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Learning Color Words Involves Learning a System of Mappings

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This research examines the difficulty children encounter when acquiring 2 specific sets of adjectives, color and size words, and suggests that children must acquire a system of mapping in learning these words. Children were assessed on 4 types of mappings (word–word maps, property–property maps, word–property maps, and word–word–property maps) by completing 3 color tasks. Children also participated in comparable tasks for size words. In Study 1, 13 two-year-olds were followed longitudinally at 3-week intervals. In Study 2, 56 two-year-olds participated in a cross-sectional replication. The results indicate that children acquire color maps in a characteristic order. Children demonstrated a different pattern of acquisition for size words. The results suggest that learning word associations may promote color word acquisition and that learning color words may promote selective attention to color.

One of the most remarkable facts about word learning is how easy it is. Young children, for example, fast map words to meanings from single experiences of hearing individual words used in context (Carey, 1978). But despite the general ease of word learning, there are lexical pockets that pose problems for young learners. Dimensional adjectives comprise one such pocket; as a class, these words are learned slowly and errorfully (Carey, 1982; Gasser & Smith, 1998; Nelson, 1973; Smith & Sera, 1992). The most difficult dimensional terms for children to learn may be color terms (Mervis, Bertrand, & Pani, 1995; Shatz, Behrend, Gelman, & Ebeling, 1996); indeed, they may be learned only with explicit instruction (Bornstein, 1985; Rice, 1980). In the present article, we seek to understand why color words are so hard for young children to learn.

One framework for thinking about word learning construes the child's task as a mapping problem—as one of linking the words one hears to the concepts one has. By this framework, words should be difficult to learn if the words are infrequent in the language, if the concepts are not available, or if the word–concept mapping is not transparent or is in some way ambiguous. The difficulty of color word learning is perplexing from this perspective because color words are frequent in language and because infants can be shown to perceive colors in much the same way as adults do (e.g., Bornstein, Kessen, & Weiskopf, 1976). The implication is that the problem lies in the mapping, that the connection of color words to perceived colors is somehow nonobvious (Soja, 1994). This may be so because learning color words not only involves making mappings from words to colors but in total requires learning a system of several different kinds of mappings. In this article, following an earlier suggestion by Backscheider and Shatz (1993), we pursue this idea.

Figure 1 illustrates four kinds of mappings relevant to color word acquisition. One mapping is from the word *color* to the words that label specific colors. These word–word associations constrain answers to the question "What color is this?" to the class of color names. A second mapping is among perceived objects. These property–property mappings presumably underlie the ability to abstract the same property from different objects—redness from a red cup, a red ball, and a red box. The next mapping, a word–property map, links words to the perceived colors of objects, for example, the word *red* to the redness of a red cup. Finally, the last mapping, word–word–property, combines components of previous mappings and links the question "What color is this?" to a set of color words and to the perceived color of objects. For example, the question "What color is this?" is linked to the word *red,* and the word *red* is linked to the redness of a red cup. The present experiments explored the development of this complex system of mappings. The experiments were specifically motivated by two questions raised by previous research on color word learning.

Color Words as a Lexical Class

The first question concerns the relation between learning word–word maps and learning word–property maps. Evidence from Backscheider and Shatz (1993) and others (e.g., Bartlett, 1978; Binet, 1969; Cruse, 1977; Istomina, 1963; Landau & Gleitman, 1985) suggests that children readily form word–word maps in the domain of color and often do so without any knowledge of the specific properties named by specific color words. In brief, young children seem to know that color words, such as *red, yellow,* and *blue,* form a lexical class, which can be used to answer questions about color (e.g., "What color is this?") with a perhaps wrong color word but not with a word from another lexical domain. For example, when asked what color a red cup is, a child might be wrong by answering "blue" or "green" but is rarely wrong by answering "cup" or "big" (see also Gardner, Van Cantfort, & Gardner, 1992, for similar evidence from chimpanzees). These

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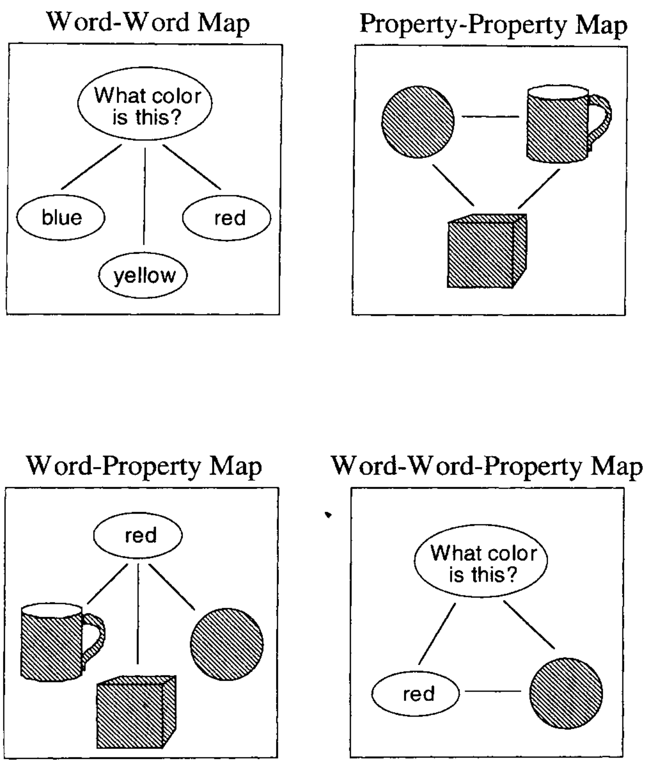

Figure 1. Four kinds of mappings involved in color word learning.

errors clearly suggest knowledge of the relatedness of words (see also Landau & Gleitman, 1985).

What is unclear is how or whether these linguistic associations contribute to the acquisition of word–property maps in the domain of color, for example, mapping from the word *red* to the color red. In Study 1, we used a longitudinal design to explore children's word–word associations and their relation to color word comprehension and production.

The Abstraction of Color

The second question concerns the developmental relation between making property–property maps and learning word–property maps. Logically, it might seem that the ability to abstract color—to perceive the common color of same-colored objects—is a prerequisite to learning color words. Soja (1994) reported evidence consistent with this idea. The bulk of the evidence on color matching, however, suggests that the opposite conclusion may be correct, that learning color words contributes to the abstraction of color. The key findings concern children's ability to match objects by color in nonlinguistic tasks. This evidence indicates that children's success in matching objects by color depends critically on the overall similarity of the objects. That is, when children are asked to match objects by color, they easily do so when the same-colored objects are identical (e.g., two identical red cats) or highly similar overall (e.g., two slightly different red cats) but then fail this same task when the same-colored objects are different overall, for example, a red cup and a red cat (Bartlett, 1978; Rice, 1980; Smith, 1984; Soja, 1994; Waxman & Markow, 1997).

This pattern of results is consistent with the evidence on the development of comparison and selective attention. The general developmental trend in comparison seems to be one that proceeds from holistically comparing objects to comparing them by their similarity on single dimensions (Gentner & Ratterman, 1991; Smith, 1989). This trend fits the case of matching objects by color in that children initially make color matches only when that match is supported by the overall similarity of the objects and only later match dissimilar objects by their color. What is perplexing about this overall pattern of findings is the suggestion that children can know color words, that is, know a red object is called *red,* prior to being able to match objects by color (Rice, 1980; Smith, 1984). The correct use of color words would seem to require that the children know that two color-matching objects are the same color even when those objects are highly dissimilar overall. To better understand the relation between matching objects by color and knowing color words, we tracked developmental changes in both tasks in Study 1. In light of these data, we return to the contrary findings reported by Soja (1994) in the General Discussion section.

Experimental Rationale

Our empirical goal in the present research was to study children's emerging knowledge of color and color words. In Study 1, we used a longitudinal design. Children who did not know color words were selected to begin the study and were followed for 6 months (or until they reached a preset criterion). They participated in three tasks: a color word comprehension task, a color word production task, and a color matching (abstraction) task. Table 1 lists the three tasks and the four mappings assessed by them. Study 2 replicated the major findings of Study 1 in a cross-sectional design. A cross-sectional replication was necessary to ensure that the relations observed among tasks in Study 1 were not somehow created by the long-term participation in the tasks. To determine whether the developmental dependencies that we observed in both studies among the various tasks reflected the nature of color word learning and not something specific to our particular tasks, we created analogous tasks measuring children's knowledge of size words.

Table 1
Tasks, Questions, and Mappings Tested in Study 1

Task	Question	Mapping
Comprehension	"Show me the red one."	Word–property
Production	"What color is this?"	Word–word (any color) Property–word (correct color)
Abstraction	"What matches this?"	Property–property

Our goal in choosing a control task was to show that children's responses to our tasks were not due to a general response pattern or multiple exposure to the tasks. We chose size words as a comparison task because we expected the structure of the task required to learn size words to be different than the structure of the task required to learn color words. Size and color words differ in several fundamental ways. For example, the very way in which parents teach children about color and size is different. Although parents may ask "What color is this?" they only rarely ask the comparable size question "What size is this?" preferring instead to ask questions like "How big is it?" or "Is it big or little?" (Landau & Gleitman, 1985); thus, children would be unlikely to form word–word maps between the dimension word *size* and specific size words. Moreover, although color learning is a considerably difficult task for 2-year-olds (Andrick & Tager-Flusberg, 1986; Rice, 1980; Soja, 1994), Carey (1982) reported that 2-year-olds performed perfectly in a task that assessed comprehension of the two sizes big and little. Thus, our reasoning was as follows: If our particular experimental tasks strongly determine the pattern of results, then the pattern should be the same for both color and size terms. If, in contrast, the pattern reflects how children make mappings given the structure of the color-term learning task, then there is no reason for the patterns to be similar given the different structure of the size-term learning task.

Study 1

Method

Participants

Six boys and 7 girls participated. These 13 children were selected from birth announcements and newspaper advertisements. Only children who did not know color words and who were native speakers of English were selected to participate. Knowledge of color words was assessed by questioning parents on the first phone contact. Family histories detailing color blindness were used to "screen" for color blindness. None of the children participating had histories suggesting a likelihood of color blindness. One additional child began the study but withdrew because of illness. The children were tested in the laboratory at 3-week intervals for 6 months or until they reached a preset criterion of task performance (50% correct performance in the production task). Table 2 presents the mean ages and ranges of the children at the start and end of the study and the mean number and range of sessions.

Stimuli and Procedure

Word comprehension. In this task, children were shown six disks of different colors and sizes and asked to select one and then another by a property label, for example, "Show me the red one," and after the child chose, the child was asked, "Show me another red one." In the color task, there were six trials: Each term—*red, orange, yellow, green, blue,* and *purple*—was queried once. In the size task, there were two trials: The two terms *big* and *little* were each queried once. Color trials and size trials were blocked; order of queried terms within a block was randomly determined for each participant.

Table 2
Mean Ages and Number of Sessions for Children in Study 1

Ages and no. of sessions	*M*	*SD*	Range
Age at start of study (in months)	25.38	3.04	21–31
Age at end of study (in months)	30.23	2.35	27–35
Number of sessions	6.54	2.37	2–10

Table 3
Sets of Objects Used in Production Task

Large object	Small object
Big orange hat	Little green hat
Big red car	Little blue car
Big purple hammer	Little red hammer
Big yellow shoe	Little purple shoe
Big blue cup	Little orange cup
Big green dinosaur	Little yellow dinosaur

On each trial, the experimenter presented the child with 6 disks. These 6 disks were selected from a parent set of 12 disks: Half were 20 cm in diameter, and the other half were 8.5 cm in diameter. One disk at each size in the parent set was covered with Coloraid$_{TM}$ brand paper of one of the following six colors (in Coloraid notation): R-HUE, ROT1, Y-Hue, Gw-T1, B-HUE, and V-T1, corresponding to the following color names: red, orange, yellow, green, blue, and purple, respectively.

In the color task, the set of six disks presented on a trial was structured as follows: two disks (one large, one small) of the queried color, two disks (one large, one small) of a second color, and two disks (one large, one small) of a third and a fourth color. In the size task, the set of six disks was structured as follows: two disks (differently colored) of the queried size, two wrong-sized disks of which each matched one of the right-sized disks in color, and two wrong-sized disks of a third and a fourth color.

Production task. On each trial, participants were presented with three 3-D objects selected from the set listed in Table 3. Each triad contained objects of three different colors, two sizes, and two kinds. For example, one triad consisted of a big orange hat, a little green hat, and a big purple hammer. The child was asked "What color is this?" about one object, "What size is it?" about the second object, "What is this?" about the third object. Six triads were constructed for each session, such that each of the six colors was queried once, each of the two size terms was queried three times, and each of the six object names was queried once. The order of trials and the order of questions within a trial were counterbalanced across children and sessions.

Matching task. The basic structure of the matching task was as follows: The child was shown one or two exemplar objects in a transparent bucket. The child was then shown six choice objects and asked to select from those six an object that matched the one(s) in the bucket. After this first selection, the child was asked to select another object from the set of choice objects that matched. There were two types of color trials and size trials: one-exemplar and two-exemplar. Examples of each trial type are given in Table 4. The one-exemplar trials presented the possibility of a match to the exemplar on only the relevant dimension. The two-exemplar trials presented the child with two objects in the bucket that matched on (and thus defined) one relevant dimension, and the choice objects presented competing kinds of similarities to each of the two exemplar objects.

On the one-exemplar trials, the child was given one object and told, "Look at this," and on the two-exemplar trials, the child was told in addition (as the experimenter gave the child the two exemplar objects), "Look these match! They're the same. These two belong together." For all trials, the child was then told, "Now we're going to find the blocks that belong with that/those. We're going to find the ones that match, the ones that are the same." The child was shown the set of six choice objects and asked to find "the ones that match, the ones that are the same as the block(s) in the bucket." The child was encouraged to put his or her choice into the bucket. If the child's first choice did not match on the relevant dimension, the experimenter removed the child's pick and repeated the

Table 4
Examples of Sets From the Matching Task

Trial type	Exemplar	Choice objects
One-exemplar	Green cube	Green wheel, green wheel, blue wheel, blue wheel, red wheel, and orange wheel
Two-exemplar	Green cube and green stick	Green sphere, green spool, red cube, red wheel, orange stick, and yellow heart

question to the child. When the child's first choice matched the exemplar on the relevant dimension, the experimenter repeated the question without removing any blocks from the bucket. Thus, the child was asked to find a match twice on each trial. Notice that no dimensional language was used in the matching task. This task assessed the child's ability to match objects on a dimension unguided by dimensional language.

Six color sets and two size sets were presented at each session. These sets were constructed from wooden blocks painted to match the six Coloraid hues used in the comprehension task. The four trial types in this task (one-exemplar color, one-exemplar size, two-exemplar color, and two-exemplar size) were presented in blocks, with the order of the blocks randomly determined for each session.

The order of the comprehension, production, and matching tasks within a session was randomly determined and varied across sessions for individual children.

Results and Discussion

We first present the group pattern of performance in each task across sessions. In these group analyses, we compared the performances on the size and color tasks. Subsequently, we consider the relationships among the tasks in the performance of individuals.

Analyses of Group Data

Because children progressed through the experiment at different rates and participated in different numbers of sessions, our global analyses of the group data compared performances on each child's first and last sessions. These mean performances are shown in Table 5.

Comprehension task. In this task, children were asked to find two referents for each color or size term from an array of six objects. We computed two dependent measures: (a) correct identification—overall correct choices— and (b) consistent identification—consistent choice of the same value (correct or incorrect) on the two successive choices in a trial. An analysis of variance (ANOVA) conducted on the number of correct identifications in the first and last sessions revealed a significant effect of dimension; overall, children comprehended the size terms better than the color terms, $F(1, 12) = 12.62, p < .01$. The ANOVA also revealed a main effect of session, $F(1, 12) = 35.91, p < .01$; overall, children performed better on the last session than on the first session. The interaction was not reliable. Note that whereas children began the study with performance at chance levels in the color comprehension task (chance = .33), $t(12) = 0.33$, *ns*, they performed at above chance levels in the size comprehension task (chance = .33), $t(12) = 2.82, p < .05$.

The consistency scores for color and size are not directly comparable because the probability of selecting two matching objects by chance alone was greater for the size set than the color set. However, as can be seen in Table 4, children became significantly more consistent from the first session to the last session for the color tasks, $t(12) = 3.81, p < .01$, and the increase in consistency approached significance in the size task, $t(12) = 1.48, p = .083$.

Production task. Table 4 shows the mean number of correct responses and within-dimension errors children made in response to the questions "What color is this?" and "What size is this?" Within-dimension errors are those in which children supplied the wrong property label on the right dimension, that is, they provided a wrong color word when asked about color and a wrong size word when asked about size. A repeated measures ANOVA on correct responses revealed a main effect of session, $F(1, 12) = 51.06, p < .01$, but no effect of dimension, $F(1, 12) = 0.84$, and no interaction. Thus, children's productions of the correct label of an object's size or color increased over the course of the experiment. A second repeated measures ANOVA conducted on the proportion of within-dimension errors yielded a main effect of dimension, $F(1, 12) = 30.32, p < .01$, but no effect of session, $F(1, 12) = 0.12$, and no interaction. In brief, children produced within-dimension errors for color terms throughout the experiment but rarely did so for size terms, responding more often with an object name when asked "What size is this?" Of course the lack of within-dimension errors for size may have been because there were fewer size terms overall in children's lexicon and thus less room for within-dimension errors. This conclusion that children produced many more within-dimension errors when queried about color terms is also supported by considering the data for all sessions. At no point in the experiment did the mean proportion of within-dimension errors for color fall below .40; in contrast, in no session did the mean proportion of within-dimension errors for size rise above .12.

These findings suggest that early in color word learning, children make word–word maps for color terms before they map the

Table 5
Mean Proportion Correct by Task for Children in Study 1 on First and Last Sessions

	First session		Last session	
Task	*M*	*SD*	*M*	*SD*
Color				
Comprehension				
Correct identification	.32	.14	.69	.27
Consistent identification	.03	.06	.46	.38
Production				
Correct response	.01	.05	.36	.50
Within-dimension errors	.42	.42	.40	.28
Matching				
Correct response	.37	.25	.41	.23
Consistent response	.21	.17	.28	.28
Size				
Comprehension				
Correct identification	.56	.29	.77	.28
Consistent identification	.73	.33	.89	.22
Production				
Correct response	.02	.06	.24	.30
Within-dimension errors	.12	.28	.07	.11
Matching				
Correct response	.67	.28	.56	.34
Consistent response	.62	.36	.65	.24

color names to color properties. A further examination of the within-dimension errors suggests that initially, these word–word maps involve very few color words. Over the entire course of the experiment, children responded to the question "What color is this?" with a color word 219 times. Of these color responses, 143 (65%) were errors. The majority of these errors consisted of an individual answering all questions about color with one or two color words for an entire session (though not necessarily the same word across sessions), for example, always answering "orange" no matter what the actual color or randomly switching between "red" and "blue." Seventy errors (49%) resulted from children consistently responding with one color word during a session, and 64 errors (45%) were the result of children responding with only two different color words during a session. In fact, 12 of the 13 children responded with one of these two error patterns in at least one session. Thus, children at first seem to learn only that the word *color* designates a limited set of words, and they solve the problem of answering questions about color by latching onto one or two color words during a session and repeatedly offering those words as the answer.

Matching task. Children's performance on the one-exemplar and two-exemplar matching trials did not differ for either color or size trials; thus, performances on the two trial types were combined. The mean scores across all matching trials for the first and last sessions are given in Table 4. A repeated measures ANOVA revealed a main effect of dimension, $F(1, 12) = 9.02$, $p < .05$. However, there was no main effect of session, $F(1, 12) = 0.26$, and there was no interaction. Children better matched objects on sizes than on color, and their ability to make such matches changed little over the course of the 6-month experiment. Children made size matches above the level expected by chance (chance = .33), $t(12) = 2.41$, $p < .05$, but did not exceed chance-level performance on the color trials even on the last session (chance = .33), $t(12) = 1.26$, *ns*.

Summary. Altogether, the pattern of results affirms what is evident in the literature: Color words are harder for children to learn than are other dimensional terms. The ability to selectively attend to color and match dissimilar objects by their color is apparently quite slow in emerging and emerges much more slowly than the ability to match dissimilar objects by their size. Furthermore, the ability to match objects by color lags behind children's comprehension of color words.

Developmental Dependencies Among Tasks

Our next goal was to identify the order in which four mappings were acquired: (a) word–property maps as measured by correct performance on the comprehension task, (b) property–property maps as measured by correct performance on the matching task, (c) word–word maps as measured by correct responses and within-dimension errors on the production task, and (d) combined word–word–property maps as measured by correct performance on the production task.[1] We calculated the mean age of acquisition of each mapping as follows. First, we judged a mapping to be acquired when the child's performance was outside the 95% confidence interval for chance.[2] Second, we defined the age of acquisition as the child's age at the first session at which that level of performance was achieved. There was no requirement that the child maintain that level in subsequent sessions, although he or she did so with one notable exception. That exception, Erich, showed a pattern of development across the four color tasks unlike any other child. Accordingly, Erich's data were not included in all following analyses of performance on color trials and are presented and discussed separately.

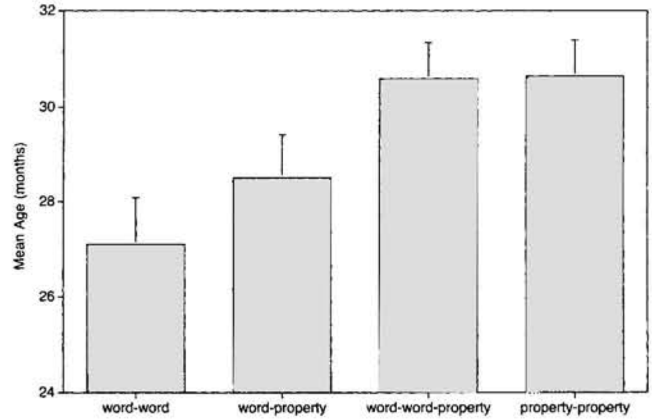

Figure 2. Mean age of acquisition in the four color mapping tasks. Vertical lines depict standard errors of the means.

Figure 2 shows the mean age of acquisition on the color trials for the remaining 12 children. A repeated measures ANOVA revealed a significant main effect of task, $F(3, 11) = 18.06$, $p < .01$. Post hoc analyses (Tukey's honestly significant difference [HSD], $p < .05$) revealed that word–word mappings were acquired earliest, reliably before word–word–property maps or property–property maps. The mean age of acquisition of these last two mappings, word–word–property and property–property, did not differ reliably. Notice that the abstraction of color—the matching

[1] A correct response on the production task would be coded as demonstrating both word–word mapping and word–word–property mapping. That is, a correct response would indicate knowledge that the question "What color is this?" should be answered with a word from the lexical domain of color and further knowledge of the correct name of a specific color.

[2] Chance for the production tasks, both word–word and word–word–property mappings, was calculated as follows. Given that children could answer the question "What color is this?" with an infinite number of possible responses, the probability of answering this question with either the correct color word or any color word by chance alone should approach zero. However, we conservatively estimated chance on the production task as responding appropriately to one of six trials to account for the many children who consistently responded with the same color word (e.g., always answered "blue" in response to the question "What color is this" and thus were correct when shown a blue stimuli).

Thus, using the 95% confidence intervals for chance, children needed .33 color responses to demonstrate word–word acquisition (chance = .17), .58 correct to demonstrate word–property acquisition (chance = .33), .33 correct to demonstrate word–word–property acquisition (chance = .17), and .58 correct to demonstrate property–property acquisition (chance = .33). In the size tasks, children needed to score over .33 size responses to demonstrate word–word acquisition (chance = .17), .54 correct to demonstrate word–property acquisition (chance = .33), .33 correct to demonstrate word–word–property acquisition (chance = .17), and .54 correct to demonstrate property–property acquisition (chance = .33).

of red things to red things—emerged after, not before, children mapped color words to the colors of things.

For comparison, Figure 3 shows the mean age of acquisition of the corresponding mappings for all 13 children on the size trials. A strikingly different pattern of age of acquisition emerged. A repeated measures ANOVA revealed a significant difference across tasks, $F(3, 12) = 5.29$, $p < .05$. For size, property–property mappings were acquired earliest, reliably before word–word–property maps (Tukey's HSD, $p < .05$). In marked contrast to the case of color, then, the ability to abstract the sizes of things emerged before or at the same time that children mapped size words to sizes.

These contrasting patterns in the age of acquisition of color and size mappings suggest that children's difficulty in our color matching task was not due to the matching task per se but was instead due to the requirement to match by color. The contrasting patterns also suggest the potential value in future work of comparing in more detail the differences between learning different dimensional terms (e.g., see Bloom & Wynn, 1997, and Backscheider & Shatz, 1993, for accounts of the acquisition of number terms). The remainder of the present analyses concentrate on our primary focus—how children learn color words.

Individual Analyses

Do word–word mappings benefit the learning of color words? The mean age of acquisition of color mappings suggests that word–word maps—maps between the word *color* and specific color words—are acquired prior to mappings between specific color words and the properties of objects that those color words label. This ordering also characterizes the data of individual children. Specifically, all but 1 child acquired (by our age-of-acquisition measure) word–word mappings prior to success in the comprehension task, a contingency pattern reliably different from that expected by chance, $\chi^2(1, N = 12) = 8.33, p < .01$. Moreover, the age at which children acquired word–word mappings predicted the age at which they subsequently succeeded in the comprehension task ($r = .76, p < .05$). These results suggest that knowing the word–word relations, that the word *color* signals a request for a

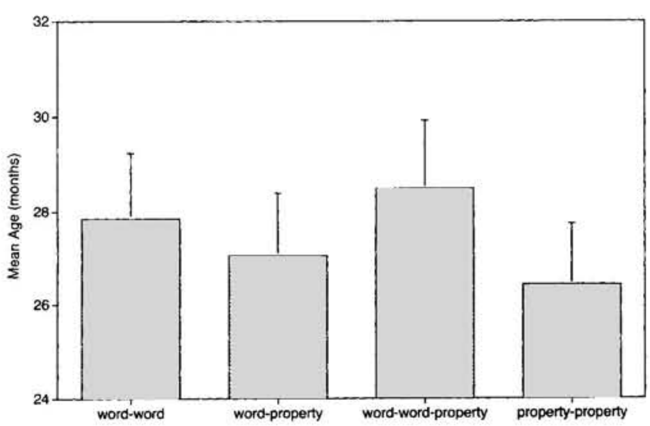

Figure 3. Mean age of acquisition in the four size matching tasks. Vertical lines depict standard errors of the means.

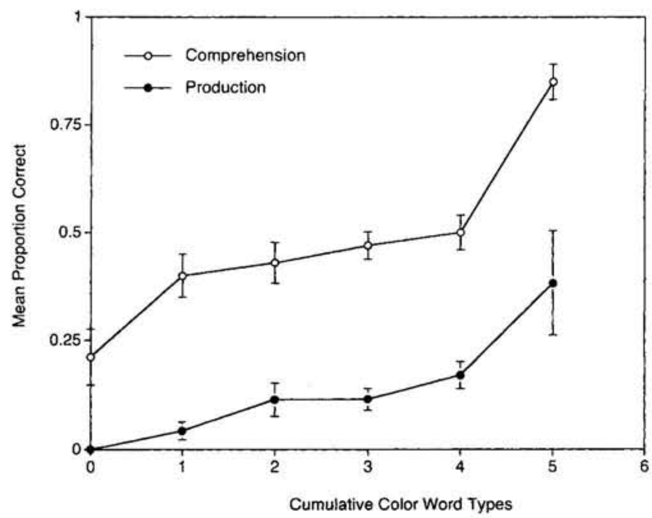

Figure 4. Mean proportion correct on the comprehension and production tasks as a function of the cumulative color word types in the child's productive vocabulary. Vertical lines depict standard errors of the means.

specific set of words, might somehow prepare children for learning word–property maps.

By our analysis, success in the production task required more than success in the comprehension task because it required both word–word maps and word–property maps. All of the children acquired word–property maps, demonstrating color comprehension at some point during the course of the study. However, not all children acquired word–word–property maps, demonstrating color production, and those who did did so only after they had achieved success in the comprehension task. Thus, every child in this study demonstrated comprehension of color words prior to production of color words, a contingency pattern reliably different from chance, $\chi^2(1, N = 12) = 12.00$, $p < .01$. Moreover, the age at which children achieved success in the comprehension task predicted the age at which they succeeded in the production task ($r = .87$, $p < .05$). The individual patterns were thus like the group pattern; children first acquired word–word maps, then word–property maps, and only after both of these mappings were acquired did children succeed in the production task that required both of them.

But how does learning word–word maps facilitate the acquisition of color words? One possibility is that knowing that color words form a lexical class encourages children to seek out a class of like properties to which they might refer. If this idea is correct, one might expect correct color word comprehension and production to emerge only after children have acquired some number of word–word maps—only after they know that "red" and "blue" and "green," for example, are all possible answers to the question "What color is that?" To examine this possibility, we counted the number of color word types produced (correct or incorrect) by individual children over the course of the experiment. Children's performances in the comprehension task as a function of this first measure, cumulative color types in the production task, are shown in Figure 4. There was a sharp rise in color word comprehension, $t(15) = 4.37$, $p < .01$, and in correct productions, $t(15) = 2.73$, $p < .05$, at the point that children had five unique color words in their vocabulary. We also examined children's performances as a

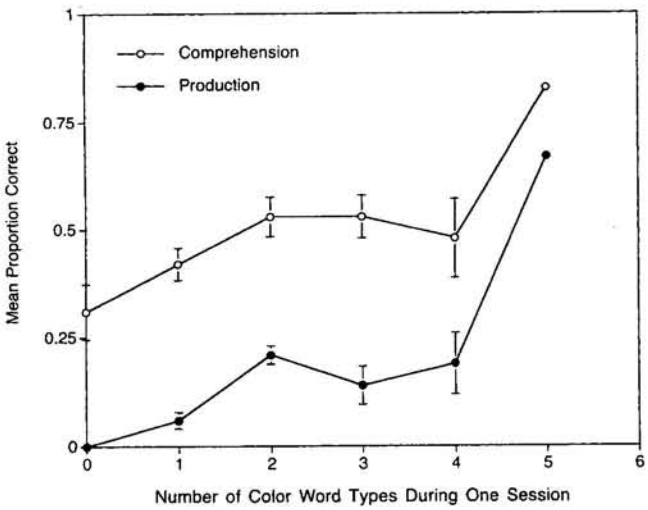

Figure 5. Mean proportion correct on the comprehension and production tasks as a function of the number of color word types produced within a single session. Vertical lines depict standard errors of the means.

function of unique color word types produced in a single session. The results shown in Figure 5 yielded the same conclusion. A marked rise in children's comprehension, $t(8) = 7.04$, $p < .01$, and production, $t(8) = 10.82$, $p < .01$, of color words occurred at the point when children used five unique color words to answer the question "What color is this?" in one session. Thus, as children increased their color lexicon, their performance on both comprehension and production measures improved.

We also asked when in the course of the experiment each child mapped an individual color word to its corresponding property, as measured in the comprehension task. We deemed a particular word–property map (e.g., *red*–RED) to be acquired at the point when an individual child always indicated the right color when asked within a session and in all subsequent sessions. By this admittedly conservative measure, no child comprehended any color words prior to the point at which he or she used (often incorrectly) four color words in the production task. Altogether, these results strongly suggest that knowing that there is a set of words that are all answers to the question "What color is it?" fosters the mapping of those words as a set to the appropriate class of object properties.

Does learning word–property maps help children to make property–property maps? Next, we asked whether learning mappings from words to properties facilitated children's ability to make property–property maps in the matching tasks, the one task that did not explicitly involve the use of color language. Although all 12 children acquired word–property maps, only 3 of the 12 children ever demonstrated acquisition of property–property maps in the color tasks by the end of the study, and those children were able to match objects by color only after they had learned to comprehend color names, a contingency pattern reliably different from chance, $\chi^2(1, N = 12) = 12.00$, $p < .01$. This is consistent with the idea that learning maps from words to the colors of objects may help children perceptually isolate and selectively attend to color. However, the more remarkable result is that the majority of children, even after many months of correct color comprehension, could not match objects by color. How is it that children can pick out a red object when asked to get a red object but not know that two red objects match? One possibility is that the matching task instructions were too hard for the children to understand. However, this is unlikely because the same children did succeed in the size matching task. We return to this perplexing issue in the General Discussion section.

Alternate Routes to Color Word Knowledge

Recall that 1 child showed a pattern unlike all the rest in the color tasks. Figure 6 shows Erich's ages of acquisition for each of the four mappings. Unlike the other 12 children, Erich acquired property–property maps before he demonstrated comprehension or production of color words, a pattern that on the surface resembled that of the other children learning size words rather than color words. However, Erich's story is not that simple. Figure 7 shows Erich's performance on the comprehension and matching tasks across sessions. Initially, Erich made rapid progress, correctly identifying 67% of the colors in the comprehension task. In the following sessions, performance in this task declined to a low of 0% correct in the sixth session and then rebounded to nearly perfect performance in the eighth session. During the period in which comprehension performance declined, performance in the matching task increased. During the sixth session, in which Erich did not answer a single comprehension question correctly, he successfully matched colors in the matching task 92% of the time. This suggests that at the sixth session, although Erich was not using word–property maps, he was mapping the properties of color to each other, that is, using property–property maps. This conclusion was supported by the results in Figure 8, which shows Erich's consistency and correctness on the comprehension task. A high consistency score means that on a given trial, the child selected objects of the same color when asked to get "the ____one" and then "another ____one," regardless of whether the two objects were the specific color requested. As can be seen in Figure 8, before the sixth session, Erich was not highly consistent in his choices. However, on the sixth session, although he never selected the color requested by the experimenter, he always selected an object that matched his first selection in color when asked to get "another one."

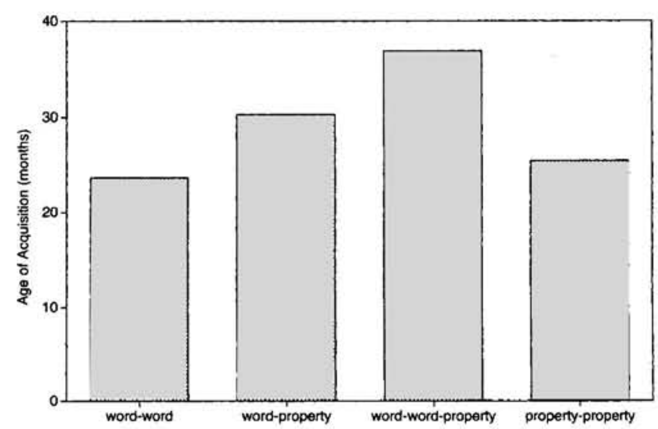

Figure 6. Erich's age of acquisition in the four color mapping tasks.

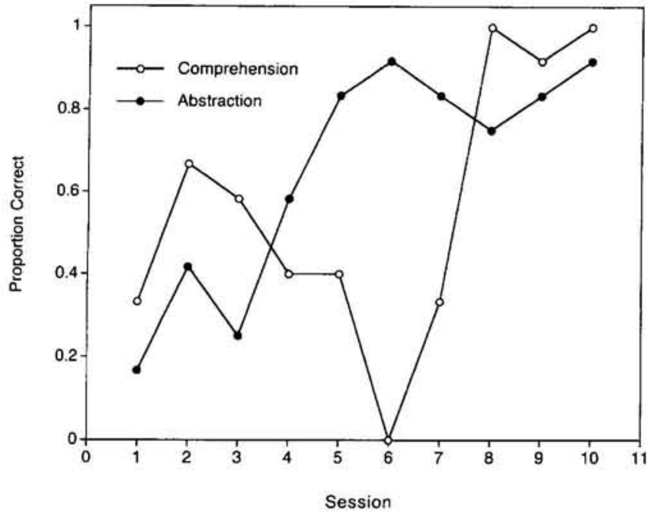

Figure 7. Erich's proportion correct on the comprehension and abstraction tasks as a function of session.

Erich's initial success and subsequent decline in the comprehension task suggest that he may have switched strategies for learning about color words. Initially, Erich may have begun to learn about color in a manner like the other 12 children, but as he learned to selectively attend to color, he abandoned that strategy and began to concentrate on ensuring that colors with the same label "matched" each other. Given that the other children in this study either did not succeed in matching objects by color or did so only after they had learned to identify colors by name, it is intriguing that Erich had made some initial progress in learning word–property maps before mastering property–property maps.

Study 2

The purpose of this study was to replicate the developmental ordering observed among mappings in Study 1 but in a cross-sectional design. This was critical because the children's repeated exposure to the same tasks over the course of Study 1 could have created the observed developmental trend.

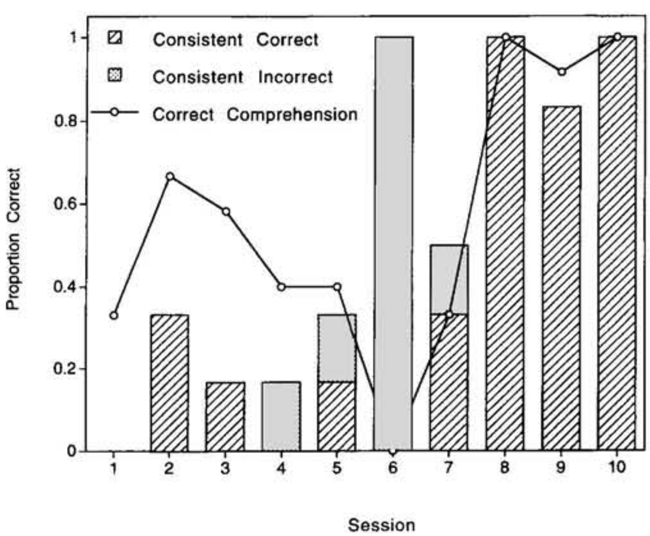

Figure 8. Erich's consistency scores and proportion correct on the comprehension task as a function of session.

Method

Participants

A total of 56 children, 25 boys and 31 girls (mean age = 2 years 3 months, *SD* = 3 months, range = 1 year 8 months to 2 years 9 months), participated. Family histories detailing color blindness were used to "screen" for color blindness. None of the children participating had histories suggesting a likelihood of color blindness. Two additional children were asked to participate but were dropped from the study for refusal to participate in any of the tasks.

Stimuli and Procedure

The stimuli and procedure were identical to those in Study 1 for the production, comprehension, and matching tasks. Each child participated in all tasks once, in one session. The order of tasks was randomly determined for each child.

Results

Overall Results: Color and Size

Overall, children presented a great deal of variation in the present study, with children ranging from 0% to 100% correct on each of the four color tasks and from 0% to 100% correct on three of the four size tasks. Table 6 presents the group data for children in Study 2. In the color tasks, children as a group performed better when making either word–word maps or word–property maps than either word–word–property maps or property–property maps. However, the children displayed a very different pattern in the size tasks. As a group, children performed best when making word–property or property–property maps in the size trials but had little success making word–word or word–word–property maps. That is, on the size trials, children seemed unsure about how to answer the question "What size is this?"

Order of Acquisition

The results of Study 1 suggested that children typically acquired the four color mappings in the following order: (a) word–word maps as measured by responding with a color word in response to the question "What color is this?" (b) word–property maps as measured by correct comprehension of color labels, (c) word–word–property maps as measured by correctly answering the ques-

Table 6
Mean Proportions Correct on Mapping Tasks for Children in Study 2

	Color		Size	
Mapping	*M*	*SD*	*M*	*SD*
Word–word	.64	.38	.18	.22
Word–property	.67	.32	.69	.42
Word–word–property	.41	.22	.17	.20
Property–property	.42	.35	.56	.29

tion "What color is this?" and finally (d) property–property maps as measured by correctly matching objects by their color. We assessed whether children in the present study had acquired the mappings in the same order as observed in Study 1 by using the same definition for acquisition as in Study 1—performance above the 95% confidence interval for chance performance.

Table 7 presents all of the patterns of color acquisition observed in Study 2. The top five patterns were those expected by the results of Study 1. As can be seen, 50 of the 56 (89%) children performed congruently with the order of acquisition demonstrated in Study 1. A Guttman (1950) scale performed on the order of acquisition of the mappings indicated that the predicted order—word–word, word–property, word–word–property, and property–property—was reliable for the cross-sectional data (coefficient of reproducibility = .96). Thus, children appeared to typically acquire the color mappings in the hypothesized order.

Table 8 presents all the patterns of size acquisition observed in Study 2. As is apparent, children performed much less systematically in the size tasks than in the color tasks, and most critically, the patterns of acquisition dominating color word mapping were more rare in the case of acquisition of size words. The top five patterns in Table 7 were those expected in the color tasks. As can be seen, only 29 of the 56 children displayed these patterns in the size tasks. Although the patterns of color and size acquisition observed in Study 2 were not directly comparable with the time course data of Study 1, the patterns observed in Study 2 were consistent with the order of acquisition observed in Study 1.

The data in Study 2 were also examined for children who displayed a pattern of acquisition similar to Erich's, that is, a pattern in which the child acquired property–property maps prior to acquiring word–property and word–word–property maps. Of the 56 children participating, no children demonstrated a pattern similar to Erich's during their one-time visit. Moreover, none of the children exhibited Erich's consistent-but-wrong strategy on the comprehension task. That is, none of the children when asked, for example, "Show me a red one" and then "Show me another red one" insisted that both objects be the same color (e.g., both yellow) when they selected an incorrect color as their first choice. However, as seen in Table 6, 6 children produced patterns of mappings that were neither consistent with the typical pattern observed in Study 1 nor consistent with the alternative pattern produced by Erich. This suggests that there are potentially many alternate routes to acquiring color words.

In addition, we asked whether, as in Study 1, children who had many word–word maps demonstrated more correct comprehension and production of colors than children with fewer word–word maps in their lexicon. To do this, we counted the number of color word types (either correct or incorrect) produced by individual children during the experimental session. Children's performance on the comprehension task as a function of the number of color word types produced is shown in Figure 9. As can be seen, as the number of color words in children's lexicons increased, children's performance on both the comprehension, $F(6, 48) = 6.30, p < .01$, and production, $F(6, 48) = 17.64, p < .01$, tasks improved. Moreover, there was a sharp rise in performance on the production task between the children who had three and the children who had four color words in their lexicon (Tukey's HSD, $p < .05$). Thus, as in Study 1, learning word–word maps appeared to facilitate the acquisition of color words.

In conclusion, the critical point is that the pattern of development for color words observed in the longitudinal study of Study 1 was replicated in this cross-sectional study. Thus, repeated exposure to the tasks of these studies did not appear to create the pattern. Together, both studies suggest that learning color words depends on learning multiple mappings. The order of acquisition observed in Study 1 was replicated in the present cross-sectional

Table 7
Patterns of Mappings in Color Acquisition Observed in Study 2

Word–word	Word–property	Word–word–property	Property–property	Number
–	–	–	–	6
+	–	–	–	14
+	+	–	–	5
+	+	+	–	17
+	+	+	+	8
+	–	+	–	3
+	–	+	+	1
–	+	–	+	2

Table 8
Patterns of Mappings in Size Acquisition Observed in Study 2

Word–word	Word–property	Word–word–property	Property–property	Number
–	–	–	–	5
+	–	–	–	0
+	+	–	–	10
+	+	+	–	9
+	+	+	+	5
–	+	–	–	2
+	+	–	+	1
–	–	–	+	5
+	–	+	+	6
+	–	–	+	1
–	+	–	+	12

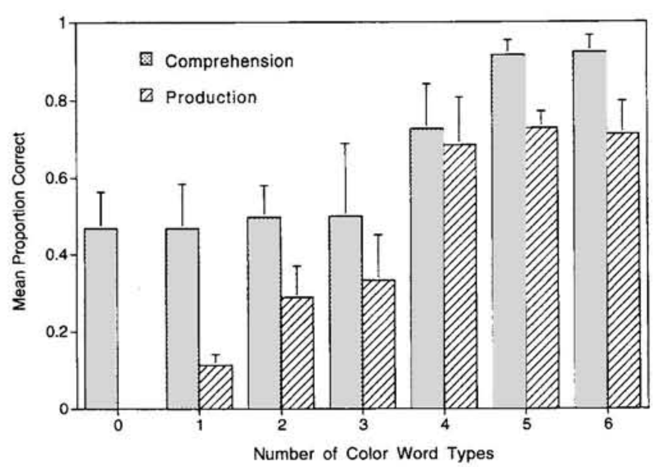

Figure 9. Mean proportion correct on the comprehension tasks as a function of color word types produced during Study 2. Vertical lines depict standard errors of the means.

study, that is, children appeared to acquire the mappings necessary for the acquisition of color in the following order: (a) word–word maps, suggesting children have linked the question "What color is this?" to a set of color words; (b) word–property maps, indicating correct comprehension of color; (c) word–word–property maps, demonstrating correct production of color terms; and finally (d) property–property maps, indicating selective attention to color.

General Discussion

The starting point for this article was the idea that in learning color words, children learn multiple mappings—among words and from words to object properties. The results support this idea and suggest that there is both a usual order to and dependencies among the acquired mappings. Moreover, this ordering, although true of color words, is not characteristic of the learning of size terms. In learning color words, children appear to first learn relations among words—that the word *color* signals a request answerable by specific words such as *red* or *green.* Next, children appear to map specific color words to the specific properties of objects—*red* to red things and *green* to green things—and succeed in comprehension tasks that ask them to pick out objects of specific named colors. Then, our results suggest, children put these two mappings together and produce the correct color name for the queried object when asked "What color is this?" Finally, sometime after this already protracted developmental course, children successfully selectively attend to color and match objects by color in tasks not involving color words.

Why Should Learning Word–Word Maps Promote the Learning of Word–Property Maps?

Our results suggest that learning word–word maps both precedes and promotes the acquisition of word–property maps. The results of the longitudinal study in particular show not only that children learned to answer questions about the color of things with color words first but also that they did not map the names to the appropriate property until they knew five or more unique color words as possible answers to the question "What color is it?" The results thus suggest that the linking together of individual color words into a lexical domain somehow helps children map color labels to colors. We speculate that it does so in two ways.

First, these word–word maps may tell children that there is a class of related words to be learned (Backscheider & Shatz, 1993). Knowing that *red, green,* and *yellow* are all members of the same class of words should promote comprehension because once children realize that even one color word maps to the color of a thing, they may be able to quickly map the remaining members of the lexical class to the right colors.

A second way that word–word associations may be crucial to the learning of color words is that such associations may serve as context cues that ultimately come to shift attention to the appropriate object property. Children do not learn about color in isolation. For example, when looking at a little red dog one might ask "What is it?" "Is it big?" as well as "What color is it?" To answer all these questions, children must be able to look at the very same object differently in different linguistic contexts, perceptually isolating shape when asked about shape, size when asked about size, and color when asked about color. Words must come to be context cues that shift attention to the relevant property for that specific context (see also Smith, 1999; Smith, Jones, & Landau, 1996).

In a recent connectionist model of dimension word learning, Smith, Gasser, and Sandhofer (1997) demonstrated the potential importance of word–word associations and of words as context cues in recruiting attention to object properties. In that study, a four-layer connectionist network was taught to answer questions about three different perceptual properties. For example, the network might be given an input specifying a bumpy, rectangular, red object and asked "What texture is it?" or on other trials, "What shape is it?" or on other trials, "What color is it?" The network had to learn to output a particular property term that depended on both the object and the question. Critically, what the network learned first was not maps from object properties to labels but maps between the question asked and the possible answers, that is, word–word maps. That is, like children, the network rapidly learned to answer questions about color with color words. Moreover, with learning, the linguistic input—the specific question asked of the network—came to shift the attention weights between layers in the network. The result was that the pattern of activation on the hidden layer, the network's internal representation of the presented object, mostly contained information about the queried property rather than the object's other properties. Put simply, after training, given an object and the question "What color is it?" the network's internal representation of the object emphasized the object's color. Critically, both the question being asked and the specific property labels were associated with increased attention to the dimension.

We are not suggesting that this connectionist model of learning in one task is a correct model of color word learning by children. However, the simulation results do suggest how learning word–word associations may be mechanistically involved in learning color words.

Why Should Learning Word–Property Maps Precede Learning Property–Property Maps?

The most perplexing result of the present study is that children seem to learn color words—correct mappings from a color label to a color property—without being able to actually match objects by color. This result is not without precedence. In a sorting task, Rice (1980) found that "most of the beginning color-namers did not respond according to the dimension of color on the sorting task, although some of these subjects had at least two color terms used correctly" (p. 78). Smith (1984) also found a similar result in a follow-the-leader-type task. In her task, many children who passed a color comprehension task also failed to match objects by color. In light of these previous findings, it would appear that the present result—that children match objects by color only after being able to identify objects by color—is robust with regard to task variations. However, there is at least one study that suggests an opposite result. In Soja's (1994) study, many children who could not correctly identify objects by color nevertheless could match objects by color. Soja used a triad matching task. For example, in one trial, children were asked to decide if a red disk went with a red suitcase or a black horse.

Soja's (1994) task differed in several important ways from the matching tasks used in the present studies and by Rice (1980) and Smith (1984). Most critically, Soja's task could be solved without the abstraction of or selective attention to color. That is, if one calculated the overall similarity of objects in the triads, one test object (e.g., the red disk) matched the exemplar (the red suitcase) on one dimension, and the other exemplar (the red disk) matched on no dimensions. Children could solve this task simply by choosing the two objects most alike overall. We suspect that Soja used this task rather than the more appropriate one, for example, requiring children to choose whether a red disk matched a red suitcase or a black disk, in order to avoid relying on verbal instructions. Tasks that pit matches specifically by color against matches by other dimensions require instructions (verbal or otherwise; see Smith, 1984) because without such instructions—without a contextual cue that says this task is about color—the child has no reason to match by color rather than by the other competing dimension. Thus, one of our matching tasks, like Soja's task, did not pit a competing dimensional match against a color match (the one-exemplar task) and, thus, like Soja's task, was potentially solvable by using overall similarity. However, the particular structure of our task made choosing the most similar object overall a difficult strategy to use. In our task, children had to compare the relative overall similarity of six choice objects with the exemplar to find the most similar overall. In Soja's task, only two such similarities had to be compared. Note our second matching task (the two-exemplar task) pitted competing dimensional similarities against each other. Children were instructed to make a color match by providing them with a starting match. Note that it cannot simply be the case that our matching tasks were too hard overall for the children to solve, because they were generally successful in solving them when the relevant dimension was size. In sum, the evidence strongly suggests that children who comprehend color terms also fail to selectively attend to color in matching tasks.

How can this be? How can children know that all sorts of different red things are *red* without being able to abstract the redness of all those things sufficiently well to group them by color? One possible answer to this question is suggested by Smith et al.'s (1997) simulation of dimension word learning. Smith et al. trained the network to a level of nearly perfect performance in answering the questions "What color is it?" "What shape is it?" and "What texture is it?"—all questions structured like those asked of children about color. Over a domain of randomly chosen objects of potentially infinite number, the network learned to call all red things *red,* blue things *blue,* and so forth. This level of performance would seem to suggest that the network had learned, in the context of a question about color, to abstract redness from red things and blueness from blue things.

Smith et al. (1997) sought confirmation for this conclusion by directly examining the internal representations of the network at the end of learning. They did this by presenting the network with the instruction "What color is this?" and then first with one object of a particular color and then second with another object of the same color. If the network had learned to abstract the color of things away from shape, size, texture, and so forth in the context of a question about color, then the pattern of activation on the hidden layer should have been the same for both of these objects and, indeed, for all red objects in the context of a correctly answered question about color. However, the internal representations were not similar. The internal pattern of activation that yielded the output *red* given a red fuzzy octagon and the pattern of activation that yielded the output *red* given a red smooth sphere were not alike—even at the point at which the network could be presented with any object and correctly label its color. Although the network had learned to emphasize the color of objects in the context of color words well enough to label its color, the network had not learned to selectively attend perfectly to color; it had not learned to inhibit all the other information about the particular object. Indeed, it succeeded in the task through word–word associations that limited possible outputs to one small set of words (the color words) and an increased weighting of color information that was far short of perfect selective attention to color. That is, even after achieving errorless performance in answering questions about color, texture, and shape, the network's internal representation of, for example, the redness of things contained information about the particular object's shape and texture as well. These demonstrations are important because they indicate that it is not logically necessary to be able to perfectly attend selectively to color, to ignore other object properties, in order to understand and use color words perfectly.

This point has been noted before. Luria (1976) came to the same conclusion in his study of unschooled Russian adults. He showed the individuals four items—a glass, a saucepan, spectacles, and a bottle—and asked them questions about common features between the objects, for example, "Could you put the bottle and the spectacles and the glass together in one group? How are they alike?" (Luria, 1976, p. 64). These participants experienced considerable difficulty with this task. For example, one replied, "When you get right down to it none of the things are alike. Sure, the bottle's like the glass and the saucepan's like our boiling pans. And the spectacles are for your eyes" (Luria, 1976, p. 64). This individual knew the word *glass* and could apply it to bottle, glass, and spectacles. But knowledge of the word did not bring with it an explicit or easily accessible understanding of the sameness.

It may be that such an explicit understanding of kinds of sameness, an awareness of the redness of red things or the common material of glass things, requires more than learning the labels for the properties. One possibility is that abstraction in this sense requires explicit training in making property–property maps, explicit comparisons of how one object is like another. Several recent studies (Gentner & Ratterman, 1991; Kotovsky & Gentner, 1997) have supported this conclusion. Gentner and her collaborators have shown that training in explicitly comparing objects promotes selective attention and the abstraction of relations. They also have shown that learning names for relations facilitates comparison. This makes sense and may be why, in the present study, learning names for colors preceded and possibly promoted subsequent success in the matching task. Knowing that one object is labeled *red* and another dissimilar object is also labeled *red* may invite the child to explicitly compare the two objects and look for the similarities between them.

The present results suggest that word learning may actually help to recruit attention to relevant properties, that the act of learning a label may in some instances help the child to abstract the appropriate referent. Furthermore, these results remind us to pay close attention to the structure of the task that children are being required to master. Although both size and color words are dimensional adjectives, the learning requirements and structure of the two tasks are distinct. Future studies should examine more closely how the structure of the learning task influences acquisition.

In conclusion, this study set out to systematically study the factors important in the acquisition of color words. Why is learning color words so hard? In the past, researchers have pointed to a number of possibilities (see Soja, 1994, for review). Among these are suggestions that the structure of the learning task itself creates difficulty, that color—unlike most sets of dimensional adjectives—is not polar (binary) but is labeled categorically by a relatively large set of terms (Carey, 1982; Park, Tsukagoshi, & Landau, 1985; Soja, 1994). These results are consistent with this prior proposal and expand on this general idea that it is the structure of the task itself that determines learning. The results of this study suggest that children learn color words by acquiring a system of mappings and that the structure of the system as a whole determines the learning trajectory.

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