement were calculated for 8 randomly selected participants for each test session (17% of the sample) using exact percentage agreement. Two coders judged which object was placed at each of the 20 locations for each of these participants and sessions. Coders agreed on 100% of the 640 locations coded.

Table 3
Mean percentage of locations substituted and omitted for each age group and session in Experiment 3

Age and session	Percentage of locations	
	Substituted (%)	Omitted (%)
7-year-olds		
Session 1	0.83	0.42
Session 2: Initial	5.00	2.08
Session 2: Final	0.00	0.42
9-year-olds		
Session 1	0.00	0.83
Session 2: Initial	6.67	2.92
Session 2: Final	0.42	0.42
11-year-olds		
Session 1	0.83	0.42
Session 2: Initial	5.00	2.08
Session 2: Final	0.42	0.83
Adults		
Session 1	0.83	0.83
Session 2: Initial	7.50	7.50
Session 2: Final	0.00	0.00

4.2. Results

One goal of Experiment 3 was to investigate the stability and flexibility with which children and adults form spatial categories based on spatiotemporal experience. A second goal was to examine how the relative strength of organization affected category flexibility and stability. Recall that participants experienced the locations belonging to the quadrant-defined groups together in time during learning at the first session. These groups were consistent with spatiotemporal experience and the perceptual structure of the task space, rendering them relatively strong. At the second session, they learned a second set of objects such that the locations belonging to the side-defined groups were experienced together in time. These groups were consistent with spatiotemporal experience but inconsistent with the perceptual structure of the task space. Thus, the initial organization was relatively stronger than the subsequent organization.

First, we examined the stability of spatial categories based on spatiotemporal experience by comparing performance across Session 1 and the Initial test at Session 2. We expected spatial categories to be relatively stable for all age groups; thus, the results should be similar across repeated sessions. Second, we examined the flexibility with which children and adults form spatial categories by comparing performance across Sessions 1 and 2 when a new organization was experienced. We predicted that only the adults would flexibly organize locations into groups based on spatiotemporal experience, given the relative strength of the initial organization and the lack of strength of the new organization. As such, the pattern of placement should differ across sessions (for which spatiotemporal organization was different) for the adults, but not for the children.

4.2.1. Category stability: comparison of results from Session 1 and Session 2 initial test

4.2.1.1. Error. Was error similar across the repeated test phases for the different age groups? We addressed this question by entering error scores into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Session (Session 1, Session 2 Initial) repeated-measures ANOVA with the first factor as a between-subjects factor and the second factor as a within-subjects factor. The ANOVA yielded a significant effect of age, $F(3,44) = 3.67$, $p < .05$. Follow-up tests indicated that the 7- and 9-year-olds exhibited larger errors than did the adults. The mean distances from correct locations were 3.07 in. ($SD = .69$) for 7-year-olds, 2.95 in. ($SD = .76$) for 9-year-olds, 2.64 in. ($SD = .66$) for 11-year-olds, and 2.36 in. ($SD = .55$) for adults.

The analysis also revealed a significant effect of session, $F(1,44) = 12.68$, $p < .001$. Follow-up tests indicated that participants exhibited smaller errors during Session 1 ($M = 2.60$, $SD = .67$) than during the Initial test phase at Session 2 ($M = 2.91$, $SD = .73$). These findings suggest that memory for locations becomes less certain as the delay between learning and reproducing the locations increases, consistent with findings from other studies (e.g., Engebretson & Huttenlocher, 1996; Hund & Plumert, 2002; Hund & Spencer, 2003; Huttenlocher, Hedges, & Duncan, 1991; Spencer & Hund, 2002, 2003).

4.2.1.2. Patterns of displacement. The primary question of interest was whether the pattern of displacement was stable across repeated test sessions. Results from the one-sample *t*-tests comparing side and quadrant displacement scores to the expected score with no displacement (i.e., 0 in.) are shown in Table 4. As expected, at Session 1, all four age groups placed the target objects significantly closer to the quadrant-defined corners than they really were, $ts(11) > 3.94$, $ps < .005$, but not significantly closer to the side-defined corners than they really were, $ts(11) < 2.01$, *ns* (see Table 4). These findings support the conclusion that children and adults organized the locations based on their spatiotemporal experience during the learning phase, and that this organization led them to place the locations closer to the corresponding corners of the box than they really were. These findings are consistent with those of Experiment 2, demonstrating organization based on spatiotemporal cues.

At the Initial test phase of Session 2, 7-, and 11-year-olds and adults placed the target objects significantly closer to the quadrant-defined corners than they really were, $ts(11) > 2.70$, $ps < .05$. Nine-year-olds also placed the target objects closer to the quadrant-defined corners than they really were, $t(11) = 2.19$, $p < .055$, though the effect did not reach statistical significance. In contrast, none of the age groups placed the objects significantly closer to the side-defined corners than they really were, $ts(11) < 1.64$, *ns* (see Table 4). Again, these findings support the conclusion that children and adults organized the locations based on their spatiotemporal experience during the learning phase. More importantly, this organization was relatively stable across the 5-day delay between sessions for all four age groups.

Side and quadrant displacement scores were also entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Score Type (side, quadrant) × Session (Session 1, Session 2 Initial) repeated-measures ANOVA with the first factor as a between-subjects factor

Table 4
Displacement Scores (in inches) for each age group and session in Experiment 3

Age and session	Score type	
	Side	Quadrant
7-year-olds		
Session 1	.39 (.67)	1.06 (.73)*
Session 2: Initial	.12 (.86)	1.31 (1.11)*
Session 2: Final	.37 (1.10)	.82 (.65)*
9-year-olds		
Session 1	−.37 (1.21)	1.19 (1.04)*
Session 2: Initial	−.59 (1.24)	1.02 (1.61)+
Session 2: Final	.77 (1.33)+	.10 (1.05)
11-year-olds		
Session 1	−.12 (.83)	.90 (.70)*
Session 2: Initial	.08 (1.10)	.75 (.96)*
Session 2: Final	.66 (.97)*	.52 (.78)*
Adults		
Session 1	−.04 (.62)	.90 (.48)*
Session 2: Initial	−.34 (.84)	.83 (.74)*
Session 2: Final	.73 (.93)*	−.02 (.83)

Note. Standard deviations are listed in parentheses. Asterisks denote significance ($p < .05$) on one-sample t tests comparing displacement scores to the expected score with no displacement (i.e., 0). Plus signs denote marginally significant results ($p < .08$) from the one-sample t tests.

and the last two factors as within-subjects factors. Results revealed a significant effect of age, $F(3,44) = 6.49$, $p < .05$. Follow up tests revealed that the 7-year-olds showed significantly more displacement than did the other three age groups. Displacement scores were .72 in. ($SD = .96$) for 7-year-olds, .31 in. ($SD = 1.49$) for 9-year-olds, .41 in. ($SD = .98$) for 11-year-olds, and .34 in. ($SD = .85$) for adults.

This analysis yielded a significant main effect of score type, $F(1,44) = 21.64$, $p < .001$. As expected, quadrant displacement ($M = .99$, $SD = .96$) was significantly greater than side displacement ($M = -.11$, $SD = .96$). The analysis also revealed a significant main effect of session, $F(1,44) = 5.59$, $p < .05$. Displacement was significantly greater at Session 1 ($M = .49$, $SD = .97$) than at the Initial test ($M = .40$, $SD = 1.23$). (Session 1 quadrant score: $M = 1.01$, $SD = .75$; Session 1 side score: $M = -.03$, $SD = .88$; Session 2 Initial Test quadrant score: $M = .98$, $SD = 1.13$; Session 2 Initial Test side score: $M = -.18$, $SD = 1.04$). Together, these findings suggest that participants organized the locations in ways consistent with their initial experience during the learning phase and that this organization was stable across test sessions separated by a long delay.

4.2.2. *Category flexibility: comparison of results from Session 1 and Session 2 final test*

Comparing performance across Session 1 and the Final Test of Session 2 provided an index of flexibility. If people can flexibly organize the same locations into different groups based on spatiotemporal experience, then the pattern of placement should differ across these sessions (for which spatiotemporal organization was different).

4.2.2.1. Error. Was error greater after children and adults experienced the new organization? An Age (7 yrs., 9 yrs., 11 yrs., and adult) × Session (Session 1, Session 2 Final) repeated-measures ANOVA on error scores with the first factor as a between-subjects factor and the second factor as a within-subjects factor yielded a significant effect of age, $F(3, 44) = 3.36$, $p < .05$. Follow-up tests indicated that adults exhibited significantly less error than did the 7- and 9-year-olds. The mean distance from correct locations was 2.76 in. ($SD = .65$) for 7-year-olds, 2.59 in. ($SD = .60$) for 9-year-olds, 2.45 in. ($SD = .60$) for 11-year-olds, and 2.17 in. ($SD = .43$) for adults.

The analysis also revealed a significant effect of session, $F(1, 44) = 5.46$, $p < .05$. Overall, participants exhibited significantly less error at Session 2 Final test ($M = 2.39$, $SD = .53$) than at Session 1 ($M = 2.60$, $SD = .67$), perhaps resulting from a slight practice effect during Session 2. Note that this was the second test participants were given during Session 2. Although the objects were different, the locations were the same, leading to better memory for the precise metric information about the locations.

4.2.2.2. Patterns of displacement. The primary question of interest was whether children and adults can flexibly form spatial categories. More specifically, the goal was to determine whether participants displaced the same locations in different ways, consistent with differing patterns of spatiotemporal experience. Recall that participants experienced the objects in the side-defined groups together in time during the learning phase of Session 2. We expected that only the adults would flexibly shift organization based on their spatiotemporal experience; thus, we predicted that they would displace the target objects toward the side-defined corners.

Displacement scores for each age group and session can be seen in Table 4. One-sample t tests revealed that, at Session 2 Final Test, 7-year-olds did not place the target objects significantly closer to the side-defined corners than they really were, $t(11) = 1.17$, *ns*, but they did place the target objects significantly closer to the quadrant-defined corners than they really were, $t(11) = 4.39$, $p < .005$, revealing a lack of flexibility in organization. Nine-year-olds placed the objects marginally closer to the side-defined corners than they really were, $t(11) = 2.01$, $p < .07$, but not closer to the quadrant-defined corners than they were, $t(11) = .32$, *ns*. Eleven-year-olds placed the target objects significantly closer to both corners, $ts(11) > 2.32$, $ps < .05$, providing little evidence of flexibility. Only adults placed the target objects significantly closer to the side-defined corners than they really were, $t(11) = 2.74$, $p < .05$, but not significantly closer to the quadrant-defined corners, $t(11) = -.07$, *ns*, demonstrating a clear pattern of flexibility in organization. Together, these findings suggest that the flexibility with which people organize locations into groups based on spatiotemporal cues increases across development: 7-year-olds showed a clear lack of flexibility in organization following the shift in organization at Session 2. Nine- and 11-year-olds showed a mixed pattern. Only adults showed clear evidence of flexibility following a shift in the organization at Session 2.

Side and quadrant displacement scores were also entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Score Type (side, quadrant) × Session (Session 1, Session 2 Final) repeated-measures ANOVA with the first factor as a between-subjects factor and the last two factors as within-subjects factors. This analysis yielded a marginally significant effect of age, $F(3, 44) = 2.79, p < .052$. Follow up tests revealed that 7-year-olds exhibited significantly greater displacement than did the 9-year-olds and adults. The mean displacement scores were .66 in. ($SD = .84$) for 7-year-olds, .42 in. ($SD = 1.28$) for 9-year-olds, .49 in. ($SD = .88$) for 11-year-olds, and .40 in. ($SD = .83$) for adults.

The analysis also revealed a significant main effect of score type, $F(1, 44) = 7.93$, $p < .01$, and a significant Session × Score Type interaction, $F(1, 44) = 10.55, p < .005$. As predicted, simple effects tests revealed that quadrant displacement was significantly greater at Session 1 ($M = 1.01, SD = .75$) than at the Final test during Session 2 ($M = .36, SD = .88$), $F(1, 47) = 12.25, p < .005$. Conversely, side displacement was significantly greater at the Final test phase ($M = .63, SD = 1.07$) than at Session 1 ($M = -.03, SD = .88$), $F(1, 47) = 8.34, p < .01$.

4.3. Discussion

The central questions of interest focused on the stability and flexibility with which children and adults organize locations into groups based on spatiotemporal contiguity. Here, participants first experienced the quadrant-defined locations together in time, and later experienced the side-defined locations together in time. As expected, children and adults tended to place the target objects closer to the corners consistent with the organization experienced during the learning phase both at the original test phase at Session 1 and at the Initial test phase during Session 2. These findings provide clear evidence that spatial category formation based on spatiotemporal cues is stable for both children and adults even over a relatively long time delay.

As predicted, adults demonstrated evidence of flexibility following a shift in spatiotemporal experience at Session 2. For the children, findings concerning flexibility were less clear, but they generally revealed a lack of flexibility in organization following the change in spatiotemporal experience at Session 2. These findings suggest that the flexibility with which children organize locations into groups based on spatiotemporal experience increases across development (see Oakes et al., 1996; Plumert, 1994 for similar ideas). Thus, as expected, stability was similar across age groups, whereas flexibility changed dramatically across the age range studied. These findings support the notion that children might first exploit spatiotemporal cues to stably maintain an initial categorical organization and only later exploit these same cues to flexibly alter an existing categorical organization in light of task changes. Moreover, they are consistent with our predictions regarding the influence of the relative strength of the initial and subsequent organizations of locations on category flexibility.

5. Experiment 4

Experiment 4 further examined how the flexibility and stability with which children and adults form spatial categories based on spatiotemporal cues changes as a function of the initial and subsequent organization of locations. This experiment was identical to Experiment 3, except that participants first experienced the locations belonging to the *side-defined* groups together in time during the learning phase of Session 1. At Session 2, they experienced the locations belonging to the quadrant-defined groups together in time during learning. As in Experiment 3, we expected that all ages would be able to stably maintain over a long delay organization based on spatiotemporal experience during learning and that adults would demonstrate flexibility of organization. In addition, we expected that children would demonstrate more flexibility here than in Experiment 3 because the second organization experienced was supported by the perceptual structure of the task space (i.e., axes of symmetry dividing the box into identical regions) and spatiotemporal experience with the locations, facilitating a shift in organization following the new spatiotemporal experience.

5.1. Method

5.1.1. Participants

Forty-eight 7-, 9-, and 11-year-old children and adults participated in the study. There were 12 participants in each age group, with approximately equal numbers of males and females. The mean ages were 7 years 7 months (range = 7 years 2 months to 7 years 9 months), 9 years 5 months (range = 9 years 0 months to 9 years 7 months), 11 years 7 months (range = 11 years 2 months to 11 years 10 months), and 20 years 1 month (range = 18 years 10 months to 26 years 9 months), respectively. One additional 7-year-old was excluded because she did not reach the learning criterion. One additional 7-year-old and one 9-year-old were excluded because too much time elapsed between their experimental sessions. One 7-year-old was excluded because she was unable to schedule a second session. One additional 7-year-old was excluded due to an experimenter error. Children and adults were recruited and compensated in the same manner as in Experiment 3.

5.1.2. Apparatus and materials

The box, locations, and miniature objects were the same as those used in Experiment 3.

5.1.3. Design and procedure

As in Experiment 3, participants completed two testing sessions. The sessions were identical to those used in Experiment 3, except that participants experienced the locations belonging to each side-defined group together in time during the learning phase of Session 1, and they experienced the locations belonging to the quadrant-defined groups together in time during Session 2.

Participants were allowed to incorrectly place one item following a correct learning trial. At Session 1, 7 participants incorrectly placed one item following a correct learning trial. One 7-year-old, one 9-year-old, and one adult missed more than one object following a correct learning trial; thus, they required one additional learning trial to reach our criterion. The mean number of trials to criterion during Session 1 was 4.75 ($SD = 1.60$) for 7-year-olds, 4.25 ($SD = 1.29$) for 9-year-olds, 4.67 ($SD = 1.97$) for 11-year-olds, and 3.42 ($SD = 1.31$) for adults.

Participants completed a second testing session approximately 5 days following the completion of Session 1 ($M = 5.44$ days; $SD = 2.02$ days; range = 2–10 days). The number of days between sessions did not differ significantly across age groups, $F(3,44) = 1.58$, *ns* (7 years: $M = 5.08$, $SD = 2.28$; 9 years: $M = 5.92$, $SD = 2.23$; 11 years: $M = 5.50$, $SD = 1.88$; and Adults: $M = 5.25$, $SD = 1.82$). Eight participants incorrectly placed one item following a correct learning trial. Two 7-year-olds missed more than one item following a correct learning trial and required an additional learning trial to reach our criterion. The mean number of trials to criterion during Session 2 was 4.25 ($SD = 1.42$) for 7-year-olds, 4.08 ($SD = .79$) for 9-year-olds, 3.67 ($SD = .99$) for 11-year-olds, and 3.25 ($SD = .87$) for adults. Unlike the previous studies, the mean number of learning trials differed significantly across age groups, $F(3,44) = 5.97$, $p < .005$. In particular, 11-year-olds and adults required significantly fewer learning trials than did the 7- and 9-year-olds (7 years: $M = 4.58$, $SD = 1.74$; 9 years: $M = 4.71$; $SD = 1.63$; 11 years: $M = 3.46$; $SD = .72$; and Adults: $M = 3.13$, $SD = .99$). Learning trials also differed significantly across sessions, $F(1,44) = 17.09$, $p < .001$. Participants required significantly fewer learning trials to reach criterion at Session 2 ($M = 3.58$; $SD = 1.05$) than at Session 1 ($M = 4.35$; $SD = 1.76$), suggesting that participants benefited from previous experience in the task.

5.1.4. Coding and measures

The coding and measures were identical to those used in Experiment 3. As in the previous experiments, we used the x- and y-coordinates for the locations, regardless of whether the correct objects were placed in the locations. These substituted locations were used in all analyses. As in the previous experiments, objects placed in a completely wrong configuration were omitted from analyses. The mean percentage of substituted locations for each age group and session was between 0 and 20%. The mean percentage of omitted locations for each age group and session was between 0 and 4.17% (see Table 5).

Inter-coder reliability estimates of object placement were calculated for 8 randomly selected participants for each test session (17% of the sample) using exact percentage agreement. Two coders judged which object was placed at each of the 20 locations for each of these participants and sessions. Coders agreed on 99.06% of the 640 locations coded.

5.2. Results

5.2.1. Category stability: comparison of results from Session 1 and Session 2 initial test

5.2.1.1. Error. Was error similar across the repeated test phases? An Age (7 yrs., 9 yrs., 11 yrs., and adult) × Session (Session 1, Session 2 Initial) repeated-measures ANOVA on error scores with the first factor as a between-subjects factor and the second factor as a within-subjects factor yielded a significant effect of session, $F(2,44) = 16.50$, $p < .001$. As in Experiment 3, follow-up tests indicated that participants exhibited smaller errors during Session 1 ($M = 2.23$, $SD = .60$) than during the Initial Test phase during Session 2 ($M = 2.62$, $SD = .64$). These findings lend further

Table 5
Mean percentage of locations substituted and omitted for each age group and session in Experiment 4

Age and session	Percentage of locations	
	Substituted (%)	Omitted (%)
7-year-olds		
Session 1	1.67	0.42
Session 2: Initial	10.00	3.75
Session 2: Final	1.25	1.25
9-year-olds		
Session 1	0.83	0.42
Session 2: Initial	14.58	4.17
Session 2: Final	0.00	0.42
11-year-olds		
Session 1	0.00	0.42
Session 2: Initial	20.00	4.17
Session 2: Final	0.83	0.42
Adults		
Session 1	0.00	0.42
Session 2: Initial	5.42	2.92
Session 2: Final	0.00	0.00

support to the notion that memory for locations becomes less certain as the delay between learning and reproducing locations increases.

5.2.1.2. Patterns of displacement. The primary question of interest was whether the pattern of displacement was similar across repeated test sessions. One-sample t tests comparing side and quadrant displacement scores to the expected score with no displacement (i.e., 0) revealed that at Session 1, all four age groups placed the target objects significantly closer to the side-defined corners than they really were, ts(11) > 2.51, ps < .05. None of the age groups placed the target objects closer to the quadrant-defined corners than they really were, ts(11) < 1.54, *ns* (see Table 6). Thus, as expected, all age groups exhibited clear evidence of organization at Session 1.

At the Initial Test phase of Session 2, 9- and 11-year-olds and adults placed the target objects significantly closer to the side-defined corners than they really were, ts(11) > 2.61, ps < .05. Seven-year-olds also placed the target objects closer to the side-defined corners than they really were, $t(11) = 2.15$, $p < .056$, although the effect did not reach statistical significance. None of the age groups placed the target objects closer to the quadrant-defined corners than they really were, ts(11) < 2.02, *ns* (see Table 6). These findings support the conclusion that both children and adults were able to maintain the organization of the locations based on their spatiotemporal experience during the learning phase of Session 1.

Quadrant and side displacement scores were also entered into an Age (7 yrs., 9 yrs., 11 yrs., and adult) × Score Type (side, quadrant) × Session (Session 1, Session 2 Initial) repeated-measures ANOVA with the first factor as a between-subjects factor and the last two factors as within-subjects factors. This analysis revealed a significant

Table 6
Displacement scores (in inches) for each age group and session in Experiment 4

Age and session	Score type: Side	Score type: Quadrant
7-year-olds		
Session 1	.74 (1.02)*	.40 (.90)
Session 2: Initial	.69 (1.12)+	.59 (1.02)
Session 2: Final	.28 (.72)	.85 (.82)*
9-year-olds		
Session 1	.79 (.72)*	−.09 (1.02)
Session 2: Initial	1.33 (1.49)*	−.75 (1.39)
Session 2: Final	.45 (.50)*	.46 (.82)+
11-year-olds		
Session 1	.67 (.73)*	.22 (.80)
Session 2: Initial	.83 (1.10)*	−.05 (.76)
Session 2: Final	−.02 (.72)	.60 (.82)*
Adults		
Session 1	.82 (.59)*	−.18 (.51)
Session 2: Initial	1.22 (1.26)*	−.69 (1.50)
Session 2: Final	.22 (.56)	.33 (.50)*

Note. Standard deviations are listed in parentheses. Asterisks denote significance ($p < .05$) on one-sample t tests comparing displacement scores to the expected score with no displacement (i.e., 0). Plus signs denote marginally significant results ($p < .08$) from the one-sample t tests.

main effect of age, $F(3,44) = 3.86$, $p < .05$. Follow up tests revealed that the 7-year-olds placed the target objects significantly closer to the corners of the box than did the 9-year-olds and the adults. The mean displacement scores were .61 in. ($SD = .99$) for 7-year-olds, .32 in. ($SD = 1.41$) for 9-year-olds, .42 in. ($SD = .91$) for 11-year-olds, and .29 in. ($SD = 1.28$) for adults.

Results also yielded a significant main effect of score type, $F(1,44) = 14.45$, $p < .001$, and a significant Session × Score Type interaction, $F(1,44) = 4.29$, $p < .05$. Simple effects tests revealed that side displacement was significantly greater than quadrant displacement at Session 1, $F(1,47) = 9.66$, $p < .005$, and at the Initial test phase during Session 2, $F(1,47) = 12.50$, $p < .001$. At Session 1, mean side displacement was .75 in. ($SD = .75$), whereas mean quadrant displacement was .09 in. ($SD = .84$). At the Initial test phase at Session 2, mean side displacement was 1.02 in. ($SD = 1.24$), whereas mean quadrant displacement was −.22 in. ($SD = 1.29$). The similarity in the pattern of displacement across Session 1 and the Initial test phase at Session 2 suggests that organization based on spatiotemporal experience was stable across time.

5.2.2. Category flexibility: comparison of results from Session 1 and Session 2 final test

As in Experiment 3, comparing performance across Session 1 and 2 provided an index of flexibility. We predicted that children and adults would flexibly organize the same locations into different groups based on spatiotemporal experience when the new organization was consistent with spatiotemporal experience and the perceptual structure of the task space. As such, we expected that the pattern of displacement would differ across these sessions (for which spatiotemporal cues were different).

5.2.2.1. Error. Was error greater after children and adults experienced the new organization? An Age (7 yrs., 9 yrs., 11 yrs., and adult) × Session (Session 1, Session 2 Final) repeated-measures ANOVA on error scores with the first factor as a between-subjects factor and the second factor as a within-subjects factor yielded a significant effect of age, $F(3,44) = 6.35$, $p < .005$. Follow-up tests indicated that adults exhibited significantly less error than did the other three age groups. The mean distance from correct locations was 2.55 in. ($SD = .49$) for 7-year-olds, 2.32 in. ($SD = .53$) for 9-year-olds, 2.27 in. ($SD = .58$) for 11-year-olds, and 1.81 in. ($SD = .35$) for adults. Again, these findings suggest that error decreases across development.

5.2.2.2. Patterns of displacement. The primary question of interest was whether children and adults can flexibly form spatial categories when the second organization was consistent both with spatiotemporal experience and with the perceptual structure of the task space. In particular, the goal was to determine whether participants organized the same locations in different ways, consistent with differing patterns of spatiotemporal experience. Recall that participants experienced the objects in the quadrant-defined groups together in time during the learning phase of Session 2. We predicted that both children and adults would flexibly shift organization; therefore, we expected that they would displace the target objects toward the quadrant-defined corners at Session 2.

Displacement scores for each age group and session can be seen in Table 6. One-sample t tests revealed that at the Final Test of Session 2, 7- and 11-year-olds and adults placed the target objects significantly closer to the quadrant-defined corners than they really were, $t\text{s}(11) > 2.26$, $p\text{s} < .05$. Nine-year-olds also placed the target objects closer to the quadrant-defined corners than they really were, $t(11) = 1.93$, $p < .08$, although the effect did not reach statistical significance. Only the 9-year-olds placed the target objects significantly closer to the side-defined corners than they really were, $t(11) = 3.08$, $p < .05$. Unlike Experiment 3, these findings demonstrate flexibility in organization following the change in organization at Session 2 for both children and adults. These findings are consistent with our predictions, demonstrating that the relative strength of the initial and subsequent organization influences category flexibility, particularly for children.

The ANOVA revealed a significant effect of age, $F(3,44) = 3.68$, $p < .05$. Follow up tests indicated that the 7-year-olds placed the target objects significantly closer to the corners of the box than did the 11-year-olds and adults. The mean displacement scores were .57 in. ($SD = .87$) for the 7-year-olds, .40 in. ($SD = .82$) for the 9-year-olds, .37 in. ($SD = .79$) for the 11-year-olds, and .30 in. ($SD = .64$) for the adults.

There was also a significant Session × Score Type interaction, $F(1,44) = 13.08$, $p < .001$. Simple effects tests revealed that quadrant displacement was significantly greater at the Final test during Session 2 ($M = .56$, $SD = .75$) than at Session 1 ($M = .09$, $SD = .84$), $F(1,47) = 10.75$, $p < .005$. Conversely, side displacement was significantly greater at Session 1 ($M = .76$, $SD = .75$) than at the Final test during

Session 2 ($M = .23$, $SD = .64$), $F(1,47) = 14.96$, $p < .001$. These findings demonstrate flexibility in organization across sessions, for which spatiotemporal experience during learning differed.

5.3. Discussion

Recall that Experiments 3 and 4 were identical, except that participants experienced the quadrant-defined groups together in time during Session 1 in Experiment 3, whereas they experienced the side-defined groups together in time during Session 1 in Experiment 4. Thus, comparisons across experiments yielded details regarding how stability and flexibility might depend on the initial and subsequent organization of locations. For the adults, the overall pattern of results was identical across Experiments 3 and 4. That is, adults demonstrated clear organization at Session 1, stability of organization at the Initial test phase of Session 2, and flexibility of organization at the Final test phase of Session 2. For the children, the pattern of initial organization and stability was similar across experiments. All three child ages demonstrated organization during the test phase of Session 1 and remarkable stability of this organization at the Initial test phase of Session 2. In contrast, the pattern of flexibility differed across experiments. In Experiment 3, in which children experienced the quadrant-defined groups together in time at Session 1 and the side-defined groups together in time at Session 2, none of the child ages demonstrated a shift in organization following the change in spatiotemporal experience. In Experiment 4, in which children experienced the side-defined groups together in time at Session 1 and the (stronger) quadrant-defined groups together in time at Session 2, 7- and 11-year-olds showed a clear shift in organization following the change in spatiotemporal experience at Session 2.

Note that it was easier for children to flexibly shift from the side organization to the quadrant organization than vice versa. Children demonstrated flexibility when both spatiotemporal experience and perceptual cues (i.e., axes of symmetry) marked the new organization, but not when only spatiotemporal cues marked the new organization. These findings suggest that children may require highly salient cues when adopting a new organization. As such, we would expect children to benefit from experience with salient cues marking novel patterns of organization. That is, repeated experience using salient cues to shift to new organizations of locations may facilitate children's ability to use more subtle cues to shift to new organizations, thereby promoting precise mapping between task goals and on-line organization.

6. General discussion

6.1. Using spatiotemporal cues

The results of these experiments clearly show that children as young as 7 years can use spatiotemporal cues alone (i.e., in the absence of visible boundaries) to organize locations into groups following a relatively brief exposure (e.g., one 45-min session).

In all four experiments, children and adults alike displaced the target objects toward the corners of the box that were consistent with their spatiotemporal experience during learning. These findings suggest that spatiotemporal information serves as a very salient cue for forming spatial categories. What might be the origins of this sensitivity to spatiotemporal information? This ability to use spatiotemporal cues to organize locations into groups might result from everyday experiences in which spatial and temporal information typically are correlated. That is, locations that are near each other are much more likely to be experienced close together in time than are locations that are distant from each other. For example, children are much more likely to consecutively visit locations in the same room than they are to consecutively visit locations in adjacent rooms. These everyday experiences with locations may lead children to form expectations about the relations between spatial and temporal contiguity. Thus, children may be particularly sensitive to spatiotemporal cues for forming spatial categories.

The fact that children use spatiotemporal information to form spatial categories is consistent with other findings from the event memory literature suggesting that children use information about when and where routine events occur to rapidly learn about events (e.g., Bauer, Hertsgaard, & Dow, 1994; Bauer & Mandler, 1992; Bauer & Shore, 1987; Fivush, 1984). For example, Fivush (1984) found that after only 2 days of school, kindergartners exhibited script-like knowledge of school-day occurrences. Their school-day scripts were organized temporally and spatially. Thus, they tended to recall activities in the correct temporal order: arrival, playtime, snack, meeting, lunch, gym class, and so on. Moreover, they tended to discriminate events based on changes in locations. For example, the most common events mentioned (e.g., "coming in" and "playtime") were marked by clear spatial transitions (e.g., from the hallway to the classroom and from one area of the classroom to another area). Thus, even young children use spatiotemporal information to organize information in memory (for related ideas, see Schank & Abelson, 1977), suggesting that spatiotemporal cues play an important role in the early development of memory skills.

Adults extracted the pattern of spatiotemporal organization even when the correlation between spatial and temporal contiguity was less than perfect. Children, on the other hand, were able to exploit a perfect correlation between spatial and temporal contiguity but had more difficulty extracting the pattern of spatiotemporal organization when the correlation between spatial and temporal contiguity was less than perfect. These findings suggest that infants and children might require fairly consistent statistical regularities early in development, but that they might benefit from less systematic regularities across development.

How consistent are the spatiotemporal regularities children experience in everyday life? Although future research is needed to determine the precise relation between spatial and temporal contiguity in everyday experience, we suspect that these regularities generally are quite high. Nonetheless, everyday spatiotemporal regularities are rarely perfect, particularly in cases where barriers do not prevent children from visiting some of the locations in one group before visiting those in another group. How might children then benefit from less than perfect spatiotemporal regularities in their everyday experience? Unlike most laboratory situations (including the one used here), it seems likely that everyday situations involve repeated and distributed experiences with visiting nearby locations close together in time. These repeated and distributed experiences may well make up for less than perfect correlations between spatial and temporal contiguity. As such, even young children might benefit from less than perfect statistical regularities if given sufficient exposure. Over development, however, children may become increasingly efficient at noticing imperfect correlations even during relatively brief exposure periods. Further research is necessary to determine how such changes come about.

6.2. Category stability and flexibility

A central claim of the on-line approach to categorization is that categories are not static representations. Rather, categories emerge from real-time cognitive processes (e.g., perceiving and remembering) involving the soft assembly of multiple cues in a given task situation (Jones & Smith, 1993; Madole & Oakes, 1999; Smith & Samuelson, 1997; Thelen & Smith, 1994). The experiments presented here are a clear demonstration that children and adults can use spatiotemporal experience to organize locations into categories and to maintain that organization across a lengthy delay. Importantly, adults were able to shift to a new pattern of organization following a change in spatiotemporal experience. Children also shifted to a new pattern of organization when the new pattern was supported by spatiotemporal experience and perceptual cues. These findings highlight the cues that children and adults might use when remembering the locations of objects. In our task, these cues include memory for the particular locations (e.g., their distances and directions from the edge of the box), memory for the categories, or groups, to which the locations belong (which was determined by spatiotemporal experience during the learning phase), and visually available perceptual information (e.g., the perceived symmetry axes that divided the box into four identical regions).

How might these cues combine to jointly determine developmental changes in the stability and flexibility of spatial categories observed here? We have seen that adults were able to flexibly shift organization at Session 2 based on their recent spatiotemporal experience with the side-defined groups of locations (in Experiment 3) and with the quadrant-defined groups (in Experiment 4). In contrast, children (i.e., 7- and 11-year-olds) only showed a shift in organization at Session 2 in Experiment 4, when they experienced the quadrant-defined groups of locations together in time during the second session. That is, they demonstrated flexibility when the initial spatiotemporal organization conflicted with perceptual cues and the new spatiotemporal organization was consistent with perceptual cues. Children did not show a shift in organization in Experiment 3, when the initial spatiotemporal organization was consistent with perceptual cues and the new spatiotemporal organization conflicted with perceptual cues. These findings suggest that memory for spatiotemporal information and perceptually available information jointly determine the stability and flexibility of category formation, especially for children who were more transitional with regard to these abilities. Children might have found it easier to shift to a new organization in Experiment 4 when both spatiotemporal experience and perceptual organization supported this new organization. In contrast, children may have found it more difficult to shift to a new organization in Experiment 3 because they needed to override perceptual cues and previous memory using only spatiotemporal experience.

One issue that remains unresolved is whether asking people to learn two sets of objects paired with the same locations led them to treat the locations as different (because different objects were used) or the same (because the locations were in fact identical). Our results provide preliminary support for the latter view. In particular, error scores for the final test phase of the second session were lower than were the error scores for the first session, suggesting some savings even though different sets of objects were paired with the same locations. This savings implies that people were treating the locations as one set, used across sessions. We chose this design involving two sets of objects as a first step in investigating flexibility using a within-subjects design. Using different object sets allowed us to provide highly similar learning experiences during the learning phases (e.g., continuing with learning trials until participants could correctly replace the objects on two learning trials), thereby ensuring that spatiotemporal experience was similar across the two sessions. Future research is needed to test whether people can organize the *same* objects and locations in different ways based on their experience. We suspect that adults could flexibly organize the same objects and locations in different ways, though this might be challenging for children.

7. Explaining categorical bias in estimates of location

The present study has implications not only for understanding how people form spatial categories, but also for understanding how they use this categorical information to estimate locations. Several related models have been proposed to explain how categorization influences judgments about individual items (e.g., Hund & Plumert, 2002, 2003; Huttenlocher et al., 1991; Schutte & Spencer, 2002; Spencer & Hund, 2003). In particular, these models attempt to explain how memory for categorical information leads to biases in estimates of location. In the present investigation, for example, why did people show bias toward the corners of the box consistent with the spatial categories they experienced during learning? The following section considers how we might explain categorical bias evidenced in the present investigation using these models.

According to the category adjustment (CA) model, biases result from the combination of two types of information when estimating locations: fine-grained information about the location to be remembered and coarse-grained information about the category to which the location belongs (Huttenlocher et al., 1991; see also Engebretson & Huttenlocher, 1996; Huttenlocher, Newcombe, & Sandberg, 1994; Newcombe & Huttenlocher, 2000; Newcombe, Huttenlocher, Sandberg, Lie, & Johnson, 1999; Sandberg, Huttenlocher, & Newcombe, 1996). When trying to remember a previously learned 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 (i.e., region membership). According to the model, this categorical information is represented by a prototype located at the center of the spatial region. Hence, adjustments based on spatial category information lead to systematic distortions toward the centers of spatial categories. Moreover, the weighting of categorical information depends on the certainty of fine-grained, metric information. In particular, the magnitude of distortion toward category centers (i.e., categorical bias) depends on the certainty of fine-grained information. When fine-grained information is certain, categorical information receives a low weight, resulting in minimal distortion toward the category center. When fine-grained information is less certain, categorical information receives a higher weight, resulting in an increase in categorical bias.

Recently, we extended the category adjustment model by proposing that fine-grained metric information and course-grained categorical information are weighted independently (Hund & Plumert, 2002, 2003). Thus, the weighting of categorical information does not depend solely on the certainty of fine-grained information. Instead, the weights given to fine-grained and categorical information depend on the coding of fine-grained and categorical information at learning and on the maintenance of fine-grained and categorical information over time. Thus, developmental differences in categorical bias result both from how fine-grained and categorical information are initially encoded and from how well fine-grained and categorical information are maintained over time. This perspective underscores the idea that estimates of location are emergent properties of a dynamic cognitive system that combines remembered and perceptually available inputs to arrive at estimates of location (see also Spencer & Schöner, 2003).

Results from the present investigation suggest that there are age-related changes in the weight given to both fine-grained and categorical information (see also Hund & Plumert, 2002, 2003; Hund et al., 2002; Hund & Spencer, 2003; Plumert & Hund, 2001). For example, we have consistently found that 7-year-olds are significantly less accurate than are older children and adults, suggesting that the precision of metric coding changes with development. Likewise, we have consistently found that adults show categorical bias in their estimates of location even when only a single cue for forming spatial categories is present. Children, on the other hand, sometimes do not show categorical bias unless two or more cues for forming spatial categories are present. This suggests that adults may code categorical information more readily than do children.

There may also be age-related changes in how rapidly fine-grained and categorical information decays over time. That is, younger children may experience greater decay in memory for fine-grained information than do older children and adults, resulting in a fairly low weight given to fine-grained metric information by the end of a long delay such as the one between the test at the end of Session 1 and the test at the beginning of Session 2 in the present investigation (see also Hund & Plumert, 2002; Hund & Spencer, 2003; Schutte & Spencer, 2002; Spencer & Hund, 2002). Moreover, the results of the present investigation suggest that categorical information may decay very little over delay. That is, even younger children may be quite good at remembering groups of locations over relatively long delays. In fact, the 7-year-olds in Experiment 3 not only maintained the organization experienced at the first session at the Initial test phase of the second session, they also "maintained" this pattern of organization at the Final test phase of Session 2, after a shift in the pattern of spatiotemporal experience during the learning phase. These changes in the rates at which fine-grained and categorical information decay over time have important implications for children's estimates of locations.

What processes might underlie developmental change in memory for location? Recent work by a variety of researchers all points to the idea that developmental change in memory for location is a joint function of changes in how inputs are coded and maintained, changes in the ability to extract perceptually available structure, and changes in sensitivity to the goals or demands of the task. As outlined above, researchers have documented developmental changes in how precisely children code and maintain metric information (e.g., Hund & Plumert, 2002; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Plumert & Hund, 2001; Schutte et al., 2003) and in how easily children code and maintain categorical information (Huttenlocher et al., 1994; Hund & Plumert, 2003). Likewise, the results of the present investigation suggest that the ability to extract perceptual structure such as perceived symmetry axes may contribute to developmental changes in memory for location (see also Hund & Spencer, 2003; Huttenlocher et al., 1994). Finally, a number of studies have found developmental differences in children's ability to tailor their use of spatial information to the task at hand (e.g., Plumert, 1994; Plumert & Strahan, 1997). The challenge now is to develop coherent models that detail how these kinds of changes work together to produce age-related patterns of performance. Recently, some progress has been made in developing process-based accounts of developmental change in categorical bias. The Dynamic Field Theory (DFT), for example, is a computational model of how long-term memory for repeatedly experienced locations, perceptual structure in the form of perceived symmetry axes, and short-term memory for a recently seen location combine to produce bias in estimates of the recently seen location (Schutte et al., 2003; Spencer & Hund, 2003; Spencer & Schöner, 2003). This model further proposes that continuous developmental change in the precision of spatial memory accounts for qualitative developmental change in patterns of bias (Schutte et al., 2003). Further behavioral and computational work is needed, however, to provide a complete account of how multiple sources of information (i.e., remembered information, perceptually available information, and task goals) are soft assembled at different ages to produce predictable patterns of performance.

8. Summary and conclusions

This investigation is one of the first to explore the stability and flexibility with which children and adults organize locations into groups, or categories. Experiment 1 demonstrated that children and adults can use temporally contiguous experience with nearby locations during learning (in the absence of visible boundaries) to categorize locations. The ability to form categories of locations based on spatiotemporal experience alone emerges quite early during childhood (e.g., by 7 years of age), suggesting that spatiotemporal information serves as a powerful organizational cue. Experiment 1 also demonstrated that the precise relation between spatial and temporal contiguity (i.e., the magnitude of the correlation) affects spatial category formation. Providing a perfect correlation between spatial and temporal contiguity served as a very salient cue. Providing a lesser correlation also facilitated category formation for adults, but not for children. This suggests that there is developmental change in the ability to extract statistical regularities from input that is less than perfect.

Experiment 2 showed that children and adults organize the same locations into different spatial categories based on differing initial experience with the locations during learning. That is, people who experienced the locations along the sides of the box together in time during learning organized the locations in ways consistent with their experience. Conversely, people who experienced the locations in the quadrants of the box together in time organized the locations in ways consistent with their experience. These findings provide important parallels to findings from the object categorization domain, suggesting that category formation is a domain-general process.

Experiments 3 and 4 investigated the stability and flexibility with which children and adults form spatial categories based on spatiotemporal experience during learning using a within-subjects design. Importantly, the relative strength of the initial and subsequent organization of locations differed across experiments. Categories based on spatiotemporal experience were remarkably stable for all four age groups included in the studies. Moreover, adults who experienced the locations belonging to the quadrant-defined groups together in time during learning at Session 1 and 7-, 11-year-olds, and adults who experienced the locations belonging to side-defined groups together in time during learning at Session 1 showed evidence of flexible category formation based on spatiotemporal experience during learning at Session 2. These findings suggest that the flexibility with which children and adults organize locations into groups based on spatiotemporal cues increases across development and depends on the strength of the original and new categorical organizations. Importantly, these results are among the first to assess category stability and flexibility by asking the same people to organize items following repeated experiences with the items, thereby providing critical information regarding how categories emerge over time.

In conclusion, children and adults can use spatiotemporal experience to organize locations into groups. Moreover, spatial categories based on experience are remarkably stable and flexible in adults, illustrating important hallmarks of human cognition. These findings provide valuable insights into underlying categorization processes. First, they underscore the idea that categories are not static representations with stable structures, but are emergent products of real-time processes combining multiple cues in particular task contexts (e.g., Jones & Smith, 1993; Madole & Oakes, 1999; Smith & Samuelson, 1997; Thelen & Smith, 1994). Second, these results parallel findings from the object categorization domain that demonstrate stability and flexibility in category formation, suggesting that categorization processes are similar across domains. Moreover, the present results revealed a developmental increase in category flexibility, but no developmental changes in stability, across childhood. For children, flexibility was evident when the new pattern of organization was relatively strong, suggesting that the relative strength of cues is particularly important for children's ability to demonstrate flexible categorization. Additional empirical and theoretical work is needed to clarify similarities in processes, as well as differences based on the content of the particular domains. Nevertheless, this study provides an important first step toward understanding on-line categorization processes by integrating empirical and theoretical work in two key domains. As such, it provides valuable information about the mechanisms that underlie the categorization of objects and locations.

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