Color word learning is a gradual inductive process

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Abstract

Most current accounts of color word acquisition propose that the delay between children's first production of color words and adult-like understanding is due to problems abstracting color as a domain of meaning. Here we present evidence against this hypothesis, and show that, from the time children produce color words in a labeling task they use them to represent color. In Experiment 1, an analysis of early color word production errors finds that, before acquiring adult-like understanding, children make systematic hypotheses about color word meanings, which are best characterized as overextensions of adult meanings. Experiment 2 analyzes comprehension errors and finds that these overextensions result from overly broad categories, rather than a communicative strategy. These results indicate that the delay between production and adult-like understanding of color words is largely attributable to the problem of determining language-specific color boundaries.

Keywords: Concepts and Categories; Language Acquisition; Cognitive Development

Introduction

Color words like *red*, *green*, and *blue* pose a difficult problem to children learning language. According to early reports from the turn of the 20th century, children did not acquire the meanings of color words until as late as 8 years of age. Recent reports suggest that children now acquire color words earlier around 3 or 4 years of age (possibly due to early education, see Shatz et al., 1996), but nevertheless struggle to learn them (e.g., Backscheider & Shatz, 1993; Sandhofer & Smith, 1999). The primary evidence of children's difficulty is that, similar to the domains of number (Wynn, 1990) and time (Shatz et al.,2010), children produce color words well before they use them with adult-like meanings. Also, it's often argued color word use is initially "haphazard and inconsistent" (p.70, Pitchford & Mullen, 2003). By most current accounts, this delay between production and adult-like understanding is caused by a difficulty abstracting color as a dimension of linguistic meaning (e.g., O'Hanlon & Roberson, 2006; Kowalksi & Zimilies, 2006; Sandhofer & Smith, 1999). Here we present evidence that children's initial use of color words is in fact systematic rather than haphazard, and that children have abstracted color by the time they begin using color words. We argue that the main source of children's delay is the problem of inferring category boundaries for color words.

Current accounts of color word acquisition typically assume that once children have conceptualized color as a domain relevant to word meaning, the mapping of color words to their target color categories proceeds quickly. According to some, the moment of abstraction resembles a conceptual epiphany. For example, according to Franklin (2006), "Children seem to struggle with their first color word yet learn most of the other basic terms fairly rapidly over the next several months…. This seems to suggest that there is some kind of 'switch' for children's ability to learn and map color words correctly¬" (p. 324). On this view, once children have mapped their first color word, mapping of other color words to adult-like meanings is relatively simple and fast (see Franklin, 2006; Soja, 1994).

The idea that the mapping process ought to be rapid comes from two main lines of research. First, in an often-cited study of color words in 110 languages, Kay and colleagues reported evidence for cross-linguistic universals in linguistic color categories (Kay et al.,, 2009) and argued that the number of color categories cross-linguistically is relatively small and constrained. Second, there is mounting evidence suggesting that pre-linguistic infants possess perceptual color categories very similar to those found in adults (e.g., Bornstein, Kessen & Weiskopf, 1976; Bornstein, 1976; Franklin et al., 2008; Franklin et al., 2005). In each case, the purported existence of constraints on language and perception have led researchers to conclude that color word learning is a simple mapping problem, whereby largely innate perceptual categories are associated with labels provided in language input.

Examples of this view are common in the literature, with important consequences for how color word learning is studied. For example, according to Pitchford and Mullen (2004), "Developmental studies have shown young children's perceptual colour space is organized in a similar manner to that of the adult… Thus, when children engage in the learning of colour terms, they already possess colour percepts on which colour concepts can be mapped." (p.53) The implication of such arguments is that, because color words can be mapped to pre-existing perceptual categories, the lag between production and adult-like understanding must not be due to the problem of determining boundaries. Instead, the delay must be due to the prior problem of identifying color as a domain of linguistic meaning.

There are good reasons, however, to believe that the acquisition of color words is not a simple mapping problem. Despite being restricted by universals of human perception, languages vary both in the number of color words they have (2 to 12) and how these words encode color (Kay et al, 2009). For example, some languages that have four basic color terms mark a boundary between red and yellow (e.g., Culina, spoken in Peru; Waorini, spoken in Ecuador) whereas others do not (e.g., Chácobo, spoken in Bolivia; Múra-Pirahã, spoken in Brazil; Kay et al.,

2009). Also, Russian, Korean and English have roughly the same number of basic color terms (11-12; Berlin & Kay, 1969), but divide the blue-green region of color space differently (e.g. Roberson et al.,2009; Winawer et al., 2007). In sum, while infants may perceive color like adults, the categories encoded by language are not fully determined by perception, suggesting that inductive learning plays a significant role in color word learning.

In the present study, we explored the idea that children acquire preliminary meanings for color words well before they converge on adult-like meanings, and thus abstract color much earlier than typically thought. On this hypothesis, the delay between color word production and adult-like understanding is mostly due to a gradual process of determining language-specific color word boundaries.

Past studies have typically failed to address the nature of the mapping problem because of how they characterized children's color word meanings. For example, researchers often classify children according to their knowledge of adult-like meanings – e.g., using *red* to label only red objects (e.g., Kowalski & Zimiles 2006; Soja, 1994; O'Hanlon & Roberson, 2006). In doing so, such studies may underestimate children's color word knowledge, and thus the point at which they first abstract color. Consistent with this concern, a number of studies have found that before children acquire all 11 adult-like color word meanings, they make errors that are systematic in nature (Pitchford & Mullen, 2003; Davies et al.,1998; Bartlett, 1977). For example, Pitchford and Mullen found that 3-year-olds often use their color words to incorrectly label hues adjacent to the target category (e.g., labeling orange as *red*). On the basis of this, they argued that pre-linguistic perceptual categories strongly constrain early color word meanings. However, proximity errors are not easily explained by this hypothesis. Instead, such errors most strongly support the existence of categories that are broader than those used by adults, and thus that are not acquired on the basis of pre-defined perceptual categories.

In the current study, we investigated the first meanings that children assign to color words by analyzing the errors they make in both language production and comprehension. Although some past studies have reported error data in early color word use (see above), here we present new evidence and analyses that directly address the nature of the delay between production and adult-like understanding. In Experiment 1, we present data from a color-labeling task sampled from a large group of children including a subset who have not yet acquired any adult-like meanings. This experiment finds that children make errors that are systematic in nature prior to acquiring any adult-like meanings. These data suggest that children in our study have abstracted color and possess partial knowledge of color words by at least the time they begin producing them. In Experiment 2, we corroborate these findings using a language comprehension task, and show that children's early overextensions of color words reflects overly broad meanings, rather than a communicative strategy.

Experiment 1

Methods

Participants 141 children (68 girls) participated. Children with a 25% chance or higher of protanopia or deuteranopia color deficiency (based on family history) were excluded (n=5). Children who made no errors (n=21), used only one color term (n=6) or did not cooperate (n=11) were also excluded. Data from the remaining 98 children (50 girls) were analyzed (mean age 3;0, range 22 to 61 months).

Stimuli Stimuli were constructed using 11 pieces of colored posterboard, which were chosen by a consensus of five experimenters as being prototypical of the 11 basic color terms in English (i.e., *red, orange, yellow, green, blue, purple, pink, brown, black* & *gray*). The posterboard was cut into a set of 11 fish shapes (Fish Task) and a set of 11 squares (Book Task). For the Fish Task the colored fish were glued to black foam and were presented on a black background. For the Book Task, the colored squares were glued onto black pages and covered with white flaps.

Procedure

Fish Task. Each child was presented with a black box containing the 11 colored fish, placed color-side down. The experimenter (E) began by announcing, "My turn!" and randomly picking up one of the fish asking, "What color is it?" After the child responded, E placed the labeled fish on the table and told the child, "Your turn!", indicating that the child should pick up a fish. E and the child continued taking turns until each fish had been selected and labeled.

Book Task. Following the Fish Task, E presented the child with a book that contained the colored squares. For each page, the child lifted the flap that covered the color and E asked, "What color is it?" Colors were presented in the following order: orange, blue, yellow, pink, white, purple, gray, brown, green, red, black. When children did not respond, E repeated the question and gave the child another chance to respond. Trials with no response (103 trials, 4.7%) or with two responses (e.g., the child said both *blue* and *red*, 13 trials, 0.05%) were not analyzed.

Results

Color-Knowledge Groups Children were separated into four groups based on the number of Basic Color Terms they used in an adult-like manner (e.g., using *red* consistently and exclusively for red stimuli).

Level 1: Adult-like knowledge of 0 color terms. Produced between 2 and 6 color terms during experiment (mean=3.1). Mean age of 2;5 (n=8, 1 girl).

Level 2: Adult-like knowledge of 1-3 color terms (mean=2.0). Produced between 3 and 9 color terms during experiment (mean=6.6). Mean age of 2;8 (n=16, 5 girls).

Level 3: Adult-like knowledge of 4-6 color terms (mean=5.1). Produced between 8 and 10 color terms during experiment (mean=9.1. Mean age of 3;2 (n=19, 9 girls).

Level 4: Adult-like knowledge of 7-9 color terms (mean=8.2). Produced between 9 and 12 terms during experiment (mean=10.3). Mean age of 3;2 (n=53, 34 girls).

Error Consistency Analysis. Given that a child used an incorrect label for a particular stimulus color on one task (using *red* to label the orange stimulus on the Fish task), we asked how likely it was for the child to repeat the error on the other task (using *red* to label orange on the Book task). Using a binomial test, we asked whether the proportion of consistent trial pairs was greater than chance.

For this analysis, we excluded trial pairs in which the child labeled the stimulus correctly on both tasks (725 pairs). The remaining 275 pairs were classified as either consistent (the same incorrect label for a color on both tasks, 122 pairs) or inconsistent (153 pairs).

The probability of repeating any single label on two separate trials was defined as the square of the proportion of total trials a child used that label. For example, if a child used *red* on 6 of 22 trials, that child's probability of using *red* incorrectly on both the orange fish trial and the orange book trial was $(6/22)^2$. A child's overall chance probability of consistency was defined as the sum of the probability of repeating each label. Each color knowledge group's overall chance probability of consistency was defined as the average of the individual participant probabilities, weighted by the number of data points each individual contributed to the analysis. In other words:

$$p(consistency) = \sum_c \sum_j (\frac{l_j}{n})^2 (\frac{i_c}{i})$$

where i is the total number of stimulus pairs in which at least one label (either book or fish) was incorrect, i_c is the number of such incorrect pairs that each child, c, contributed to the analysis, l_j is the number of times a child produced each label j and n is the total number of responses a child produced. Note that by this definition, the chance probability of consistency appropriately decreases as a child adds more color words to his/her lexicon.

Averaged across the different Color-Knowledge groups, the proportion of incorrect trial pairs that was consistent (0.44) was greater than expected by chance (0.28), using a binomial test, p<0.001. When this analysis was conducted separately for the different Color-Knowledge groups, rates of consistency were greater than chance for all groups except Level 1, see Table 1.

Table 1: Chance and Observed Rates for Exp 1 Analyses

	Consistency		Overextension		Proximity	
	Chc	Obs	Chc	Obs	Chc	Obs
Level 1	0.57	0.61	0.23	0.72*	0.18	0.26*
Level 2	0.27	0.41*	0.062	0.73*	0.25	0.44*
Level 3	0.14	0.31*	0.028	0.75*	0.33	0.66*
Level 4	0.11	043*	0.024	0.81*	0.54	0.82*
Total	0.28	0.44*	0.054	0.76*	0.27	0.52*

Overextension Analysis This analysis asked whether, in some cases, children's color errors were overextensions of adult color categories. For example, a child may correctly know that *red* refers to red objects, yet have a broader meaning for *red* than adults and overextend it to orange and yellow objects. Given that a child used a label incorrectly for at least one trial (e.g., using *red* to label an orange or yellow stimulus), we asked whether they used that label consistently for its target color (i.e., using *red* to label both the red book and red fish stimulus). In other words, when a child used the word *red* to label orange and yellow, was this a case of overextension of the *red* category? For this analysis, if the child did not produce responses for the target hue on both tasks, that color word was not included in the analysis (19 incidences). Using a binomial test, we asked whether the proportion of errors that reflect overextensions was greater than chance.

As noted in the consistency analysis (above), the probability of repeating any single label on two separate trials is the square of the proportion of total trials a child used that label. In contrast to the consistency analysis in which consistent use of any incorrect label to any color stimulus was sufficient, in order for an incorrectly applied *red* label to be classified as an overextension a child must specifically use *red* (not any other color) in response to the red stimulus in both tasks. To calculate chance for this analysis, we first squared the base rates of every term a child used incorrectly (e.g., using *red* for purple) to calculate the probability that each of these incorrect terms would also be used on both trials containing the correct color stimulus (e.g., red fish and red book trial). We then took the mean of these probabilities to calculate the child's overall probability of overextension. To calculate the overall probability of overextension for each group, we calculated a group mean, weighted by how many labels each child used incorrectly. In other words:

$$p(overextension) = \sum_c \frac{i_c}{i} \frac{\sum_j (\frac{i_{cj}}{n})^2}{i_c}$$

where i is the total number of labels that were used incorrectly at least once, i_c is the number of such incorrect labels that each child, c, contributed to the analysis, i_{cj} is the number of times a child produced each incorrect label j, and n is the total number of responses a child produced.

A very large proportion of children's errors – 0.76 – were overextensions, which was significantly greater than expected by chance (chance = 0.054), as measured by a binomial test (p<0.001). This high proportion indicates that if a child produced a color word, they were very likely to use it correctly when presented with its target hue. Thus, it suggests that most of children's errors were overextensions of color terms that were anchored to adult-like focal hues. Critically, rates of overextension were statistically greater than chance and above 0.72 for each Color Knowledge Group (all ps<0.001, see Table 1), including children who had no adult-like color meanings (Level 1).

Proximity Analysis The overextension analysis indicates that before children acquire adult-like color word meanings, they use color words correctly for their target hues. However, the analyses described so far do not

address errors were made to proximal colors or to distant ones. An error was considered proximal if the stimulus color and the correct referent color for the misused label were from adjacent categories in Munsell Color Space (Long & Luke, 2001). Critically, although overextension to distant hues would be consistent with a gradual inductive process (e.g., since children's initial categories may be very large), the inclusion of proximal hues should be significantly more likely even in this case, since any category that includes red and yellow, for example, should also include intervening hues like orange.

Given that a child used a color label incorrectly, we asked whether the label and its referent stimulus were from perceptually adjacent categories. Using a binomial test, we asked whether the proportion of errors that were from proximal color categories was greater than expected by chance. Chance was defined using both the frequency with which children made errors for each stimulus and the frequency with which they used each label incorrectly. It was necessary to account for these base rates because some color words are proximal to a greater number of color categories than others. For example, red is considered proximal to orange, pink, purple, and brown, while gray is proximal to black and white. To determine chance, we calculated the probability of each label-stimulus error pair (the probability of using *red* for an orange stimulus) as equal to the product of the base rates. For example, if 20% (0.2) of errors were in response to an orange stimulus and 80% (0.8) of errors involved the label *red*, the probability of using *red* to label orange would be 0.2*0.8, or 0.16.

To compute the chance probability of proximal errors, we summed across the probability of all label-stimulus pairs that are classified as proximal. In other words:

$$p(proximity) = \sum_i \sum_j p(r|l_j \cap s_i) p(l_j|incorrect) p(s_i|incorrect)$$

where, $p(s_i|incorrect)$ is the probability of a particular stimulus i given an incorrect response; $p(l_j|incorrect)$ is the probability of a particular elicited label j given an incorrect response to stimulus i; and r is the probability of proximity. Note that $p(r|l_j \cap s_i)$ is either 1 or 0 because a given label/stimulus pair is either proximal or not.

The proportion of total errors that were proximal was 0.52. This was significantly greater than the rate predicted by chance (0.27), p<0.001. Rates of proximity were statistically greater than chance for all Color-Knowledge groups, including Level 1 children who had no adult-like color word meanings (see Table 1). Like the findings of the overextension analysis, this indicates that even before a child acquires the adult meanings of any color terms, they already have partial knowledge of some color words.

Discussion

Experiment 1 examined children's color word production errors in early acquisition. Our results revealed that if children used a word in the study, they were very likely to have a systematic meaning for the word, despite the fact that these meanings were often non-adult-like in nature. Together, these results suggests that (1) children

have abstracted color around the time they begin using color words to label stimuli, and thus well before they acquire their adult-like meanings, and (2) they learn color words by making overly broad hypotheses about their meanings, and gradually narrowing these meanings as they acquire additional, contrasting words.

Several pieces of evidence support these conclusions. First, in our Error Consistency Analysis we found that all but the Level 1 children made highly consistent in their errors, demonstrating that these children were able to abstract color across different objects despite their other differences, and use this knowledge to formulate hypotheses about color word meanings. Although Level 1 errors were not consistent, these children were nonetheless highly systematic, as shown by our two other analyses. In our Overextension Analysis we found that, at all color-knowledge levels, a majority of children's errors were overextensions. This indicates that children have partial knowledge of the specific color properties denoted by a color word when they first begin producing it. Specifically, children appear to know the focal color denoted by the color words they use, though they frequently overextend these words. Finally, our Proximity Analysis revealed that the errors made by children at all levels were likely to be labels for perceptually similar colors.

In sum, the data from Experiment 1 demonstrate that children with adult-like understanding of no color words have nonetheless abstracted color. These data are consistent with the idea that children begin acquisition of color words by positing overly broad color categories and that these categories are gradually narrowed as children gain experience and acquire other color words that contrast in meaning. We refer to this as the "Broad Color Categories" hypothesis. Another possibility, however, is that overextension errors instead reflect a pragmatic strategy (for a similar discussion in the domain of nouns, see Clark 1978). For example, imagine a child who has an adult-like meaning for *red* but not for *orange*. When presented with an orange stimulus, the child may recognize that this color is not *red*, but use the word *red* to describe it nonetheless since no better word is available to them. We refer to this as the "Communicative Strategy" hypothesis.

One way of testing these hypotheses is to use a comprehension task, where the experimenter selects the label, thereby removing the possibility of communicative overextensions (Clark, 1978, Gelman et al. 1998). If a child has a broad meaning for *red* (that includes both red and orange), when asked for *red,* they should provide a stimulus that satisfies their meaning of *red* (e.g., either a red or orange one). By contrast, if the child has adult-like color categories, when asked for *red* they should always prefer a red stimulus over an orange one (even if they use *red* to label orange as a communicative strategy).

Experiment 2

In Experiment 2 we presented children with stimuli identical to those used in the Fish task in Experiment 1 and

asked them to find fish of different colors and asked whether children made proximity errors. Note that by the Communicative Strategy hypothesis, proximal errors should not occur because responding should either be correct for known color words (above example, *red*) or random for unknown color words (above example, *orange*) because children do not possess broad categories (e.g., that include both red and orange). Proximal errors are only expected under the Broad Category Hypothesis, since it claims that children possess linguistic categories that include multiple adult categories (e.g. *red* including both red and orange).

Methods

Stimuli Items were those of the Fish Task in Experiment 1.
Participants A total of 28 children (14 girls) participated. Children were screened for color deficiency via a family history questionnaire. Eight children were excluded because they made no errors. Data from the remaining 20 children (8 girls) were analyzed. These children ranged in age from 23 to 48 months (mean=2;10). Unlike in Experiment 1, we did not group children into different Color-Knowledge groups, for two reasons. First, children in this study were not asked to produce color labels, and we therefore could not test how many color terms they knew. Second, the number of subjects required to test the hypothesis of this experiment was relatively small, and thus there was insufficient power to analyze subgroups.
Procedure Children were presented with the fish stimuli placed color-side up and in a random configuration. In succession, the experimenter (E) asked the child to find a specific colored fish, "Give me a (*red*) fish. Can you put a (*red*) fish in my hand?" After the child handed a fish to E, it was returned to its place on the table (back with the other fish), and E requested the next color fish. Colors were requested in the order of Experiment 1: *red, brown, green, orange, white, blue, gray, pink, black, yellow,* and *purple*.
If the child did not respond on a particular trial (e.g., they got distracted), E repeated the question, giving the child an additional opportunity to respond. Trials with no response (n = 3 trials) or on which two or more fish were provided (n = 1 trial) were not included in the analysis.

Results and Discussion

Proximity Analysis. Across all 216 trials, 79 trials (36%) were errors and were included in the analysis. The mean number of correct responses was 6.85 (range 0 to 10).

As in the proximity analysis of Experiment 1, we accounted for the base rate of errors that involved each color stimulus and the base rate of errors made to a particular request (e.g., *red*). Consistent with the results of Experiment 1, the proportion of errors that were proximal in the comprehension task was 0.58. This was significantly greater than the rate predicted by chance (0.30), p<0.001. This suggests that the systematic production overextensions in Experiment 1 reflected broad color categories rather than a communication strategy.

General Discussion

We tested the hypothesis that the delay between color word production and acquisition of adult-like meanings is due to the gradual construction of linguistic color categories, rather than the process of abstracting color as a domain of word meaning. Consistent with this idea, we found that if children used color words in our study, they typically used them in a meaningful and consistent way. When children made errors, the vast majority (75%) were overextensions of adult-like categories. Also, these errors were frequently to proximal hues. This was true for children at all levels of color word competence – even those who had no adult-like meanings. Further, the results of a comprehension task corroborated this finding, and indicated that overextension is not the product of a communicative strategy, but instead reflects broad linguistic color categories.

These results have important implications for our understanding of color word acquisition. First, contrary to past reports, the results suggest that children abstract color at the earliest stages of color word production, and that there is little, if any, lag between children's use of color words as labels and their construction of preliminary meanings for these words. Although abstraction may pose a problem to children early in acquisition, it is likely resolved by the time children begin using colors to label things in their environment. Second, our results suggest that the observed delay between production and adult-like understanding of color words is likely due to the problem of constructing language-specific category boundaries. Our data suggest that children begin acquisition by making overly broad inductive inferences regarding the scope of their color words, and that they gradually shrink their early categories as they gain experience with the words and acquire other color words that contrast in meaning.

These data are consistent with earlier data from Carey and Bartlett (1978), which are commonly cited as evidence for children's ability to "fast map" color words to their referents. Bartlett and Carey's fast mapping proposal, unlike some theories of color word learning that followed it, did not assume that learning color word meanings was fast, or that it was a simple mapping problem. Instead, they argued that fast mapping was a first step in the learning process, used to link labels to particular referents, and that acquiring the adult-like meanings of color words involves much more additional learning (see also Swingley, 2010; Clark, 1997). Consistent with this, many of the children in Carey and Bartlett's study used the novel word chromium, which was used by experimenters to refer to an olive-colored stimulus, to refer to perceptually similar colors (e.g., green, brown) and often did not converge on the intended narrower meaning for chromium even after many trials (also, see Bartlett, 1977; Pitchford & Mullen, 2003).

These results, like ours, suggest that color word learning is a gradual inductive process, and that children form interim meanings for their color words well before they attain adult-like understanding. However, because these

studies focused on samples of children who for the most part had acquired at least one adult-like color word, their data do not address the delay between onset of color word production and children's first adult-like color word meaning. In contrast, our study addressed this question using data from a wider range of children (including those who had not acquired any adult-like meanings of color words), and using a novel set of analyses that tested not only proximity errors but also consistency and overextension. Consequently, our study was able to show that children possess broad, overextended color categories early in acquisition, before they have acquired their first adult-like meaning, and perhaps even from the time they first begin producing color words.

This view of color word learning is consistent with findings in other domains of language and conceptual development. In the case of number, children quickly recognize that numerals form a class of words that contrast in meaning (Wynn, 1992; Brooks et al., under review), despite taking years to learn what these meanings are. Similarly, young children recognize that time words like minute, second, and hour form a lexical class, but take many years to acquire their individual meanings (Shatz et al., 2010). Finally, children produce emotion words from early in development, and understand that they belong to a class of words that describe human sentiment, but nonetheless take years to master their adult-like meanings, and form many interim hypotheses along the way (Widen & Russell, 2003). Our study suggests that the case study of color is not an exception to this general pattern, and that as in other cases that involve identifying abstract content, children begin formulating preliminary meanings early in acquisition, and take years to attain adult competence.

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