COGNITIVE PSYCHOLOGY 23, 515–557 (1991)

Cross-Cultural and Developmental Trends in Graphic Productions

BARBARA TVERSKY, SOL KUGELMASS, AND ATALIA WINTER

Stanford University and Hebrew University of Jerusalem

How does space come to be used to represent nonspatial relations, as in graphs? Approximately 1200 children and adults from three language cultures, English, Hebrew, and Arabic, produced graphic representations of spatial, temporal, quantitative, and preference relations. Children placed stickers on square pieces of paper to represent, for example, a disliked food, a liked food, and a favorite food. Two major analyses of these data were performed. The analysis of directionality of the represented relation showed effects of direction of written language only for representations of temporal concepts, where left-to-right was dominant for speakers of English and right-to-left for speakers of Arabic, with Hebrew speakers in between. For quantity and preference, all canonical directions except top-to-bottom were used approximately equally by all cultures and ages. The analysis of information represented in the graphic representations showed an age trend; more of the older children represented ordinal and some interval information in their mappings. There was a small effect of abstractness of concept on information represented, with more interval information represented by children for the more concrete concepts, space, time, quantity, and preference in that order. Directionality findings were related to language-specific left-to-right or right-to-left directionality and to universal association of *more* or *better* with upward. The difficulties in externally representing interval information were related to prevalent difficulties in expressing comparative information. Children's graphic productions were compared to other invented notation systems, by children and by cultures, particularly for numbers and language. © 1991 Academic Press, Inc.

This research was supported by NSF-IST Grant 8403273 to Stanford University, by a grant from the Human Development Institute of the Hebrew University, and by a grant from the Cognitive Psychology Institute of the Hebrew University. Preparation of the manuscript was aided by AFOSR Grant 89-0076 to Stanford University. For such a large, multinational project, we are indebted to many people and institutions. Rochel Gelman provided invaluable assistance on many aspects of earlier drafts of the manuscript. Linda McGarvey was outstanding in organizing data collection in the United States, persistent, and dedicated, and ably assisted by Linda Covington. Ragda and Iman Zuaby provided dedicated assistance in Israel. We are grateful to Dale Griffin and Linda Covington for excellent statistical assistance. Diane Gong performed pilot studies for this research. We thank the staff and children of the following schools for their enthusiastic cooperation and assistance: Bethany Lutheran School (Menlo Park, CA); Keys School (Palo Alto, CA); Mountain View CA School District; L. M. Nixon School Day Care (Palo Alto, CA); Palo Alto Unified School District (Juana Briones, Duveneck, Escondido, L. M. Nixon, Walter Hays, and Palo Alto High

0010-0285/91 $7.50

The earliest forms of written communication were pictorial: cave drawings, petroglyphs, maps, tallies, pictographic forms of writing (Gelb, 1963). The invention of the phonetic alphabet revolutionized written communication, yet, in many ways, it limited communication as well. Alphabetic communication is language specific; in contrast, many pictorial communiqués are produced similarly by and can be comprehended by speakers of different languages with little or no training. Simple line drawings of common objects, for example, were identified immediately by a child raised virtually without pictures (Hochberg & Brooks, 1962). Similarly, no matter what one's language and with little training, depictions of movements and emotion can be "read" from wordless comics, and information and instructions are transparent or readily learned from the common set of pictograms found in airports and highways throughout the world.

Although maps and tallies have been produced by numerous cultures throughout the history of civilization, far earlier than written language (e.g., Brown, 1949; Hughes, 1986; Wilford, 1982), graphs did not appear in any number until the late eighteenth century (e.g., Beniger & Robyn, 1978; Tufte, 1983) when an Englishman, Playfair, and a Swiss, Lambert, began to use them primarily to display economic and political data. Even so, they did not become widely used until the following century. Both maps and graphs use Euclidean space to represent relations among a set of objects; however, maps do this literally and graphs metaphorically. Interpreting simple graphs, that is, X–Y coordinates with a relation represented, like reading phonetic writing, does not seem to be immediate, but rather based on conventions that are learned.

Several aspects of graphic representation may be distinguished. The first consideration is the level of *information* in the conceptual relation that is *represented* by the graphic mapping. Typically, four scale types are distinguished (Krantz, Luce, Suppes, & Tversky, Chap. 1, 1971; Stevens, 1946): nominal, ordinal, interval, and ratio (the last case is not considered here). These scale types are inclusive: an interval representation is also an ordinal and a nominal one, and an ordinal representation is also a nominal one. Because nominal mappings are simpler—in the sense of requiring less information to be represented—than ordinal, and ordinal is simpler than interval, it is natural to expect children to produce nominal relations

---

Schools); Peninsula Christian Schools (Redwood City, CA); Phillips Brooks Academy (Menlo Park, CA); Redeemer Lutheran School (Redwood City, CA); Trinity School (Menlo Park, CA); the Bet Zfafa, Shuafat, Abu-Tor, Horev, Luria, Rehavia, and Talpiot schools in the Jerusalem area; and the Al-Horsh school in Nazareth. Reprint requests should be addressed to Barbara Tversky, Department of Psychology, BLDG 420, Stanford University, Stanford, CA 94305-2130.

earlier than ordinal and ordinal relations earlier than interval. Specifically, in the task used here, children place stickers on pieces of paper to indicate three levels of a conceptual relation. To be counted as a nominal representation, stickers merely have to be spatially separate; to be counted as an ordinal representation, the stickers must be separate and also properly ordered (in any direction) and more or less on a line; to be counted as an interval representation, in addition to separation and order, the distance between the two stickers representing a larger conceptual distance must be spatially larger than the distance between the two stickers representing a smaller conceptual distance. Thus, the greater the amount of information to be represented the greater the complexity of the graphing task.

The second aspect of graphic representation to be investigated is the *direction of increases* used by children. By convention, increases go from left to right and/or from bottom to top. In the case of bottom-to-top, the correspondence to increases may reside in what might be called a cognitive universal. Much of the evidence for this lies in common linguistic expressions, to be discussed below. This case cannot be made for left and right, where there does not seem to be a cognitive association to increases. Rather, the direction of writing may affect the direction of increases. To investigate this, children from three writing cultures participated in the experiments: English-speaking American children, who write from left to right; Arabic-speaking Israeli children, who write both numbers and letters from right to left; and Hebrew-speaking Israeli children, who write letters from right to left, but numbers from left to right. The final aspect of graphic representation to be considered is *content independence*. By convention, graphic form does not usually depend on the particular content of the relation to be graphed. There are some conventions relating to content, for example, plotting the independent variable on the X axis and the dependent variable on the Y axis. However, there are no conventions of form for the three types of conceptual relations investigated here: temporal, quantitative, and preference. These three aspects of graphic representation, information represented, directionality, and content independence, will be investigated in a developmental and cross-linguistic study of spontaneous graphic productions. We turn first to directionality.

DIRECTIONALITY

Languages are permeated with concrete, frequently visual, frozen metaphors for the most ordinary of expressions (e.g., Bierwisch, 1967; Clark, 1973; Clark, 1974; Cooper & Ross, 1975; Lakoff & Johnson, 1980). The universality and transparency of such expressions may reveal pervasive cognitive biases and tendencies not only in comprehension and production of literal and metaphoric extensions of the visual world, but also in the very way the visual world is conceived (e.g., Clark, 1973; Clark & Clark, 1977; Franklin & Tversky, 1990; Shepard & Hurwitz, 1984). A large set of such expressions correspond to the vertical spatial dimension, up and down, high and low, and top and bottom: "What's up?" "He's feeling down today." "She's high on something." "That's a low thing to do." "She's at the top of the class." "He's hit the bottom." In general, *more, better,* and *good* are associated with *up, high,* and *top,* and *less, worse,* and *bad* are associated with *low, down,* and *bottom.* Like the metaphoric expressions based on it, the vertical dimension is asymmetric with the *down* side literally grounded and the *up* side unbounded. Also asymmetric and perfectly correlated with verticality are gravity and the canonical orientation of people. If these metaphoric expressions are indicative of a cognitive universal or general cognitive bias, then in pictorial representations as well, *good* and *more* should be mapped toward the top of a page and *bad* and *less* toward the bottom of a page. In fact, graphic conventions conform to this; increases generally go from down to up, although they may also go from left to right.

In contrast to the up/down dimension, the left/right dimension is not correlated with global physical and biological characteristics. In fact, part of the trouble people have with left and right derives from general symmetry about the left/right axis. Not only do humans have global left–right symmetry, but so do many other members of the biological world, from termites to trees, as well as many manufactured goods designed to serve the biological world, from bicycles to buildings. Despite terms such as "sinister" and "dexterity," derived from the Latin for left and right, respectively, there does not seem to be strong universal cognitive associations of quantity or quality to left or right.[1] In the absence of compelling universal perceptual or cognitive reasons for giving precedence to either left or right, other reasons prevail, for example, handedness, or perceptual/motor habits derived from writing. Like many others, Ladavas (1988) found that people in general judge *up* or *above* faster than *down* or *below* (Braine, Plastow, & Greene, 1987; Corballis & Beale, 1976; Clark & Chase, 1972; Farrell, 1979; Maki, Grandy, & Hauge, 1979; Seymour, 1969, 1974; Sholl & Egeth, 1981); however, she found that left-handers are faster at *left* judgments than *right,* but that right-handers are faster at *right* than *left.* Ambidextrous subjects showed no bias. Because most of the population is right-handed (or left-brain dominant) it is possible that a rightward bias may appear in some tasks.

[1] Anyone in doubt should consult politicians on both the left and the right.

In both perceptual exploration tasks and drawing tasks, the direction of written language plays a large role in whether the left–right or right–left direction is preferred. In a perceptual exploration task, pictures of objects are displayed in an unstructured array or in various structured arrays, such as in rows or in a square or in a triangle; children are asked to call out the names of the objects. Of interest is the order in which they name the objects. American children have an especially strong tendency to call out names of objects from left to right in their early years of reading (e.g., Elkind & Weiss, 1967; Elkind, 1969). In contrast to American children, Hebrew-speaking children have a tendency to call out objects from right to left that is particularly strong during the early years of reading Hebrew. When English is introduced in school, a left–right tendency appears (Kugelmass & Lieblich, 1970, 1979). Interestingly, right–left perceptual exploration is much stronger in Arabic-speaking children than in Hebrew-speaking children (Goodnow, 1977; Kugelmass & Lieblich, 1979; Nachshon, 1985).

Although both Hebrew and Arabic are read and written from right to left, Hebrew-speaking Israeli children are more likely to have extensive exposure to European languages than Arabic-speaking Israelis. In addition, young Hebrew-speaking children are taught to write numbers and perform arithmetic operations from left to right, just as in European languages, but young Arabic-speaking children are taught to perform arithmetic operations from right to left. Finally, although both Hebrew and Arabic are written from right to left, Arabic script is connected and Hebrew script is not, and each character in Arabic is formed right-to-left, while most characters in Hebrew are formed left-to-right. This difference in language culture is evident in a motor task testing directionality (Goodnow, 1977; Goodnow, Friedman, Bernbaum, & Lehman, 1973), where both English and Hebrew readers copied geometric forms from left to right. In a follow-up study, Lieblich, Ninio, and Kugelmass (1975) asked Hebrew- and Arabic-speaking children from kindergarten to ninth grade to copy horizontal and vertical lines. Both language groups copied the vertical line from top to bottom, but the Hebrew speakers copied the horizontal line from left-to-right, and the Arabic speakers—except the kindergartners—copied it from right to left. Preference for right or left, then, is open to a variety of influences. Thus, the graphic convention of displaying increases from left to right seems likely to have a cultural origin, in contrast to the convention of displaying increases from down to up, which appears to be rooted in the physics and biology of the world and, in turn, in human perception and cognition.

Examining children from different language cultures produce graphic representations of different quantitative relations allows exploration of these issues. Young children's productions of graphic representations are less likely to reflect learned conventions than those of adults. American children were contrasted to Hebrew- and Arabic-speaking Israeli children. If the graphic convention of representing increases from left to right is just that, a convention, then children from different language communities may differ in their use of direction in the horizontal dimension. In contrast, if the graphic convention of representing increases from down to up is based on a pervasive cognitive bias, children from different cultures should not differ in vertical directionality. All three languages have metaphoric expressions associating greater quantity and quality with upward.

TASK

To address these questions and more, we developed a production task that did not entail writing. Children placed stickers standing for levels of concepts on paper to represent relations between the levels. This was done for several reasons. First, we did not want motor facility with drawing implements to confound our results. Second, we wanted to minimize the application of habits from drawing and writing. Finally, previous research has examined how children compose written symbols (Cohen, 1985; Hughes, 1986; Ferreiro, 1978, 1985; Ferreiro & Teberosky, 1982; Levin & Tolchinsky Landsmann, 1989; Tolchinsky Landsmann & Levin, 1985, 1987). Under some circumstances preschool children successfully represent each real object or event with a single symbol, preserving a one-to-one correspondence between objects and symbols (see especially Hughes, 1986); however, prior to second grade, their marks do not reliably distinguish one object from another (Cohen, 1985). Because we were primarily interested in how children use space to represent relations among symbols, we relieved children of the burden of inventing symbols by providing verbally labeled stickers to stand for the stimuli to be represented. For each of the concepts to be depicted, children were given a large square blank sheet of paper. The experimenter first explained something about the concept to be represented, for example, the major meals of the day. Then the experimenter put a sticker in the middle of the page saying that this represents lunch time. The child was asked to put down stickers representing breakfast time and dinner time. The child knew ahead of time what was to be represented and was free to put the stickers anywhere on the page. The child was first warmed up to the task by producing representations of spatial concepts, for example, the relative positions of three peg dolls in front of the child. In addition to temporal concepts, the child was also asked to produce representations of quantity and preference. One of the quantitative relations to be represented was the amounts of sand in a spoon, cup, and dump truck. For preference relations, preferences were first elicited from the child, for example, the child's favorite TV show, least-liked show, and one show in the middle. Then the child was asked to put down stickers representing the relations among those three shows. Several questions of each type, temporal, quantity, and preference, were asked in order to test for consistency of effects.

INFORMATION REPRESENTED

This technique allows us to examine a second set of questions no less interesting than the questions about directionality of mapped relationship. We can also observe what information in the spatial or temporal or quantitive or preference relations is represented in the childrens' mappings. Children who place all three dots on the page but not aligned represent only *categorical* or *nominal* information. That is, they distinguish between the levels of the concept, but they do not represent the relation between the levels. Children who put all three dots on top of each other, or nearly so, fail to represent nominal relations. Children who place all three dots in order and more or less in line represent *ordinal* information, that is, the ordering of the levels of the concept. Note that the particular direction of the order is irrelevant here. Finally, children who place all the dots in order and on a line and place the dot for the 10:00 snack closer to the breakfast dot than to the dinner dot are representing some *interval* information about time in their graphic productions. They recognize that the inequal time intervals should be represented by inequal spatial intervals. Use of a truly interval scale entails selecting a unit of measurement and using it accurately. Only a weak sense of interval was tested here, namely, representing larger intervals by larger amounts of space, that is, ordering the intervals. As stated earlier, the expectation is that older children's mappings or representations will represent more of the information in the relations than younger children's mappings.

CONTENT INDEPENDENCE

The third major question of interest is whether the specific content of the conceptual relation affects the child's mapping or representation. The concepts to be represented by graphic productions range from concrete to abstract, that is, from spatial to temporal, to quantitative, to preference. Spatial concepts are the most concrete in the sense that they can actually or potentially be seen. The distances between the peg dolls, for example, are visible to the child. The temporal and quantitative relations are less concrete in the sense that they cannot be seen, yet they are more concrete than the preference relations in the sense that they have standard ways of measuring them that are known to the child. Although preschool children cannot usually tell time, they do have considerable knowledge about time and appear to know that time can be measured by hours, clocks, days, calendars, and the like (Friedman, 1989; Levin, 1989). Similarly, although young children may not be able to count and measure large quantities accurately, they seem to know that many things can be counted and that others may be measured (Gelman & Gallistel, 1978; Hughes, 1986). Finally, preference relations seem to be most abstract; they certainly cannot be seen, and there are no standard ways of assessing them. It would be consistent with a large body of developmental research (e.g., Bruner, Olver, & Greenfield, 1966; Piaget & Inhelder, 1969) if children's mappings of concrete concepts represented more information at an earlier age than their representations of more abstract ones. The specific content of the relation to be represented, temporal, quantitative, or preference, may affect either the directionality of the mapping or the information represented in the mapping, or both. Many graphic conventions do not depend on the specific content of the relation to be represented. One exception already mentioned is selection of axis: the *Y* variable is generally plotted in terms of the *X* variable, and the dependent variable in terms of the independent variable. Because children represent only one variable at a time, this exception is not relevant here. Thus, there seem to be no a priori reasons from graphic conventions to treat time, preference, and quantity differently.

The experiments were designed to induce children to produce graphic representations of a series of simple, familiar, one-dimensional, continuous concepts. The first three tasks were spatial. Although of intrinsic interest, they were primarily used as a sort of fading procedure to induce the child to use the mapping task of placing stickers on paper to represent the relations between three objects or events without giving explicit, possibly biasing, instructions. The expectation was that children would find them easy and would perform well. Recall that in the history of pictorial communication, maps appeared several millennia before graphs. A direct spatial mapping task was used first because it was thought to be simplest. For this and all tasks, the child was seated next to the experimenter. Three Fisher–Price peg dolls were lined up evenly spaced left-to-right in front of the child. The experimenter placed a round sticker in the middle of a blank square page to represent the position of the middle doll, and the child was asked to put down stickers to represent the relative positions of the other two dolls. For the second production task, one end doll was moved farther away from the other two, and the sticker task was repeated on a clean sheet of paper. Making the distances between the dolls blatantly inequal was done to induce the idea of representing inequal intervals in distance by inequal intervals on paper. Next, two imaginal spatial tasks were given. Children were asked to put down stickers representing relative positions of specific body parts of familiar objects. The objects were chosen in the expectation that one—mapping the head, neck, and feet of a person—would induce a vertical mapping, and the other—the head, fin, and tail of a fish—would induce a horizontal mapping. Note that for both tasks the spacing of the three body parts is inequal.

The next three sets of two or three mappings each were of special interest. The first of these asked children to map temporal relations; the second, preference relations; and the third, quantitative relations. As before, for each mapping, three cases were represented, one by the experimenter and the other two by the child. In all experiments, the first mapping of each of the three types was designed so that the intervals between the first and second case and the second and third case were approximately equal. This was also true for the second mapping of each type in Experiment 1, but in Experiments 2 and 3, the second and third mappings of each type were designed so that one of the intervals was clearly greater than the other. The first set of abstract mappings were based on time. Because much of the way we talk about time derives from the way we we talk about space (Clark & Clark, 1977; also, Szamosi, 1986), for example, terms like "before" and "after," temporal concepts seem the least abstract and the most transparent after spatial, so they were represented first. The early graphs in the late 18th century, as well as more than 75% of the graphs published today, depict a variable changing with time (Tufte, 1983), which is typically portrayed from left to right. The temporal mappings we used were times of meals and of scripted daily activities, such as getting dressed and going to school, for Experiments 1, 2, and 3 and also parts of the day for Experiments 2 and 3. The next set of mappings concerned preferences. In each case, the child was queried about his or her own preferences for food and games in Experiments 1, 2, and 3 and for TV shows for Experiments 2 and 3; the child's own choices were then mapped as before. The final set of mappings concerned quantities, amounts of sand and heights of babies, children, and adults in Experiment 1 and amounts of sand, books, and candy in Experiments 2 and 3. Height was dropped in Experiment 2 because it induced a relatively high number of diagonal, seemingly iconic mappings, as if the child were putting a dot at the top of the imagined heads of imagined cartoon-sized figures of a baby, child, and adult.

That early school-age children have some metric understanding of each of these domains, space, time, quantity, and preference, is supported by previous research. Conclusions about what children know and understand are necessarily based on how knowledge and understanding are measured or assessed, but each measurement procedure brings its own difficulties, partly independent of the knowledge it is meant to assess

(Gelman & Baillargeon, 1983; Miller, 1989). Recent ingenious techniques of assessing children's knowledge have revealed that children have ordinal and some interval understanding of familiar domains at earlier ages than was previously claimed (Piaget & Inhelder, 1967, 1969; Piaget, Inhelder, & Szeminska, 1960). This is not to say that there is no development in the school years. For example, preschoolers' judgments of area depend on both height and width; however, these dimensions appear to be combined more complexly and accurately by older children (Anderson & Cuneo, 1978; Cuneo, 1980; Wilkening, 1979). Spatial representations of preschoolers reflect some metric or Euclidean information, although not perfectly (Cousins, Siegel, & Maxwell, 1983; Friedman & Brudos, 1988; Miller & Baillargeon, 1990), but those of adults are not perfect either (Mandler, 1983, 1988; Tversky, 1981). Very young children have no trouble correctly listing sequences of familiar events, such as what happens at day-care or McDonald's (Fivush & Mandler, 1985; Friedman, 1977, 1989; Friedman & Brudos, 1988; Nelson, 1978, 1986). Other tasks indicate that young children can evaluate and reproduce differences in duration as well as integrate durations with some accuracy (Levin & Wilkening, 1989; Levin, 1989; Wilkening, 1981). As for quantity, providing that the numbers are small, preschoolers can count, add, and subtract (Gelman & Gallistel, 1978; Gelman, Meck, & Merkin, 1986; Hughes, 1986). Finally, young children are good at indicating finely grained differences in food preferences (Fallon, Rozin, & Pliner, 1984; Rozin, Fallon, & Augustoni-Ziskind, 1985).

Thus, these studies are not meant to investigate young children's knowledge of space, time, quantity, and preference; such knowledge has been demonstrated. These studies are designed to investigate children's external representations of that knowledge. Others have investigated children's productions of maps (Karmiloff-Smith, 1979), of numbers (Hughes, 1986), and of writing (Ferreiro, 1978; 1985; Ferreiro & Teberosky, 1982; Levin & Tolchinsky Landsmann, 1989; Tolchinsky Landsmann & Levin, 1985, 1987). Some of their findings are reviewed and compared with ours under General Discussion.

EXPERIMENTS 1 AND 2

We ran two very large experiments and one small experiment. Because they differ only in whether the relations to be represented contain blatant differences in interval or not, the two large experiments are described together. The results on directionality for both experiments are discussed first, followed by the results on information represented. The third experiment is then described and discussed. It is essentially the same as the second experiment with additional manipulations designed to encourage the representation of some interval information.

Method

Subjects

A total of 1161 subjects participated in Experiments 1 and 2. The breakdown of subjects by grade, sex, culture, and experiment appears in Table 1. School-age children were drawn from public and private schools in the Jerusalem, Nazareth, and Palo Alto, California areas. All the children were middle class and above. We attempted to equate SES across language cultures as much as possible based on consultation with the Ministry of Education in Israel and our own familiarity with the schools. Grades rather than ages are reported because we do not have the ages of the Israeli samples. On the whole, the children were the proper age for their grades, that is, 5–6 for kindergarten, 6–7 for first grade, 8–9 for third grade, 10–11 for fifth grade, and so on. The adult population included 30 Hebrew-speaking students from Hebrew University and 59 students from Stanford University (due to protection of anonymity, we do not know the sexes of all the student subjects).

Materials

For the children, for each task, each child responded by placing round colored stickers .5 cm in diameter on a 25-cm^2 blank sheet of paper. Three 4.5-cm ($1\frac{3}{4}$ in.) Fisher–Price peg dolls were used as stimuli in the first two tasks. For ninth graders and adults, self-administering booklets were prepared. Each question appeared at the top of a separate page. The remainder of the page was a ruled-off square (approximately 21.5 cm) for responses. Color-coded stickers were provided for responses.

TABLE 1
Number of Children in Each Experiment by Grade and Language

	English		Hebrew		Arabic	
Grade	Boys	Girls	Boys	Girls	Boys	Girls
			Experiment 1			
K	24	26	18	20		
1	26	24	26	23	30	11
3	25	25	23	26	13	21
5	21	29	26	25	19	21
	96	104	93	94	62	53
			Experiment 2			
K	26	24	15	12	21	19
1	25	26	18	13	15	17
3	25	26	19	11	17	10
5	13	37	16	15	17	19
	89	113	68	51	70	65
7			13	16	10	23
9	28	24				
A	59		30			

Design

For both experiments there were five tasks: spatial, imagined spatial, temporal, preference, and quantity. For all of the tasks (see Procedure), one of the cases to be mapped was mentioned and mapped first for half of the subjects in each group, and the other case was mentioned and mapped first for the other half. The two cases are called case 1/case 2 in the Procedure. For Experiment 1, there were two subtasks for the temporal, preference, and quantity tasks; these were presented in one order for half the children of each group and in the other order for the other half. Similarly, in Experiment 2, there were three subtasks for each of the temporal, preference, and quantity tasks. The equispaced subtask was presented first to all children, and the other two, unevenly spaced subtasks were presented in one order to half the children of each group and in the other order for the other half.

Procedure: Children

The experimenter brought each child individually to a private place, talking with the child to put the child at ease. The child was then seated next to the experimenter. What follows is the typical wording of instructions to the child. The experimenter said, "We are going to play a game with stickers. Each time we play, first I'll put a sticker down on the paper and then you'll put two stickers down. At the end of the game, I'll give you some nice stickers you can take home. Let's start, and I'll explain more as we go along."

Spatial. (A) Equidistant. The experimenter put out the three peg dolls equidistant in a line parallel to the edge of the table opposite the child. The experimenter said, "See these three dolls? Tell me their colors." After the child named the colors, the experimenter continued, "I'm going to put down a sticker on the paper for the place of the red (middle) doll. Then you will put down stickers for the places of the blue and yellow dolls. Here's where I'm putting the sticker for the red doll (experimenter puts sticker in middle of the page). Now you put down a sticker for the place of the blue doll (pause, while child responded), and now put down a sticker for the place of the yellow doll." After the child placed the stickers, the experimenter said, "Very good! Let's try another one." (B) Inequal distance. Then the experimenter moved one of the end dolls farther away from the other two, saying, "Now I'm moving the red/blue doll (left or right for different orders) over here." The experimenter took another piece of paper and stickers and the first procedure was repeated. Again, when the child finished, the experimenter encouraged the child by saying the child did a good job.

Imagined spatial. (A) Person. The experimenter said, "Think about a person standing and the person's head, neck, and feet. First I am going to put a sticker for the place of the person's neck and I want you to put a sticker for the place of the person's head and feet/feet and head. Here is the sticker for the person's neck. Now you please put a sticker for the person's head/feet (pause), and another sticker for the person's feet/head." As usual, the child was encouraged when the child completed the task. (B) Fish. The experimenter continued, "Now, let's think about a fish, and the fish's head, fin, and tail. I will put a sticker down for the place of the fish's fin, and you put a sticker for the head/tail and a sticker for the head/tail. OK, here is the sticker for the fish's fin. Please put a sticker for the fish's tail/head, and now put a sticker for the fish's head/tail."

Temporal, Experiment 1. (A) Meals. The experimenter said, "Now I want you to think about the times of day that we eat meals, breakfast, lunch, and dinner. I will put a sticker down for lunch time, and I want you to put a sticker for dinner/breakfast time and a sticker for breakfast/dinner time. Here's where I'm putting a sticker for lunch time. Now you put a sticker for dinner/breakfast time (pause), and another sticker for breakfast/dinner time." (B) Activities. The experimenter said: "Now let's think about the things you do in the evening. What do you do first, get undressed or brush your teeth or go to bed? What do you do next?" The experimenter repeated what the child said. "OK, now I'll put a sticker down for the time you brush your teeth (or second activity) and you will put a sticker for the time you get undressed (first activity)/time you go to bed (third activity) and another sticker for the time you go to bed (third activity)/time you get undressed (first activity). Here is the sticker for the time you brush your teeth. Now please put a sticker for the time you get undressed/go to bed (pause), and now put another sticker for the time you go to bed/get undressed."

Temporal, Experiment 2. (A) Times of day (evenly spaced): morning, noon, and night (substitute for Meals, as in Experiment 1). (B) Meals (unevenly spaced). The experimenter said, "Now I want you to think about the times of day that we eat: breakfast, afterschool snack, and dinner. I will put a sticker down for the time you eat afterschool snack and I want you to put a sticker for breakfast/dinner, and another sticker for dinner/breakfast. Here's where I'm putting a sticker for afterschool snack time. Now you put a sticker for dinner/breakfast time (pause), and another sticker for breakfast/dinner time." (C) Activities (unevenly spaced). The experimenter said, "Now let's think about some of the things you do during a day: getting up, going to school, and going to bed. OK, now I'll put a sticker down for the time you go to school, and you put down a sticker for the time you get up/go to bed and another sticker for the time you go to bed/get up. Here is the sticker for the time you go to bed/get up. Now please put a sticker for the time you get up/go to bed."

Preference, Experiment 1. (A) Food. The experimenter said, "Now let's think about food. What is you favorite food? (or, What food do you really like or like a lot?). What food do you really not like at all? And what food do you like a little bit?" The experimenter repeated the child's answers and said, "Now I am going to put a sticker for ______, the food you like a little bit, and I want you to put a sticker for ______, the food you like a lot/food you don't like at all (pause) and now put another sticker for ______, the food you don't like at all/like a lot. Here I am putting a sticker for the food you like a little. Please put a sticker for the food you like a lot/food you don't like at all (pause), and now put a sticker for the food you don't like at all/like a lot." (B) Games. The experimenter said, "Now let's think about games that you play. What game do you like to play the most? Now tell me a game you don't like at all. What about a game you like to play a little?" The experimenter repeated the child's choices and said, "Now I'm going to put down a sticker for the game you like a little, and you'll put down a sticker for the game you don't like at all/like the most and then another sticker for the game you like most/don't like at all. OK, here's a sticker for ______, the game you like a little. Please put a sticker for ______, the game you don't like at all/like the most (pause), and now put a sticker for ______, the game you like the most/you don't like at all."

Preference, Experiment 2. (A) Food: evenly spaced, as in Experiment 1. Children were asked about their "favorite" food, a food they "like," and the food they "dislike most." (B) Television shows (unevenly spaced). The experimenter said, "Now let's think about television shows. What TV show do you like a lot? What television show do you like a little? What television show do you dislike?" The experimenter repeated the child's answers and said, "Now, I am going to put a sticker for ______, the show you like, and I want you to put a sticker for ______, the show you like a lot/dislike and another sticker for ______, the show you dislike/like a lot. Here I am putting a sticker for the show you like. Please put a sticker for the show you like a lot/dislike, and now put a sticker for the show you dislike/like a lot." (B) Games (unevenly spaced). The experimenter said, "Now let's think about games that you play. What game do you like to play? Now tell me a game you dislike a lot, a game you dislike but not as much as ______." The experimenter repeated the child's choices and said, "Now I'm going to put down a sticker for ______, the game you dislike, and you'll put down a sticker for ______, the game you like/dislike a lot and then another sticker for the game you dislike a lot/you like. OK, here's a sticker for ______, the game you dislike. Please put a sticker for ______, the game you like/dislike a lot, and now put a sticker for ______, the game you dislike a lot/you like."

Quantity, Experiment 1. (A) Sand. The experimenter said, "Now I want you to think about sand. Have you ever played with sand? Let's think about amount of sand; about a very small amount of sand, a spoonful, about a medium amount of sand, a bucketful, and about a very large amount of sand, a whole dump truck full. I am going to put a sticker down for the medium amount of sand, the bucketful, and I want you to put a sticker down for the spoonful of sand/dump truck full of sand and a sticker for the dump truck full/spoonful of sand. Here is where I am putting a sticker for the bucketful of sand. Now you please put a sticker for the spoonful/dump truck full of sand (pause) and now put a sticker for the dump truck/spoonful of sand." (B) Height. The experimenter said, "Now I want you to think about the heights of different people, about how tall different people are. Think about the height of a 2-year-old child, your height, and the height of a grown-up. I will put a sticker for your height, and I want you to put a sticker for the height of a grown-up/2-year-old child and another sticker for the height of a 2-year-old child/grown up. Here's the sticker for your height. Please put a sticker for the height of the grown-up/2-year-old (pause) and put another sticker for the height of the 2-year-old child/grownup."

Quantity, Experiment 2. The general procedure was the same as for Experiment 1. The cases were referred to as follows. (A) Books (evenly spaced). The three quantities were backpack full of books, the amount of books you have at home, and the amount of books in the school library. (B) Sand (unevenly spaced). The three quantities were a spoonful, a cupful, and a dump truck full of sand. (C) Candy (unevenly spaced). The three quantities were a handful, the amount you get on Halloween, and a supermarket shelf full of candy.

Some of the cases were changed slightly in the Hebrew and Arabic versions to be familiar to children in that culture; e.g., Halloween was familiar only to American children. The Hebrew and English instructions were developed by all three experimenters, speakers of both languages, and the Arabic instructions were developed by the third author, a speaker of Arabic, and the Arabic-speaking research assistants.

Procedure: Adults

Teenagers and adults participated in self-paced groups. The instructions for the booklets read: "The following is a simple experiment originally done on small children. We are interested in how teenagers (adults) answer the same questions. The tasks will probably seem simple to you, but remember they were designed for very young children. On each of the following pages, you will be asked to indicate or represent a concept by placing stickers corresponding to events or alternatives or parts or quantities. Please answer in the most simple and direct way you can." The teen/adult booklets asked about a person, a fish, and then the three temporal, three preference, and three quantity tasks of Experiment 2. The wording of the questions was quite similar to the aural wording, asking the subject first to "think about how a person looks standing up" or "about the times of day" or "about quantities of candy," then listing the cases to be represented, and then directing the subject how to map them.

Results

Overview

Two aspects of the data were of interest: (A) the *information represented* in the mapping, and (B) the *direction* of representing increases. For information represented, three levels were coded: *nonlinear,* that is, the stickers in no way formed a line (for example, formed a triangle), or did form a line but were out of order (for example, breakfast, dinner, and lunch); *ordered,* that is, more or less formed a line with increases ordered in any direction; and *interval,* that is, ordered plus showing a larger difference between the stickers corresponding to the larger conceptual difference (for example, more space between morning snack and supper than between breakfast and morning snack). For Experiment 1, responses were coded as nonlinear or ordered because interval was not varied in the stimuli. Direction was scored as left-to-right (LR), right-to-left (RL), top-to-bottom (TB), and bottom-to-top (BT). There was a small number of diagonal cases, but they did not seem to vary systematically with anything, so they are not reported separately. For the most part, the mappings were clear and easy to score, but where there was ambiguity, the scorers and two of the experimenters consulted and agreed. The independent variables were the grades of the children, their languages, and the content of the concept to be represented, spatial, temporal, quantitative, and preference. The primary statistical tool was the χ^2 test of independence on subsets of the data. Many of the analyses were done to show that an entire set of independent variables had no reliable effect on a dependent variable. Some of these will be reported in the interest of completeness. Other analyses were done to show that a particular independent variable had a replicable effect on a dependent measure. All the effects that are taken seriously appeared in both experiments and/or within an experiment over language, over concept, or over age.

A preview of the main findings should aid the reader. For direction, the main result was an effect of language on temporal concepts alone, namely, a strong tendency by English speakers to portray temporal concepts from left to right, a tendency for Arabic speakers to represent temporal concepts from right to left, and secondarily in younger children, from top to bottom, and a strong tendency for Hebrew speakers to represent temporal concepts horizontally, with a preference for right to left that changed slightly with grade. Except for the last, there were no grade effects, and there were neither grade nor language effects on representing the other concepts. For expressing quantity and preference, people used left-to-right, right-to-left, and bottom-to-top about equally and avoided top-to-bottom. In contrast, for representing information in mappings, there were no effects of language, but strong effects of grade, with more older children representing information about interval. There were also weak effects of concept, with more information represented at an earlier age for the more concrete concepts.

Directionality

Analysis. Only ordered increases could be scored for directionality. This eliminated 15–40% of the data for the youngest children and 6–25% of the data for the older children. Direction was scored for the person and the fish as well as for the other concepts. On the whole, children of all ages and cultures performed this task well and uniformly, and where there are differences, they are reported. First, the results for consistency of direction of mapping are discussed, then the results for directionality and grade and directionality and sex are considered. Once grade and sex are dismissed as substantive factors, the significant findings for directionality in relation to language and particular concept are discussed.

Consistency of directionality (*K–5*). The consistency of direction of mapping was scored as follows: for Experiment 1, the direction was scored as consistent if the direction of a concept was the same for both examples of the concept (e.g., meals and events of the day for time); for Experiment 2, the direction was scored as consistent if it was the same for all three examples of a particular concept. Consistency was examined within each language culture. In Experiment 1, there was little evidence for increases in consistency over the four grades (kindergarten, first, third, and fifth grades), with only one of the nine comparisons significant. In that experiment, 69% of the children consistently mapped the two examples of the same concept. There were effects of language culture (two out of nine comparisons), but they were not consistent. In Experiment 2, the overall level of consistency was 60%. Again, there were no consistent effects of language culture or of concept (two out of nine comparisons significant). In this experiment, however, there were weak effects of grade. For English-speaking children, consistency of time, quantity, and preference increased with grade (time, quantity, and preference, all $p < .01$) For Hebrew-speaking children, time and preference ($p < .01$) showed grade increases, but quantity did not. For Arabic-speaking children, only quantity showed an increase with grade ($p < .01$).

Directionality and grade (*K–5*). On the whole, direction of mapping did not depend reliably on grade within each language. In Experiment 1, 3 of the 18 comparisons were significant, and in Experiment 2, five of the 27 comparisons were significant, but only one of the patterns occurred in both experiments (increased use of LR in English-speaking children for meals (Experiments 1 and 2, $p < .05$)).

Directionality and sex (*K–5*). For Experiment 1, of a total of 30 comparisons (including fish, two time concepts, two preference concepts, two quantitative concepts, and three measures of consistency for three cultures), only 1 was significant, and in Experiment 2, out of 39 comparisons, 5 were significant, but the single effect of Experiment 1 was not replicated in Experiment 2. Thus, the sex differences were minimal, and neither consistent nor interpretable.

Directionality and language (*K–5*). There were consistent differences in directionality that depended on both language and concept. Thus, children do not have a general way of treating increases graphically that they apply to all concepts. For these analyses, the data were collected over grade and sex because there were no effects of those variables.

One curious result occurred in the direction of orienting the fish. In both experiments, Arabic-speaking children tended to orient the fish head up and tail down, as if caught on a line, whereas English-speaking and Hebrew-speaking children oriented the fish horizontally, as if swimming (Experiments 1 and 2, $p < .01$).

The consistent and replicable differences in directionality dependent on language occurred only for the temporal concepts and are related to the direction of the written language. They are depicted in Fig. 1. For temporal concepts, English-speaking children preferred the LR direction,

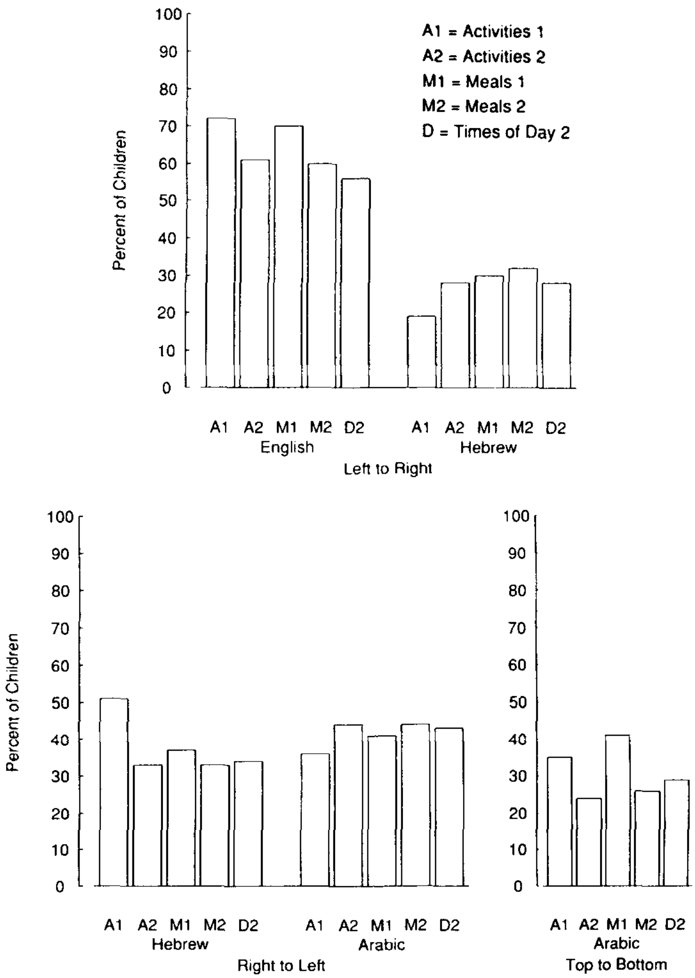

FIG. 1. Percentages of children by language indicating specified directions of increase for temporal concepts in Experiments 1 and 2.

Hebrew-speaking children preferred RL with LR a close second, and Arabic-speaking children preferred RL with TB a close second. The BT direction was used very infrequently by all groups. This pattern occurred for all temporal concepts used in both experiments (Experiments 1 and 2, activities; Experiments 1 and 2, meals; Experiment 2, times of day, all $p < .01$).

The quantitative and preference concepts in both Experiments 1 and 2 were characterized by an avoidance of TB by all language cultures and approximately equal use of the remaining three directions by all groups. There was no correspondence between language culture and use of LR or RL directions for these concepts. In Experiment 1, the quantitative and preference concepts yielded significant χ^2 seemingly due to greater relative use of TB by Arabic-speaking children and greater relative use of either RL or LR by English-speaking children. None of the quantitative or preference concepts in Experiment 2 yielded significant χ^2.

Directionality and language culture in teenagers. The same patterns of directionality were evident in teenagers and adults. For a variety of technical reasons, the American sample of teenagers came from the ninth grade and the Israeli sample came from the seventh grade. Because there were no substantial age differences in directionality from kindergarten to fifth grade in the younger children, the ninth and seventh grade samples were combined for the purposes of examining directionality. As in the younger children, language culture differences in directionality were evident in the temporal concepts. The use of TB by the Arabic-speaking children diminished, so the major difference was in the horizontal direction of increases, with a majority of English-speaking children preferring LR for all three temporal concepts, a plurality of Arabic-speaking children preferring RL, and the Hebrew-speaking children in between. At this age, LR was preferred by more Hebrew-speaking children to RL, but only slightly. This was shortly after English had been introduced in school and is consistent with early research showing a temporary preference of LR over RL at that age (Kugelmass & Lieblich, 1979). The results are displayed in Fig. 2. Note also that the English-speaking preference for LR was stronger than the Hebrew- and Arabic-speaking preference for RL, again a typical finding in directionality research (times of day, meals and activities, all $p < .01$).

For the quantitative and preference concepts, there were no consistent effects of directionality that depended systematically on concept or language culture (two of nine comparisons were significant). For all three sets of concepts, directionality was more consistent in Hebrew-speaking children than the others (for time, $p < .05$; for quantity and preference, $p < .01$).

Directionality and language in adults. The adult sample consisted only

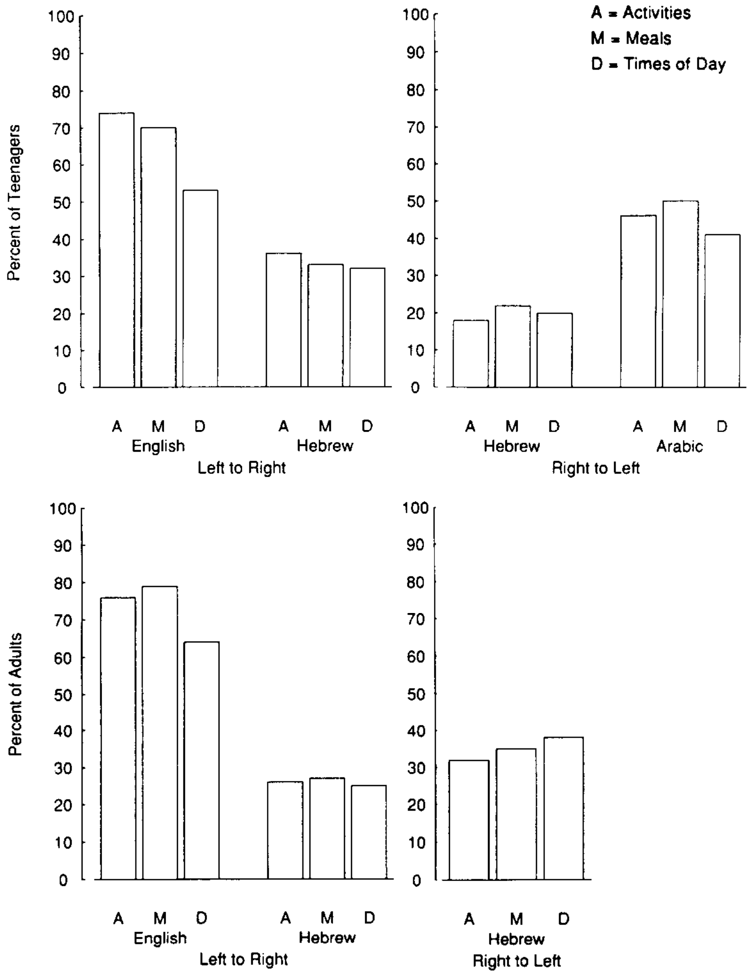

FIG. 2. Percentages of teens and adults by language indicating specified directions of increase for temporal concepts.

of English and Hebrew speakers. As before, language culture differences emerged for temporal concepts alone, and, as before, LR was strongly dominant for English speakers. For Hebrew speakers, RL was again dominant but not as strongly as LR was for English speakers. These findings appear in the lower panels of Fig. 2 (times of day, meals, and activities, all $p < .01$).

There were no differences in directionality due to language culture for preference and quantitative concepts (one of six comparisons was significant). For all quantitative and preference concepts, the dominant direction for both groups was BT, followed by LR. RL was used slightly by Hebrew speakers, but otherwise the remaining two directions were avoided. BT and LR are, of course, the canonical directions for representing increases. There were no differences in consistency due to language or concept.

Information Represented

Analysis. In contrast to the results for directionality, the primary factor influencing information represented was grade, not language culture. Thus, the findings for sex and language culture will be reviewed before the major findings for grade.

Information represented and sex. Of 52 comparisons in Experiment 1, 1 was significant and of 64 comparisons in Experiment 2, 3 were significant, so it can be concluded that there are no consistent effects of sex on information preserved in graphic mappings. In all four cases, girls outperformed boys. Because this is a spatial task, and boys have been known to outperform girls in spatial tasks, the absence of male superiority is of some importance.

Information represented and language culture in children. Considering the findings of both experiments, there were weak effects of language culture on information represented in children's graphs. Eleven of 32 comparisons in Experiment 1 and 16 of 44 comparisons in Experiment 2 were significant. In 9 of the 11 effects in Experiment 1 and 14 of the 16 effects in Experiment 2, either more of the mappings of English-speaking children or fewer of the mappings of Arabic-speaking children (or both) represented order. Because of large differences in home environments and educational systems, no attempt is made to account for these weak effects.

Information represented by grade. In both Experiments 1 and 2, for every spatial (dolls), temporal, quantitative, and preference task save one, the frequency of graphs that did not represent order decreased with grade, and the frequency of graphs that represented order for Experiment 1 and order and interval for Experiment 2 increased with grade (all $p < .05$). The single exception was uneven dolls in Experiment 1. Interval was not scored for either person or fish in both experiments because the demand to represent interval was vague, and order performance was very high even in the youngest children, so no grade trends were evident. The percentages of children representing order for each concept in Experiment 1 appear in Fig. 3. The percentages of children representing order for each concept in Experiment 2 appear in Fig. 4, and the percentages of children representing order and interval for each concept in Experiment 2 appear in Fig. 5. It is apparent from Figs. 4 and 5 that children represent

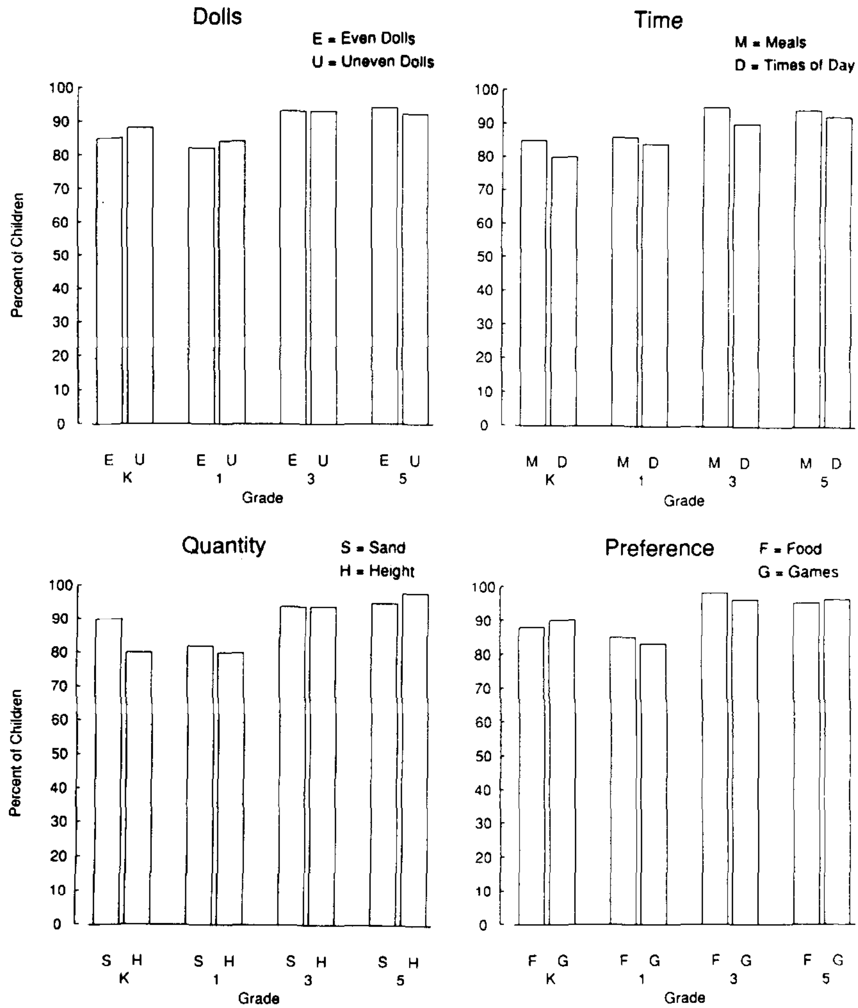

FIG. 3. Percentages of children whose graphs represent order by grade and concept in Experiment 1.

order and especially interval for the directly visible spatial task, uneven dolls, far earlier than they represent interval for the more abstract concepts. Within the more abstract concepts, there was a small effect of abstractness on information represented. This analysis used the data from Experiment 2 for the two tasks for each concept where there were interval differences collected over language and age. Each child was given a score from 0 to 2 depending on how many of the mappings for that concept represented order. Then the same analysis was done for interval. These

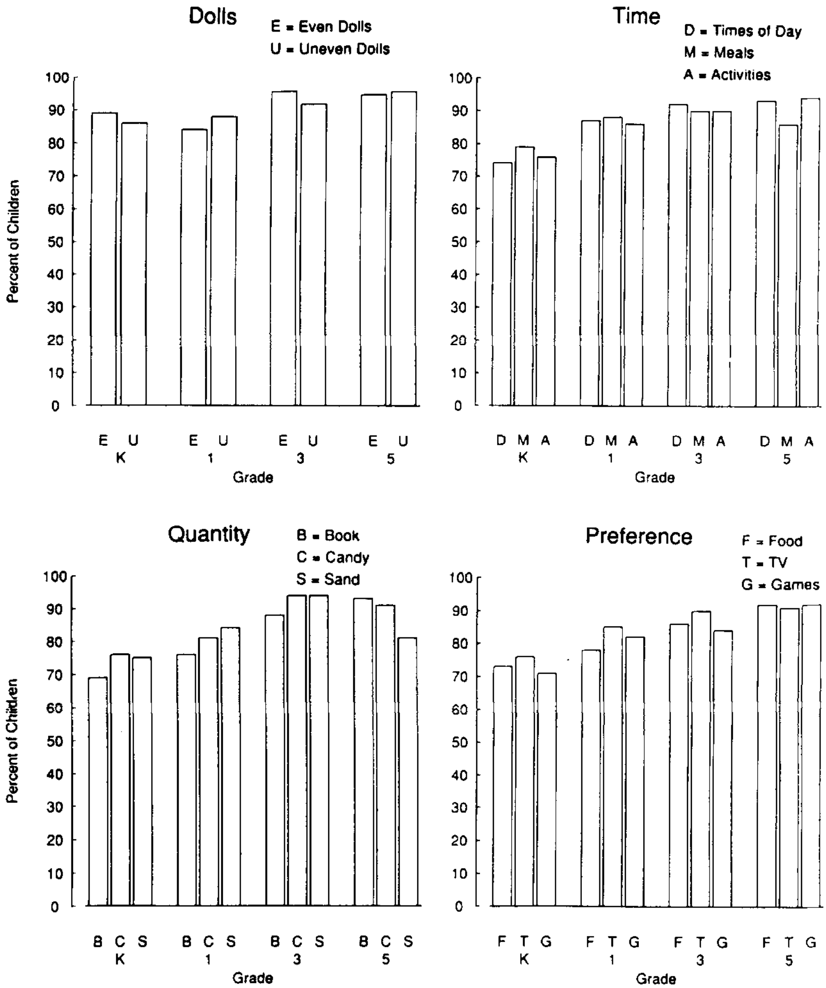

FIG. 4. Percentages of children whose graphs represent order by grade and concept in Experiment 2.

scores were subjected to one-way analyses of variance. For order, there were no significant differences. For interval, the mean score translated to percentages for temporal concepts was 32%, that for quantitative concepts was 25%, and that for preference was 23% ($F(2,1034) = 12.93$, $p < .0001$). Thus, interval was represented more frequently by children for more concrete concepts.

Information represented in teenagers and adults. The percentages of teens and adults representing order for each concept are displayed in Fig. 6, and the percentages of teens and adults representing interval for each

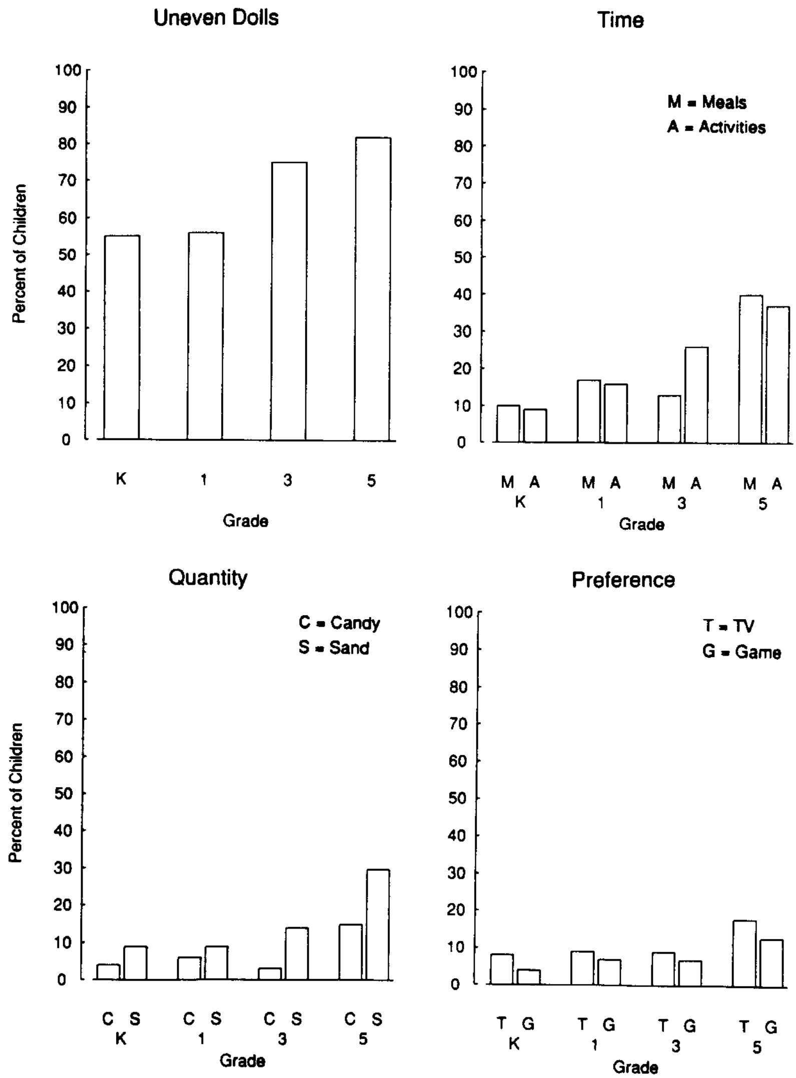

FIG. 5. Percentages of children whose graphs represent order and interval by grade and concept in Experiment 2.

concept are displayed in Fig. 7. The increasing representation of order and/or interval with age continued into the teen years for Hebrew- and Arabic-speaking children. Increases were not evident for English-speaking teens, but the technique for eliciting responses in the English-speaking children was a large classroom situation rather than individually, so the demand for representing order and/or interval may have been

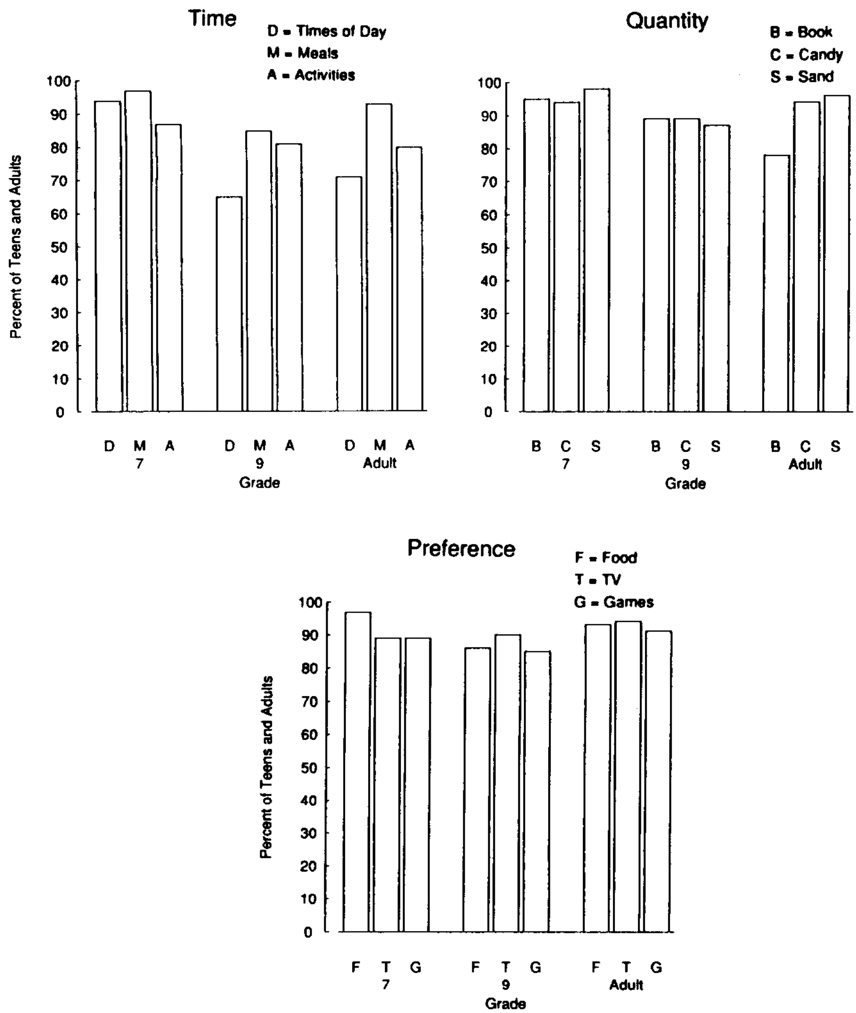

FIG. 6. Percentages of teens and adults whose graphs represent order by concept (food preferences for Hebrew speakers only.)

weaker. The adult samples, where responses were elicited by a questionnaire, were at the high levels seen in the Israeli teen sample.

Discussion

Children, teens, and adults in three language cultures, English-speakers and Israeli Hebrew- and Arabic-speakers, produced spontaneous graphic representations of spatial, temporal, quantitative, and preference con-

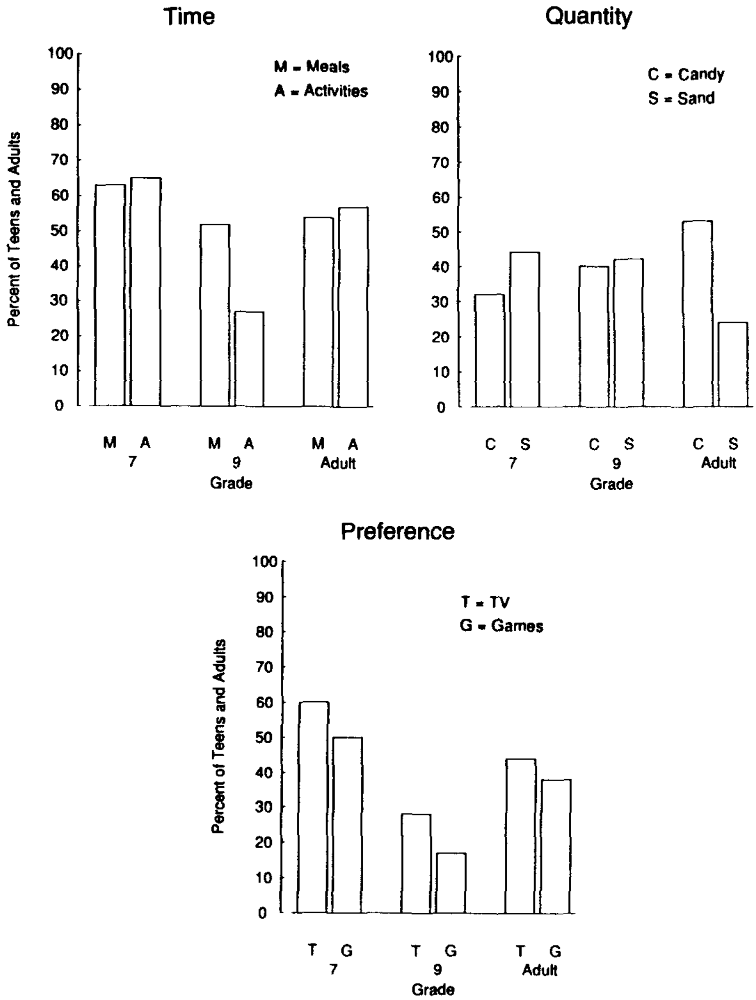

FIG. 7. Percentages of teens and adults whose graphs represent interval and order by concept.

cepts. The direction of mapping increases was scored, as well as the information represented in the mapping.

Directionality reflected language culture and particular concept. Until adulthood, it did not depend in any systematic way on age. For quantitative and preference concepts, children used left-to-right, right-to-left, and bottom-to-top directions to indicate increases in approximately equal frequencies. Top-to-bottom was avoided in all three groups. Only English-speaking and Hebrew-speaking adults were tested; these were University students presumably with extensive experience using graphs. For both quantitative and preference concepts, the modal direction for both groups was bottom-to-top, followed by left-to-right. English speakers avoided the other two directions, but Hebrew speakers used right-to-left, albeit infrequently. Thus, the directions of representing increases in college student adults seem to follow graphic conventions for the most part, but the directions used by younger children to represent increases do not.

For temporal concepts, in contrast, there was a strong effect of language culture. English speakers showed a strong preference for left-to-right, Arabic speakers showed a preference for right-to-left and top-to-bottom, and Hebrew speakers showed a preference for right-to-left that was generally weaker than that of the Arabic speakers and a secondary preference for left-to-right that was weaker than that in the English speakers. The left-to-right tendency in English speakers was stronger than the right-to-left tendency in readers of right-to-left languages, a result consistent with previous findings (Kugelmass & Lieblich, 1970, 1979; Lieblich et al., 1975; Nachshon, 1985). Also consistent with these previous findings was the preference for left-to-right over right-to-left in teenage Hebrew speakers. This reversal appears after the introduction of English in the schools.

Overall consistency of using the same direction to represent different relations was not high within children. Elementary school children used the same direction to represent the different concepts of the same type of relation about 64% of the time; across different types of relations, consistency was lower. Thus, children do not seem to have a general graphic schema that they apply readily to any quantitative relation.

The findings for information represented showed weak effects of concept and strong effects of grade. There were also weak effects of language culture that are difficult to interpret. Children's graphic mappings of the spatial array represented order and interval at an earlier grade than mappings of nonspatial concepts. Within the nonspatial concepts, more of the mappings of temporal relations represented interval than mappings of quantitative relations, and slightly more of the mappings of quantitative relations represented interval than mappings of preference relations. Within the quantitative concepts, although "sand" is a count noun and "books" and "candy" are mass nouns, and although sand and height are more continuous quantities and books and candy are more discrete, there were no differences in the way people represented these concepts. The gains with age evident in representing information in elementary school children were not continued in high school and college. This may be due to the fact that school-age children were run individually, and high school and college students were run in groups. More younger children had unordered mappings; that is, they seemed to be using nominal scales, letting each sticker represent a level on a relative concept, but not representing the relations between levels. With age, children showed increased representation of order and then of interval. The task demand for representing interval was not a strong one, and it could be that some children did not represent interval because they did not realize it was desired. For this reason, another study was done with successively stronger demands for representing interval built into the experiment in order to induce younger children to represent interval.

EXPERIMENT 3: ATTEMPTS TO INDUCE REPRESENTATION OF INTERVAL

Because relatively few children represented interval in their graphic mappings, Experiment 3 attempted to elicit interval representations by successively stronger manipulations. The first manipulation, done for all subjects, was with the uneven dolls, explicitly pointing out to subjects that one doll was being moved farther away and explicitly requesting that the child represent this difference in distance between the dolls in the distance between the stickers. In order to ascertain whether this manipulation would transfer to the other tasks, the rest of the study was completed as for Experiment 2. After completion of the experiment, further manipulations to induce children to represent interval were introduced. If a child represented order but did not represent interval for at least one of the temporal, quantitative, or preference concepts, the experimenter returned to one of these concepts, pointed out that the conceptual differences were not the same, and asked the child to represent this in placement of stickers. The second manipulation was a strong one; it essentially informed the child that distances in the concept were different and taught the child how to represent this in the mapping. This was repeated for one of each of the three types of concepts. The dependent measure of interest is the degree of interval representation after no manipulation (Experiment 2), after a spatial demonstration of interval representation (first part of Experiment 3), and after both a spatial and a conceptual demonstration of representing interval plus a specific request to do so (second part of Experiment 3).

Method

Subjects

Subjects were Hebrew-speaking Israelis drawn from middle-class schools in Jerusalem. There were 14 boys and 14 girls in kindergarten, 16 boys and 18 girls in first grade, 10 boys and 16 girls in third grade, and 15 boys and 15 girls in fifth grade.

Stimuli

The stimuli were the same as for previous experiments.

Design and Procedure

The procedure was an adaptation of Experiment 2. The first change, the spatial manipulation, was for the uneven dolls, where the experimenter said, "Now I am moving this doll. Now you can see that here, between those two dolls, the distance is small, while here, it is very big. Now I want you to put the sticker so these distances will be seen." The second change was to make two of the quantitative concepts explicitly numerical: 2, 5, and 15 pieces of chewing gum replaced sand, and 2, 10, and 15 pieces of candy replaced the vague quantities used previously. Then the procedure followed that of Experiment 2.

The conceptual manipulation occurred after completion of the original procedure. If a child represented one of the three time, quantity, or preference concepts using order but not interval, the experimenter returned to one of those concepts in order to elicit interval. For example, for time, the experimenter returned to meals, saying, "Now we will return to meals. You remember that we were talking about breakfast, 10:00 snack (this is an institutionalized meal in Israel), and supper, right? Which is longer, the time between breakfast and 10:00 snack, or the time between 10:00 snack and supper?" After the child answered, the experimenter requested that the child put the stickers down "so that we can see this." A similar procedure was adopted for the quantitative (returning to pieces of candy) and preference concepts (returning to TV shows).

Results

The results of interest are the effects of the two manipulations to increase representation of interval in mappings. To test the effect of the first manipulation, of demonstrating interval differences in spatial distance between the dolls and requesting children to show this in their mappings, we assigned each Hebrew-speaking child from grades K–5 from the second experiment and each child from the present experiment a percentage corresponding to the proportion of temporal, quantitative, and preference concepts for which the child represented interval and order. There was a total of two tasks per concept. The means of those scores are displayed in Fig. 8. The first part of Experiment 3 was identical to Experiment 2 except for the spatial demonstration of interval, and the Hebrew-speaking population from which subjects were drawn was identical as well. Analyses of variance testing the effects of grade and spatial demonstration of interval yielded significant effects of both for each concept (For time and grade, $F(3,221) = 16.137$, $p < .0001$; for spatial demonstration, $F(1,221) = 11.889$, $p < .001$; for quantity and grade, $F(3,221) = 8.513$, $p < .0001$; for quantity and spatial demonstration, $F(1,221) = 21.276$, $p < .0001$; for preference and grade, $F(3,221) = 5.226$, $p < .002$); and for preference and spatial manipulation, $F(1,221) = 10.974$, $p < .001$). The interaction between grade and spatial manipulation was significant for time ($F(3,221) = 2.957$, $p < .03$) and for quantity ($F(3,221) = 3.606$, $p < .01$). As is evident from Fig. 8, the interaction occurs because there is a relatively large increase from grades 1 to 3 and smaller increases between Kindergarten and grade 1 and between grades 3 and 5. Another analysis of variance tested for effects of concept on representing interval information in the children in Experiment 3. As in Experiment 2, this effect, although small,

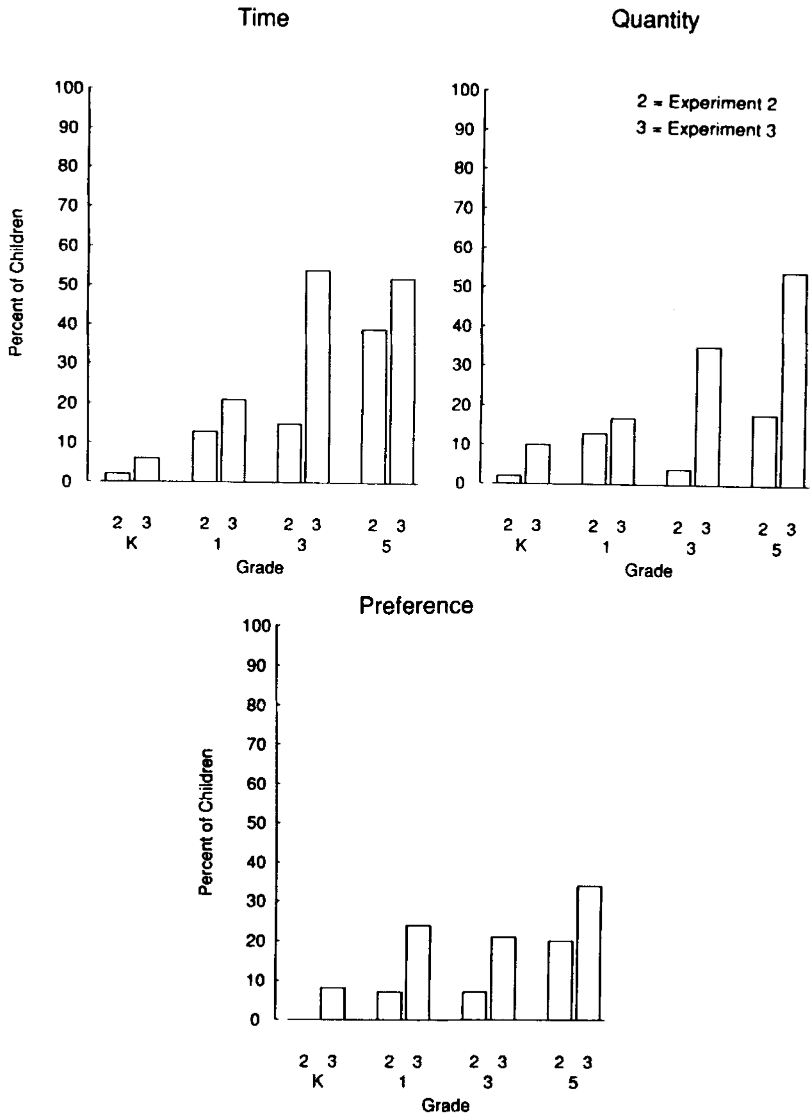

FIG. 8. Percentages of graphs per concept (maximum = 2) in which interval was represented with no demonstration of interval (Experiment 2) and with spatial demonstration of interval (Experiment 3) by grade and concept.

was significant and in the expected direction ($F(2,218) = 4.308$, $p < .01$), with an average score for time (33%) highest, followed by quantity (28%) and then preference (22%), from more concrete to more abstract. Unlike Experiment 2, grade had a significant effect on representation of order ($F(2,234) = 4.97$, $p < .01$), and here the direction was not as predicted, with average score for preference (85%) highest, followed closely by time (84%) and then quantity (77%).

The second manipulation demonstrated and requested interval for children who had represented order but not interval for one of each type of concept. Figure 9 displays the percentages of children who successfully represented interval after the second conceptual manipulation by concept and grade. Again, the largest gain seems to be between grades 1 and 3. Recall that these are not percentages of all the children, but only of those who successfully represented order but not interval. Even so, nearly half of the younger children failed to represent interval even after both spatial and conceptual manipulations. In contrast, 76–89% of the older two groups of children were able to convert their ordinal representations to interval after extensive explanation and demonstration.

Discussion

This experiment was a replication of Experiment 2 with successively stronger manipulations to induce mapping interval. The first manipulation was performed on a spatial task, the uneven dolls; children were shown that the distance between one pair of dolls was smaller than the distance between the other pair and were explicitly requested to represent the differences in distance in their mappings. This manipulation had a large effect on the older two groups of subjects and a smaller effect on the kindergartners and first graders. The second manipulation was to return to concepts for which a child had represented order but not interval. The

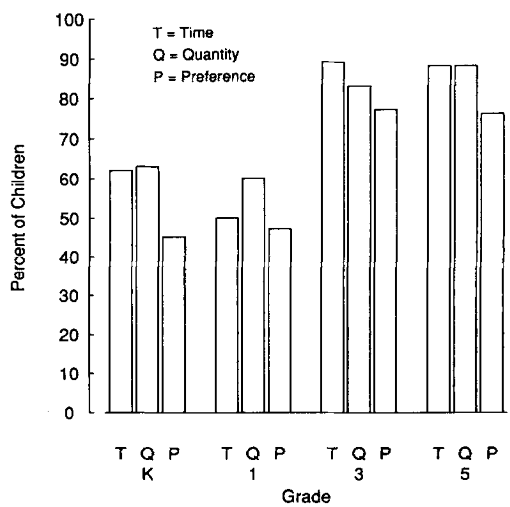

FIG. 9. Percentage of children whose graphs represented interval after conceptual and spatial demonstrations of interval by grade and concept in Experiment 3.

experimenter then induced the child to agree that the distances between one pair of points was greater than the distance between the other pair and requested that the child show this in the distances between the stickers. This was a strong manipulation as it not only requested that the child show interval, but it also taught the child how to do it. This second manipulation was also successful in increasing the frequency of representing interval, especially in the older children. As in Experiment 1, more interval information was represented for the more concrete concepts than for the more abstract concepts, but for the representation of order, the relation to abstractness of concept was not regular.

In spite of strong inducements to represent interval, many children, especially the younger ones, did not represent interval. Thus, both the spatial manipulation and the conceptual manipulation induced many children who didn't represent interval formerly to represent it. However, the manipulations did not work for all the children and did not test for transfer, that is, will interval now be represented for other concepts or at some later time?

GENERAL DISCUSSION

Three experiments examined spontaneous graphic productions of spatial, temporal, quantitative, and preference concepts in children and adults. There were several examples of each type of concept. For each example, the experimenter first explained the relation to be represented and then placed a sticker in the middle of a square page representing one level of a continuous concept; the subject was asked to place a sticker representing the other two levels and was free to place the stickers anywhere on the page. Subjects were drawn from three language cultures: English-speaking Americans, Hebrew-speaking Israelis, and Arabic-speaking Israelis. English is written from left to right, while Hebrew and Arabic are written from right to left. However, the right-to-left tendency is stronger in Arabic than in Hebrew not only in the actual writing but also in the culture and in the degree of exposure to left-to-right languages. Two different aspects of this task were of interest: first, the direction of mapping of increases in relation to language culture; and second, the information represented in relation to age. These will be discussed in turn.

Directionality

Different directions, including noncanonical directions, were used by the same people for representing different concepts, indicating that children and even adults do not treat this task as an abstract task in graphing, where the same directions would be used to represent increases for all concepts. Language culture was reflected in the direction of mapping increases, but only for temporal concepts. There were no substantial language cultural differences in directionality for quantitative and preference concepts. For temporal concepts, English speakers had a strong tendency to represent increases in the direction of writing English, from left to right. Arabic speakers used the direction of writing Arabic, right to left, and also top to bottom in elementary school. Hebrew speakers were in between; they preferred the dominant direction of writing Hebrew, right-to-left, but not as strongly as Arabic-speaking children. Moreover, in Hebrew speakers, there was a temporary preference for left-to-right over right-to-left just after English was introduced in schools. Finally, the preference for left-to-right in English speakers was much stronger than the preference for right-to-left in Hebrew and Arabic speakers. This pattern of responding corresponds to the pattern obtained from two very different tasks, that of perceptual exploration, where students are asked to copy or call out names of objects in arrays (Kugelmass & Lieblich, 1979; Nachshon, 1985), and that of drawing a horizontal line (Lieblich et al., 1975).

Why should temporal concepts be affected by writing direction and not by quantitative or preference concepts? One reason may be that quantitative and evaluative concepts are closely tied to metaphoric linguistic expressions prevalent in many languages, expressions that link "up" to "more" and "better," and "down" to "less" and "worse." The bottom-to-top direction was used more frequently to express quantity and preference than to express time, but not exclusively. Although time may be perceived to have direction, the particular direction of time is not clearly linked to a specific direction, left-to-right, right-to-left, up-to-down, or down-to-up. On the other hand, temporal relations are frequently incorporated into written text, in the form of school schedules, invitations, programs, and the like, where the direction of representing time is dictated by the direction of text. Like text, written temporal relations have a secondary direction from top to bottom, as in daily calendars, bus schedules, and the like. In fact, top-to-bottom was used by many Arabic-speaking children to express temporal relations and may be related to their stronger influence from language; like most languages, Arabic is written from top to bottom. Recall that the early graphs and the vast majority of graphs produced today have time as one variable, typically on the horizontal axis and increasing from left to right. Time is a neutral, nonevaluative variable in contrast to preference or certain quantities, like money. In fact, there was a tendency in the college students to represent neutral variables, such as time, horizontally and evaluative variables, such as preference, vertically.

For quantitative and preference concepts, students from all three language cultures used right-to-left, left-to-right, and bottom-to-top in approximately equal frequencies. They avoided using top-to-bottom in representing increases. The use of bottom-to-top and avoidance of top-to-bottom conforms to the linguistic expressions associating "up" to "more" and "better." One can only speculate on the origins of this pervasive association (see Cooper & Ross, 1975; Clark, 1973). Living things grow upwards and more prestigious and more powerful living things are taller than less prestigious and powerful. As Yertle the Turtle (Seuss, 1958) put it, as he climbed onto higher and higher mounds of turtles, "I am the king of all I can see / I can't see enough / that's the trouble with me." "Left" and "right" do not seem to be biased either quantitatively or evaluatively in linguistic expressions, both directions are used about equally frequently, and both directions are commonly adopted in written language, suggesting among other things a motoric bias toward horizontal.

Information Represented

The relational concepts students were asked to map contained information about category, about order between the categories, and, in many cases, some information about intervals between the categories. This information is successively more complex, each step building on and including the previous one. Thus, it is natural to expect more of the older children to represent more of the information contained in the relational concepts in their mappings, and this is indeed what happened. The information represented by successively older children, then, in some ways parallels the information represented by successively more constrained scales in measurement theory: categorical or nominal, ordinal, and interval. To some extent, categorical distinctions were presupposed by labeling separate stickers for the different levels of each concept. Furthermore, there was only one instance for each level. However, presupposing categorical knowledge for even the kindergartners is not unreasonable. Children of this age have been successfully grouping different exemplars of the same category for many concepts for some time (e.g., Mandler, Fivush & Resnick, 1987; Markman, 1989; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Sugarman, 1982). Nevertheless, there were isolated cases where children failed to make categorical distinctions; that is, they placed all three stickers essentially one on top of the other. In the American samples, four of the kindergartners, two of the first graders, and one third grader did that. Mappings were not truly interval in that people were not required to select a unit of measurement and use it systematically. All that was required was that the distance between the dots for the larger time, quantity, or preference interval be larger than the distance between the dots for the smaller interval. Two manipulations, one a demonstration of the representation of interval for spatial concepts and the other an explication of interval for the more abstract concepts, were partially effective in increasing the frequency of interval representation. Despite these manipulations, many of the younger children and some of the older children failed to represent interval.

In our experiments, interval was most likely to be represented for the direct spatial task, then more for temporal concepts than for quantitative concepts, and more for quantitative concepts than for preference concepts. This effect was large for the comparison between spatial concepts and the more abstract ones, but small within the abstract concepts. Even there it was in the expected direction of representing more information at an earlier age in the case of more concrete concepts than in the case of more abstract concepts. However, it is also possible that children responded more maturely to the temporal, then quantitative, then preference concepts because the temporal concepts were more familiar to the children than the quantitative, and the quantitative than the preference. We have no way of ascertaining relative familiarity; however, although it intuitively seems that young children would be more familiar with meals and events of the day than with quantities of sand or books or candy, it also seems that they would be more familiar with their food, game, and TV preferences than with quantities of sand, books, or candy. Thus the case for familiarity does not seem strong. On the other hand, children's knowledge of measurement procedures may underlie the ordering, and this seems related to the abstractness of the relation. In the case of the spatial tasks, the relative distances could be seen and directly mapped. Young children may not be able to "tell time" but they do know that time can be told, that is, that events of the day can be ordered and compared by clock time. Quantity can be measured in many ways, and young children are quite likely to know some of them, for example, that amounts of books or candy can be counted. Sand too can be counted by cupfuls, and filling buckets of sand with cupfuls is a popular playground activity. Preference, in contrast, has no well-known scale or measuring device.

The succession of types of information preserved proposed to describe children's developing mappings of nonspatial concepts onto a line may at first seem to correspond to the three gross stages of development of spatial perception and conception that Piaget and his colleagues proposed (Piaget & Inhelder, 1967; Piaget et al., 1960). Those stages are borrowed from geometry: topological, projective, and Euclidean, in order of their generality and inclusiveness, and in reverse order of their development as mathematical theories. However, for the unidimensional mappings considered here, topological space includes both nominal and ordinal mappings and Euclidean space includes more than the weak interval information examined here. Moreover, the theory of Piaget and his collaborators has been challenged by recent work (Mandler, 1983, 1988; Miller, 1989) as not accurately portraying children's knowledge of space. Interestingly, some of the evidence Piaget and his collaborators gathered in support of the theory was based on children's graphic productions, which, according to the present findings, become progressively more informative and restrictive with age, just as they found.

Representing Interval Information

Young children were quite successful using stickers to represent relative distances of tiny dolls lined up along the paper. In other research, Goodnow (1971) taught young children to use differential spatial distance to represent different time intervals. She tapped out short rhythms for children who were instructed to represent them with pencil on paper, putting a dot for each tap, and using wider spaces between dots to indicate more time between taps. Thus, children were taught exactly what to do, the patterns and intervals were short, and the performance was immediate. Most of the first and second graders succeeded, but the kindergartners did not. One strategy children could have followed is to mentally reproduce the pattern, moving the pencil at a steady rate, and putting it down on paper for every remembered tap. In our experiments, children were not as successful at representing intervals for more abstract relations, including longer time intervals.

The difficulties children had in producing external representations that reflected some interval information for temporal, quantitative, and preference concepts seem to be related to other prevalent difficulties children have in evaluating comparisons. The studies reviewed in the introduction that indicated children had interval knowledge used single-stimulus measures rather than comparative ones. For example, in the experiments on area (Anderson & Cuneo, 1978; Cuneo, 1980; Wilkening, 1979) and on food preferences (Fallon et al., 1984; Rozin et al., 1985), children selected a face from a series of faces frowning or smiling more or less intensively to represent the desirability of a particular area or food. In estimating time duration, young school-age children were able to indicate how high a magic flower would grow if given different short durations of sunlight (Janke & Kanigowski, 1988 as reported in Levin & Wilkening, 1989). Studies requesting comparative information from children have not been as successful. For example, young school-age children who had traversed a route several times, and could correctly put photographs of route landmarks in sequence, nevertheless could not correctly indicate distance between landmarks by placing the photographs at comparable distances along a string (Anooshian et al, 1984; Cousins et al., 1983). Similarly, in several experiments, young children have shown earlier facility using comparative adjectives in a nominative or categorical sense than in a truly comparative sense (Clark, 1970; Ebeling & Gelman, 1988; Sera & Smith, 1987; Smith, Cooney, & McCord, 1986). In a study of comparative and noncomparative uses of tools, Miller (1989) found that young children could put a stick in a hole to ascertain the presence or absence of an object, but could not successfully use a stick to decide which of two holes was deeper.

Our tasks were more complex. Not only did children need to compare relative values of separate stimuli, they also needed to compare relative values of the differences between the stimuli and then map these values and differences onto spatial differences. Thus, part of the difficulty that children had in externally representing interval was in making commensurate judgments on two values at the same time when those values were intervals between estimated values. Where those intervals were small, and either present, as in the case of the dolls, or in short-term memory, as in the case of the rhythms, young children have succeeded in externally representing larger intervals by larger distances. Another difficulty children may have had in externally representing interval was selection of an approximate unit of measurement in the domain of time quantity, or preference, and mapping it onto a spatial distance. Although all we required from the children was to indicate a larger conceptual distance by a larger spatial distance, it is possible that children did this by selecting an approximate unit of measurement in order to construct a mapping from conceptual distance to spatial distance. The detailed experiments of Levin and Tolchinsky Landsmann (1989) traced the development of children's understanding of the principles of measuring time durations in the elementary school years. Children understood that the unit of measuring time must be constant before they understood that the unit of measuring time is arbitrary. For the short durations in their tasks, children had a readily available way to measure time, namely, by counting at a steady pace, and many adopted this strategy spontaneously or with little coaching. In our tasks, children may have had the added burden of selecting an arbitrary unit of measurement.

Writing in Preliterate Children

Altogether, externally representing interval is a far harder task conceptually than externally representing category and order. Other investigations of children's early written productions are consonant with this view. Karmiloff-Smith (1979) asked school-age children to make marks on paper to remember a long and winding route. During the course of the long session, children introduced changes in their notations, apparently driven both by economy or brevity, but also by clarity and consistency. In a series of studies, Hughes (1986) asked preschool and young school-age children to put marks on pieces of paper to indicate different quantities of bricks. Most of the children who did not know and use numbers made tallies of one sort or another, with one mark for each brick, the marks quite frequently resembling bricks. Moreover, the tallies tended to be linearly organized in one or two horizontal rows. At a later age, the standard symbols replaced tallies. Ferreiro and Teberosky and Tolchinsky Landsmann and Levin have done similar investigations of preliterate children's writing and understanding of writing (Ferreiro, 1978, 1985; Ferreiro & Teberosky, 1982; Levin & Tolchinsky Landsmann, 1989; Tolchinsky Landsmann & Levin, 1985, 1987). At 3 or 4 children's writing reflects some of the graphic features of writing in contrast to drawing, in particular linear organization. Many children at this age produce one mark for each noun to be written. Slightly older children tend to produce marks that bear resemblance to their referents, in color, for example, or in shape, so tomato might be written in red and rope would yield a longer mark than ball. Gradually, children's marks come to resemble the letters and numbers in their language culture. In still older children, marks come to reflect words' sounds rather than their referents, so longer words yield more marks, and sounds repeated in different words tend to get the same mark. For both numbers and words, the spontaneous productions of preliterate children clearly gradually come under the influence of the prevalent written symbol system.

Interestingly, the findings of Karmiloff-Smith on notations of routes, of Hughes on numbers, and of Ferreiro and Teberosky and Tolchinsky Landsmann and Levin on written language have parallels in the historical development of written systems for numbers and words. Numbers first appeared as tallies, typically linearly arrayed. As the number of numbers grew, tallies became cumbersome. First they were grouped, and still later cipherized (see Hughes, 1986 for a review), using separate symbols for different numbers rather than repeating the same mark. As for written speech, all early systems and many highly developed ones first used pictograms which bore resemblances to their referents (see Gelb, 1963). Some of these evolved gradually into phonetic scripts, notably the Phoenician syllabary and its offshoot, the Greek alphabet (Gelb, 1963), but also the Mayan script (Morley, Brainerd & Sharer, 1983). Throughout the history of the development of writing, changes were introduced by users toward efficiency and clarity. Most writing systems, whether pictographic, logographic, or alphabetic, use linear organization, either horizontal or vertical, in columns or rows. Whether organized horizontally or vertically or whether produced from the left or from the right, most scripts are produced and read from top to bottom; this is probably due to the exigencies of writing—the hand shouldn't cover what has just been written—rather than to any cognitive correspondences. It should be no surprise that the symbolic inventions of children are similar to those invented by people in the past. The similarity of systems invented repeatedly by different children and by different cultures can be taken as evidence for some compelling cognitive correspondences between people's conceptions of the world and their external representations of them.

Notation Schemes

Writing systems for numbers and language are notational schemes whose essence, according to Goodman (1968), is a set of symbols and a way of combining them. Constructing a set of symbols must be done so that the symbols are distinguishable and that their relations to the objects they represent are unambiguous. For number tallies, this is not problematic; the only feature of objects that need be represented is their presence. Variations in the appearance of the symbols can be tolerated as long as there is one symbolic mark per object, and in fact, young children perform quite adequately (Hughes, 1986). In a task requiring production of different symbols for different musical instruments, children under 8 did not reliably produce symbols that they themselves could decode (Cohen, 1985). For language, where individual objects also need to be distinguished, the problem of mapping language units to symbolic units is all the more complex because there is more than one way to decompose language into units, most notably, meaning and sound. Early attempts by children and by cultures mapped meaning onto symbols, but this correspondence system presents difficulties for abstract words and proper names. It also yields enormous numbers of symbols. On the other hand, such a notation system can be read by speakers of different languages. Mapping sound onto symbols was not a single insight. It happened gradually, seemingly driven by the limitations of meaning symbols. The first Western phonetic scripts were syllabaries, and only later were vowel sounds represented separately. Some early writing by children also uses only consonants. Compared to selecting a mapping between language units and symbols, combining the symbols is less problematic. Universally they were combined linearly, typically in columns or rows (although circular patterns have been found; Gelb, 1963). Early on, spaces did not separate words, but later they did. Again, some children recapitulate this pattern (Ferreiro & Teberosky, 1982).

To a less extent, the development of graphic productions in children mirrors its historical development. As for tallies, symbol selection is not problematic. Most early and contemporary graphs plot time along the horizontal axis, beginning from the left as in Western writing. Children, too, tended to represent time along a horizontal axis in the direction of script. But graphs were invented very recently and were enabled by new developments in mathematics a century earlier, notably Cartesian coordinates. Thus, unlike number or writing systems, graphs were not invented repeatedly and independently in similar ways. And indeed, children's graphic productions reflect some aspects of their productions of numbers and writing, specifically, one-to-one correspondence between object and symbol and horizontal or vertical linear organization of symbols, especially in the direction of writing. Moreover, the aspects of graphing that are most problematic for children, mapping conceptual intervals onto spatial ones, have no parallels in common writing systems. Maps, which appeared early and frequently throughout the history of humankind, do use notational space to represent physical distances, and this correspondence, for reasons speculated on earlier, is apparently far easier than the metaphoric one demanded for representations of time, quantity, and preference. Not all of the graphing techniques commonly adopted by children are related to writing practice. In particular, the tendency to map increases from low to high, especially for evaluative dimensions, seems to derive from cognitive correspondences among *high, more,* and *good* that are also reflected in widespread figures of speech.

The similarities of written productions, be they maps, numbers, writing, or graphs or be they attempts of preliterate children or of different cultures are remarkable and suggest that such productions are not entirely arbitrary and happenstance. Instead, they seem to reveal pervasive cognitive correspondences, perhaps universals. Separate objects are externally represented by separate symbols. These are ordered linearly in rows or columns. The direction of order is similar in different representations and, in some cases, correspond to the direction implied in universal metaphoric linguistic expressions associating *more* and *better* with up. As to the future of this research, there is only one thing left to say, "Onward and upward!"

REFERENCES

Anderson, N. H., & Cuneo, D. O. (1978). The height + width rule in children's judgments of quantity. *Journal of Experimental Psychology: General,* **107**, 335–378.

Anooshian, L. J., Pascal, V. U., & McCreath, H. (1984). Problem mapping before problem solving: Young children's cognitive maps and search strategies in large-scale environments. *Child Development,* **55**, 1820–1834.

Beniger, J. R., & Robyn, D. L. (1978). Quantitative graphics in statistics. *The American Statistician,* **32**, 1–11.

Bierwisch, M. (1967). Some semantic universals of German adjectives. *Foundations of Language,* **3**, 1–36.

Braine, L. G., Plastow, E., & Greene, S. L. (1987). Judgments of shape orientation: A matter of contrasts. *Perception & Psychophysics,* **41**, 335–344.

Brown, L. A. (1949, reprinted 1979). *The story of maps.* New York: Dover.

Bruner, J. S., Olver, R., & Greenfield, P. M. (1966). *Studies in cognitive growth.* New York: Wiley.

Clark, E. V. (1974). Normal states and evaluative viewpoints. *Language,* **50**, 316–331.

Clark, H. H. (1973). Space, time, semantics, and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27–63). New York: Academic Press.

Clark, H. H. (1970). The primitive nature of children's relational concepts. In J. R. Hayes (Ed.), *Cognition and the development of language* (pp. 269–278). New York: Wiley.

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology*, **3**, 472–517.

Clark, H. H., & Clark, E. V. (1977). *Psychology and language*. New York: Harcourt Brace Jovanovich.

Cohen, S. (1985). The development of constraints on symbol–meaning structure in notation: Evidence from production, interpretation, and forced-choice judgments. *Child Development*, **56**, 177–195.

Cooper, W. E., & Ross, J. R. (1975). World order. In R. E. Grossman, L. J. San, & T. J. Vance, (Eds.), *Papers from the Parasession on Functionalism*. Chicago: Chicago Linguistic Society.

Corballis, M. C., & Beale, I. L. (1976). *The psychology of left and right*. Hillsdale, NJ: Erlbaum.

Cousins, J., Siegel, A. W., & Maxwell, S. E. (1983). Way finding and cognitive mapping in large-scale environments: A test of a developmental model. *Journal of Experimental Child Psychology*, **35**, 1–20.

Cuneo, D. O. (1980). A general strategy for quantity judgments: The height + width rule. *Child Development*, **51**, 299–301.

Ebeling, K. S., & Gelman, S. A. (1988). Coordination of size standards by young children. *Child Development*, **51**, 299–301.

Ebeling, K. S., & Gelman, S. A. (1988). Coordination of size standards by young children. *Child Development*, **59**, 888–896.

Elkind, D. (1969). Developmental studies of figurative perception. In L. P. Lipsett & C. C. Spiker (Eds.), *Advances in child development and behavior* (Vol. 4, pp. 1–28). New York: Academic Press.

Elkind, D., & Weiss, J. (1967). Studies in perceptual development. III. Perceptual exploration. *Child Development*, **38**, 553–561.

Fallon, A. E., Rozin, P., & Pliner, P. (1984). The child's conception of food: The development of food rejections with special reference to disgust and contamination sensitivity. *Child Development*, **55**, 566–575.

Farrell, W. S. (1979). Coding left and right. *Journal of Experimental Psychology: Human Perception & Performance*, **5**, 42–51.

Ferreiro, E. (1978). What is written in a written sentence: A developmental answer. *Journal of Education*, **160**, 25–39.

Ferreiro, E. (1985). Literacy development: A psychogenetic perspective. In D. Olson, N. Torrence, & A. Hildyard (Eds.), *Literacy, language and learning* (pp. 217–228). Cambridge: Cambridge Univ. Press.

Ferreiro, E., & Teberosky, A. (1982). *Literacy before schooling*. London: Heinemann.

Fivush, R., & Mandler, J. M. (1985). Developmental changes in the understanding of temporal sequence. *Child Development*, **56**, 1437–1446.

Franklin, N., & Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology*, **119**, 63–76.

Friedman, W. J. (1989). The representation of temporal structure in children, adolescents and adults. In I. Levin & D. Zakay (Eds.), *Time and human cognition* (pp. 259–304). Amsterdam/New York: Elsevier.

Friedman, W. J. (1977). The development of children's understanding of cyclic aspects of time. *Child Development*, **48**, 1593–1599.

Friedman, W. J., & Brudos, S. L. (1988). On routes and routines: The early development of spatial and temporal representations. *Cognitive Development*, **3**, 167–182.

Gelb, I. J. (1963). *A study of writing* (2nd ed.). Chicago: Univ. of Chicago Press.

Gelman, R., & Baillargeon, R. (1983). A review of some Piagetian concepts. In J. H. Flavell & E. M. Markman (Eds.), *Cognitive Development* (Vol. 3). In P. Mussen (Ed.), *Manual of child psychology* (pp. 167–230). New York: Wiley.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge: Harvard Univ. Press.

Gelman, R., Meck, E., & Merkin, S. (1986). Young children's numerical competence. *Cognitive Development*, **1**, 1–29.

Goodman, N. (1968). *Languages of art: An approach to a theory of symbols*. New York: Bobbs–Merrill.

Goodnow, J. (1977). *Children's drawing*. London: Open Books.

Goodnow, J. J. (1971). Matching auditory and visual series: Modality problem or translation problem. *Child Development*, **42**, 1187–1201.

Goodnow, J. J., Friedman, S. L., Bernbaum, M., & Lehman, E. B. (1973). Direction and sequence in copying: The effect of learning to write in English and Hebrew. *Journal of Cross-Cultural Psychology*, **4**, 263–282.

Hochberg, J., & Brooks, V. (1962). Pictorial recognition as an unlearned ability: A study of one child's performance. *American Journal of Psychology*, **75**, 624–628.

Hughes, M. (1986). *Children and number: Difficulties in learning mathematics*. Oxford: Blackwell.

Karmiloff-Smith, A. (1979). Micro- and macro-developmental changes in language acquisition and other representational systems. *Cognitive Science*, **3**, 91–118.

Krantz, D. H., Luce, R. D., Suppes, P., & Tversky, A. (1971). *Foundations of measurement* (Vol. 1). New York: Academic Press.

Kugelmass, S., & Lieblich, A. (1970). Perceptual exploration in Israeli children. *Child Development*, **41**, 1125–1131.

Kugelmass, S., & Lieblich, A. (1979). The impact of learning to read on directionality in perception: A further cross-cultural analysis. *Human Development*, **22**, 406–415.

Ladavas, E. (1988). Asymmetries in processing horizontal and vertical dimensions. *Memory and Cognition*, **16**, 377–382.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: Univ. of Chicago Press.

Levin, I. (1989). Principles underlying time measurement: The development of chidlren's constraints on counting time. In I. Levin & D. Zakay (Eds.), *Time and human cognition* (pp. 145–183). Amsterdam/New York: Elsevier.

Levin, I., & Tolchinsky Landsmann L. (1989). Becoming literate: Referential and phonetic strategies in early reading and writing. *International Journal of Behavioural Development*, **12**, 369–384.

Levin, I., & Wilkening, F. Measuring time via counting: The development of children's conceptions of time as a quantifiable dimension. In I. Levin & D. Zakay (Eds.), *Time and human cognition* (pp. 119–144). Amsterdam/New York: Elsevier.

Lieblich, A., Ninio, A., & Kugelmass, S. (1975). Developmental trends in directionality of drawing in Jewish and Arab Israeli children. *Journal of Cross-Cultural Psychology*, **6**, 504–510.

Maki, R. H., Grandy, C. A., & Hauge, G. (1979). Why is telling right from left more difficult than telling above from below? *Journal of Experimental Psychology: Human Perception & Performance*, **5**, 52–67.

Mandler, J. M. (1983). Representation. In J. H. Flavell & E. M. Markman (Eds.), *Cognitive development* (Vol. 3). In P. Mussen (Ed.), *Manual of child psychology* (pp. 420–494). New York: Wiley.

Mandler, J. M. (1988). The development of spatial cognition: On topological and Euclidean representation. In J. Stiles-Davis, M. Kritchevsky, & U. Bellugi (Eds.), *Spatial cognition* (pp. 423–432). Hillsdale, NJ: Erlbaum.

Mandler, J. M., Fivush, R., & Reznick, S. (1987). The development of contextual categories. *Cognitive Development, 2,* 239–254.

Markman, E. M. (1989). *Categorization and naming in children.* Cambridge, MA: MIT Press.

Miller, K. F. (1989). Measurement as a tool for thought: The role of measuring procedures in children's understanding of quantitative invariance. *Developmental Psychology,* **25,** 589–600.

Miller, K. F., & Baillargeon, R. (1990). Length and distance: Do preschoolers think that occlusion brings things together? *Developmental Psychology,* **26,** 103–114.

Morley, S. G., Brainerd, G. W., & Sharer, R. J. (1983). *The ancient Maya* (4th ed.). Stanford, CA: Stanford Univ. Press.

Nachshon, I. (1985). Directional preferences in perception of visual stimuli. *International Journal of Neuroscience,* **25,** 161–174.

Nelson, K. (Ed.). (1986). *Event knowledge: Structure and function in development.* Hillsdale, NJ: Erlbaum.

Nelson, K. (1978). How young children represent knowledge of their word in and out of language. In R. S. Siegler (Ed.), *Children's thinking: What develops?* (pp. 255–273). Hillsdale, NJ: Erlbaum.

Piaget, J. (1969). *The child's conception of time.* London: Routledge & Kegan Paul.

Piaget, J., & Inhelder, B. (1948, 1967). *The child's conception of space.* New York: Norton.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child.* New York: Basic Books.

Piaget, J., Inhelder, B., & Szeminska, A. (1960). *The child's conception of geometry.* New York: Norton.

Rosch, E., Mervis, C. B., Gray, W., Johnson, D., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology,* **8,** 382–439.

Rozin, P., Fallon, A., & Augustoni-Ziskind, M.-L. (1985). The child's conception of food: The development of contamination sensitivity to "disgusting" substances. *Developmental Psychology,* **21,** 1075–1079.

Sera, M., & Smith, L. B. (1987). *Big and* Little: "Nominal" and relative uses. *Cognitive Development,* **2,** 89–111.

Seuss, Dr. (1958). *Yertle the turtle.* New York: Random House.

Seymour, P. H. K. (1969). Response latencies in judgments of spatial location. *British Journal of Psychology,* **60,** 31–39.

Seymour, P. H. K. (1974). Stroop interference with response, comparison, and encoding stages in a sentence-picture comparison task. *Memory & Cognition,* **2,** 19–26.

Shepard, R. N., & Hurwitz, S. (1984). Upward direction, mental rotation, and discrimination of left and right turns in maps. *Cognition,* **18,** 161–193.

Sholl, M. J., & Egeth, H. E. (1981). Right–left confusion in the adult: A verbal labeling effect. *Memory & Cognition,* **9,** 339–350.

Smith, L. B., Cooney, N. J., & McCord, C. (1986). What is "high?" The development of reference points for "high" and "low." *Child Development,* **57,** 583–602.

Stevens, S. S. (1946). On the theory of scales of measurement. *Science,* **103,** 677–680.

Sugarman, S. (1982). Developmental change in early representational intelligence: Evidence from spatial classification strategies and related verbal expressions. *Cognitive Psychology,* **14,** 451–588.

Szamosi, G. (1986). *The twin dimensions: Inventing time and space.* New York: McGraw–Hill.

Tolchinsky Landsmann, L., & Levin, I. (1987). Writing in four- to six-year-olds: Representation of semantic and phonetic similarities and differences. *Journal of Child Language,* **14,** 127–144.

Tolchinsky Landsmann, L., & Levin, I. (1985). Writing in preschoolers: An age-related analysis. *Applied Psycholinguistics,* **6**, 319–339.

Tufte, E. R. (1983). *The visual display of quantitative information.* Cheshire, CT: Graphics Press.

Tversky, B. (1981). Distortions in cognitive maps. *Cognitive Psychology,* **13**, 407–433.

Wilford, J. N. (1982). *The mapmakers.* New York: Vintage.

Wilkening, F. (1979). Combining of stimulus dimensions in children's and adult's judgments of areas: An information integration analysis. *Developmental Psychology,* **15**, 25–33.

Wilkening, R. (1981). Integrating velocity, time, and distance information: A developmental study. *Cognitive Psychology,* **13**, 231–247.

(Accepted October 27, 1990)