Partial color word comprehension precedes production

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Abstract

Previous studies report that children use color words in a haphazard manner before acquiring adult-like meanings. The most common explanation for this is that children struggle to abstract color as a domain of linguistic meaning, and that this results in a stage in which children produce but do not comprehend color words. However, recent evidence suggests that children's early usage of color words is not random, and that they acquire partial but systematic meanings prior to acquiring adult-like meanings. Here we employ parent report, a color word production task and an eye-tracking comprehension task to provide further support for this conclusion and show for the first time that toddlers often acquire color word meanings even before beginning to produce them.

Keywords: word learning; adjectives; color; receptive language; expressive language

Introduction

Color words pose a difficult problem for children learning language (Sandhofer & Smith, 1999; Kowalski & Zimiles, 2006; O'Hanlon and Roberson, 2006). As noted in a number of previous reports, children produce color words for many months before converging on adult-like meanings (Pitchford & Mullen, 2003; Sandhofer & Smith, 1999; Soja, 1994), a pattern also found in other domains of word learning, such as time and number (Brooks, Audet, & Barner, 2012; Busby Grant & Suddendorf, 2011; Shatz, Tare, Nguyen, & Young, 2010; Wynn, 1992). Many previous studies have argued that this delay between production and adult-like comprehension is due to children's difficulty identifying color as the relevant domain of linguistic meaning, and thus that children initially produce color words despite lacking meanings for them (Franklin, 2006; Kowalksi & Zimiles, 2006; O'Hanlon & Roberson, 2006; Sandhofer & Smith, 1999). Challenging this, the present study shows that children often acquire partial meanings for color words before beginning to produce them. This suggests that the delay between production and the acquisition of adult-like meanings cannot stem from problems abstracting color, but instead is best explained by a gradual inductive process of determining the boundaries of individual color words.

In most domains of vocabulary acquisition, past studies have found that children acquire basic meanings of words before they begin to produce them in speech, such that in infancy and early childhood the number of words that children comprehend far exceeds the number of words that they produce (Goldin-Meadow, Seligman & Gelman, 1976; Harris, Yeeles, Chasin & Oakley,1995). However, according to some accounts there are important exceptions to this pattern. For example, children learn to count and produce number words many months before they acquire their meanings (Wynn, 1990, 1992; Carey, 2009). Also, similar claims have been made in the domains of time (Shatz et al., 2010; Friedman; Tillman & Barner, 2013), and emotion (Widen & Russell, 2003). In each of these lexical domains, when children are asked a question – e.g., "What color is this?" or "How many are there?" they respond with domain-appropriate words (e.g., *red, seven*) but often select the word incorrectly (e.g., responding *red* when asked about a purple object; for discussion see Shatz et al., 2010). Across these domains, children often produce words for months – or in some cases for several years – before they acquire their adult-like meanings.

In the case of color words, the most common explanation for this lag between production and adult-like comprehension is that children struggle to abstract color as the relevant dimension of linguistic meaning. In other words, although children quickly learn to produce and form a category of color words that are associated with one another, they struggle to identify color as the aspect of experience that this category of words encodes (e.g., Franklin, 2006; Kowalksi & Zimiles, 2006; Sandhofer & Smith, 1999). Critically, on this account, children's difficulty is specific to abstracting color, rather than with mapping individual color words to particular hues and identifying category boundaries. As evidence for this view, proponents note that preverbal infants possess perceptual color categories that are similar to those of English-speaking adults (Franklin, Pilling & Davies, 2005; Bornstein, Kessen & Weiskopf, 1976). For example, according to Shatz, Behrend, Gelman, and Ebeling (1996), "on perceptual tasks, infants treat the continuous dimension of hue categorically much as adults do. . . Thus, the apparent difficulty children have with color term acquisition cannot be primarily because the perceptual domain is continuous whereas the lexical domain is discontinuous" (p. 178). Accordingly, these accounts argue that once children identify color as the relevant dimension of meaning, they acquire color word meanings quickly, since they can easily map new color words onto pre-existing perceptual color categories: "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 Franklin, 2006).

While these accounts offer a parsimonious account both of children's difficulty with color words and the origin of color word meanings (i.e., as rooted in perceptual categories), they ultimately cannot explain how children converge on language-specific color word meanings. This is because children must be able to learn the color boundaries of any of the world's languages. And critically, languages vary both with respect to the number of categories they encode and the precise location of the color category boundaries (Kay, Berlin, Maffi, Merrifield & Cook, 2009). For example, Berinmo, a tribal language with five basic color categories spoken in Papa New Guinea, features the colors *nol* (green, blue and purple) and *wor* (green, yellow, orange and brown). Thus, Berinmo marks a color boundary that is absent in English (i.e. a boundary within the English *green* category), but also fails to mark other boundaries that are found in English (e.g. the boundary between *blue* and *purple*; see Roberson, Davidoff, Davies, & Shapiro, 2005).

This cross-linguistic variation in the number and location of color word boundaries suggests that children must use evidence from their language input to construct language-specific color word meanings. Recent studies suggest that this inductive problem, rather than problems abstracting color, may be the primary difficulty that children have when learning color words. In one recent study, Wagner, Dobkins and Barner (2013) replicated previous reports finding that 2- to 4-year-olds produce many errors when they use color words. However, when they analyzed the nature of these errors, they found that they were highly systematic in nature. For example, the children's errors were perceptually *proximal* to the target (e.g., children were more likely to label purple as *red* than *blue*). They also found that children's errors were typically *overextensions* of adult categories. For example, when children used *blue* to label green, they almost always also used it to label blue. These data suggest that rather than having trouble identifying hue as relevant to color word learning, children's main difficulty appears to be due to determining color word boundaries.

Wagner et al.'s (2013) study also suggests that, contrary to past reports, many children have meanings for color words as soon as they produce them. However, it remains unknown whether children acquire partial meanings *prior* to producing color words as is the case with object labels (Goldin-Meadow, Seligman & Gelman, 1976; Harris, Yeeles, Chasin & Oakley, 1995) or instead, after production as previous studies of color word learning have argued. Evidence of partial color word meanings prior to production would suggest that children map color words onto specific regions of color space very early in development, and that identifying the relevant dimension of meaning for color words may be no more difficult than for other domains of meaning. To investigate this, we tested 18- to 33-month-olds using an eye-tracking task, to determine the earliest moment at which they assign preliminary meanings to color words. Also, we collected parent report data regarding each child's production and comprehension of color words and conducted an in-lab assessment of color word production.

Method

Participants

Fifty-five 18- to 33-month-olds (24 girls; mean age = 1;11, SD=3.2 mo) participated. An additional 6 children were excluded due to a 50% chance of protanopia or deuteranopia color deficiency based on family history (n=1), failure to complete the task (n=3) and full knowledge of color terms demonstrated during the production task (n=2). 23 adults (6 women; mean age = 21;8, SD=1;6) also participated.

Procedures

Parent Report Parents were asked to complete a questionnaire that asked separately whether children understood and spontaneously produced each of the eleven English basic color words (*red*, *orange*, *yellow*, *green*, *blue*, *purple*, *pink*, *black*, *brown*, *gray,* and *white*) as well as the twelve nouns used in the Comprehension Task (see below).

In-lab Production Task 11 pictures of colored fish (one for each of the eleven basic English colors) were placed colored side down in front of the child, and the experimenter flipped over each card one at a time, and asked for each card, "What color is this?"

Eye-tracking Comprehension Task The purpose of this task was to assess whether children comprehended color words by presenting a spoken color word and testing (1) whether they would increase fixations to a target color and (2) whether they would also increase fixations to a distractor from a color category perceptually close to the target color. We expect that children with overextended color word meanings may increase fixations to perceptually close distractors in addition to the target color image.

Children viewed 24 scenes, each containing four pictures of the same kind of object, each in a different color. The images included socks, chairs, balloons, purses, boxes, cups, cars, kites, stars, boats, books, and bows, and were obtained from the UCSD International Picture Naming Project (Szekely et al., 2004). Prior to each trial, an attractor – centered and equidistant between all four objects – was presented to direct the child's gaze to the center of the screen. During each trial, a voice first directed the participant's attention to all of the objects (e.g., *Look at the socks*) and then to the object of the target color (e.g., *Look, the orange sock is my sister's*). Each scene was presented for six seconds and the target color word was spoken at the three-seconds. Each scene included two pairs of colors where the colors of each pair were perceptually adjacent to each other (close distractors) but distant from the members of the other pair (far distractors; e.g., red and orange vs. blue and green). On each of the 24 trials, one of the four colors (e.g., blue) served as the target color (e.g., *blue*), and the color that served as the target was counterbalanced between children.

We used Tobii Studio 3.1.6 in combination with a Tobii X120 eye tracker to track children's eye movements. Children were calibrated using Tobii Studio's standard 5-point calibration.

Results

Analysis of production errors

Of the 55 participants, only 18 produced color words during the in-lab production task. In order to determine if these 18 children were applying color words systematically or haphazardly, we replicated two of the analyses reported in Wagner, Dobkins and Barner (2013).

We first asked whether children's errors reflected overextensions of adult categories. For example, a child may know that *red* refers to red objects, yet have a broader meaning for *red* than adults, and therefore overextend it to orange and yellow objects. Given that a child used a label incorrectly on at least one of the eleven trials, we asked whether they also used that label correctly for its target color. Chance performance was defined as in Wagner et al. (2013). We calculated the base rates of how frequently a child produced each of the incorrect color words (e.g., if a child uses *red* to label 4 of the 11 colored fish) to calculate the probability that the word would be used correctly (e.g., using *red* to label the red fish, 4/11 or 36%). We then took the mean of these probabilities to calculate the overall probability of overextension. Using a binomial test, we found that the percentage of incorrectly used labels that fit the above definition of overextension – 73% – is greater than would be expected from chance (33%, $p<0.001$), and is almost identical to the rate reported by Wagner et al. (2013).

Next, given that a child used a color label incorrectly, we asked whether the hue they labeled was proximal to the hue denoted by the word they used (where proximity was defined in Munsell color space). For example, if a child labeled orange as *red,* this would be considered proximal, but if a child labeled yellow or blue as *red* this would be considered a non-proximal error. As in Wagner et al., to determine chance we calculated the probability of each label-stimulus error pair (the probability of using *red* to label 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 using the label *red*, then the probability of using *red* to label orange would be 0.2 x 0.8, or 0.16. To determine the overall chance probability of proximal errors, we summed across the probability of all label stimulus pairs that are classified as proximal. Using a binomial test, we found that the percentage of errors that were proximal (41% of 111 total errors) was greater than chance (30%; p = 0.006). This replicates Wagner et al's results and is consistent with the hypothesis that children have partial meanings for color words before they acquire full adult-like meanings.

Parent report

According to parent report, on average children's comprehension of color words exceeded production. Of the 11 basic color terms, parents reported that their children understood a mean of 4.1 words (SD = 4.5) and produced a mean of 2.6 words (SD = 3.9). Children, however, produced fewer color words on average in the lab (mean: 1.7; SD = 2.9). Of the 12 common nouns used in the eye-tracking task, on average parents reported that their children understood 7.8 (SD = 2.7) and produced 4.7 (SD = 3.9). Thus, parent report data suggest that for most children comprehension precedes production for color words as well as the 12 common nouns included in our study.

Eye-Tracking Analyses

For these analyses, children were divided into four groups based on parent report and the in-lab production task. This allowed us to verify color word comprehension in a group of children reported to comprehend but not produce any color words (Comprehension-Only; n = 11), which if confirmed suggests that comprehension sometimes precedes production. Also, it allowed us to test the small group of children who were reported to produce but not comprehend any color words (Production-Only, n=6), to ask whether these children actually lacked meanings, or had partial meanings like those documented in error analysis above, and by Wagner et al. (2013). The remaining two groups were children thought by parents to have no knowledge of color words and children who were reported to both produce and comprehend them (Comprehension–and-Production, n = 20; No-Knowledge, n = 18). In three instances where children's performance on the in-lab production task exceeded that indicated by parent report, children were classified according to performance on the in-lab task. Note, that even the most advanced group (Production-and-Comprehension Group) still had limited knowledge of color words, producing on average only 4.3 of 11 color words in lab (6.7 according to parent report) and demonstrated adult-like understanding of only 2.4 color words.

The color words that children understand and produce vary considerably between children. Thus, we performed an individual level analysis, and targeted color words that children were reported to produce only, comprehend only or both comprehend and produce. We relied on parent report and performance on the in-lab production task to determine which of the eye-tracking trials should be included in the analysis for each child. Trials were included for the analysis as follows: for each child in the Production-Only group, we included trials which tested color words that the child produced (either in lab or according to parent report); for each child in the Comprehension-Only group, we included trials that tested color words that the child comprehended (according to parent report); for each child in the Production-and-Comprehension group, we included trials that tested color words that the child produced and comprehended (either in lab or according to parent report) For the No-Knowledge and Adult groups, all trials were included.

Eye movements were successfully tracked 81% (SD = 15.4) of the time for children and 92% (SD = 4.4) of the time for adults. Total fixation durations from the eye-tracking task were binned into four time periods. The first time period (baseline) was from 250ms after the beginning of each trial to 250ms after the color word was spoken to allow time for participants to plan and execute eye-movements. The second time period was from 251ms after the color word was spoken to 1000ms, the third from 1001ms to 2000ms and the fourth from 2001ms to 3000ms. In order to compare the time spent fixating the two far distractors to the time spent fixating the close distractor and the target, we calculated the average time spent fixating the two far distractors. We then used this average far distractor fixation time to compute re-weighted proportions of the fixation time for the close distractor, the target and the mean of the far distractors during each of the four time periods. Under the null hypotheses of random looking behavior, the re-weighted proportions would be equal and if all fixations were directed to one of the images, equal to 0.33.

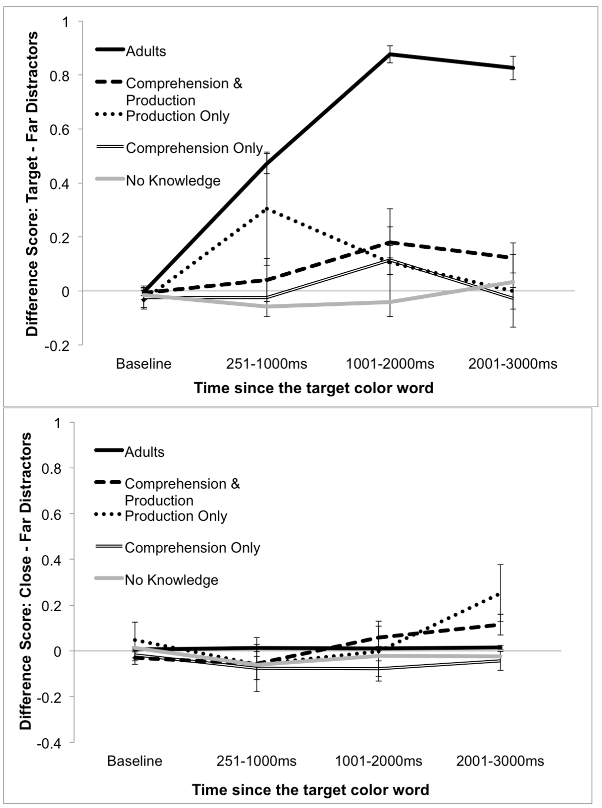

Figure 1: Fixation to targets (top) and close distractors (bottom) relative to far distractors

For each participant group, we performed a 4 (time: baseline, 251-1000ms, 1001-2000ms, 2001-3000ms) x 3 (fixated image: target, close distractor, far distractor) repeated measures ANOVA to determine whether participants' looking behavior (i.e. the proportion of time spent fixating each of the image types) changed after the target color word was spoken.

Interactions between time and fixated image were found for the Adult group ($F(6,242)=191.07$, $p<0.001$), the Comprehension-Only group ($F(6,110) = 2.53$, $p = 0.025$), the Comprehension-and-Production group ($F(6,209) = 2.40$, $p = 0.029$) as well as the Production-Only group ($F(6,55) = 2.32$, $p = 0.046$). No interactions or main effects were observed in the No-Knowledge group (all Fs < 1.5). These interactions indicate that the relative looking behavior between the images changed over time in response to the presentation of the spoken color word. We next explored these interactions by conducting planned comparisons to determine if the changes observed in the participants' looking behavior were consistent with comprehension of the spoken color word. Specifically, we calculated a difference score by subtracting the reweighted proportion of fixations to the far distractors from the reweighted proportion of fixations to the target (and in a second analysis, to the close distractor). We expected that difference scores after presentation of color words would be greater than during baseline if participants comprehended (or partially comprehended) the words in question. For all of these planned comparisons, we conducted one-tailed dependent-samples t-tests. Two-tailed tests were not employed because there is no hypothesis that would predict fixations to the target (or close distractor) to decrease after the color word was spoken.

Adults showed increased fixations to the target (relative to far distractors) when compared to baseline during all three post-color word time windows (all ts(22) > 12, all ps < 0.001; all Cohen's ds > 3.5), but did not show increased fixations to the close distractor during any time windows (all ts < 1).

Like the adults, the Comprehension-Only Group showed increased fixations towards the target during the time window 1001-2000ms after the target color word was spoken ($t(10) = 1.93$, $p = 0.041$, $d = 0.91$) but did not show increased fixations to the close distractor during any of the time windows (all ts < 1). Thus, these children, like adults, exclusively increased fixations to the target despite failing to produce any color words. The Production-and-Comprehension group showed increased fixations towards the target during both the 1001-2000ms ($t(19) = 2.71$, $p = 0.0069$, $d = 0.94$) and 2001-3000ms ($t(19) = 2.04$, $p = 0.028$, $d = 0.67$). Also, they exhibited increased fixations to the close distractor during the 2000-3000ms time window ($t(19) = 2.12$, $p = 0.024$, $d = 0.84$) and fixations to the close distractor approached significance during the 1001-2000ms time window ($t(19) = 1.46$, $p = 0.081$, $d = 0.48$), suggesting that the children in this group may have overextended meanings of the color words. Finally, although a significant interaction between time and fixated image was observed for the Production-Only group (see above), none of the planned comparisons reached statistical significance due to the very low number of participants that qualified for this group. However, as in the Production-and-Comprehension Group, this group exhibited increased fixations to the target (though beginning one time period earlier during the 251 to 1000ms time window), an effect which approached significance ($t(5) = 1.54$, $p = 0.092$, $d = 0.92$). Also like the Production-and-Comprehension group, the Production-Only group exhibited a trend of increased fixations to the close distractor during the later 2001-3000ms time window ($t(5) = 1.46$, $p = 0.10$, $d = 0.80$). Furthermore, although these effects did not reach statistical significance, the effect sizes were comparable to those in the Production-and-Comprehension Group.[1] See Figure 1.

Discussion

We investigated color word knowledge in a group of young English-speaking children, including a subset who had yet to produce any color words. Replicating previous reports (Pitchford & Mullen, 2003; Sandhofer & Smith, 1999; Soja, 1994), we found that children make many errors when labeling colors, but that these errors are non-random: children appear to learn preliminary, non-adult-like, meanings for color words very early in the acquisition process, often before they begin producing them in speech (Wagner, Dobkins, & Barner, 2013; Bartlett, 1978). These data provide evidence against the idea that the delay between color word production and the acquisition of adult-like meanings stems from a failure to abstract color as a domain of meaning (Franklin, 2006; Kowalksi & Zimiles, 2006; O'Hanlon & Roberson, 2006; Sandhofer & Smith, 1999). Instead, our data suggest that children identify color as relevant to color word meaning very early in acquisition, often before they even begin producing color words, and that adult meanings emerge late due to a gradual inductive learning process.

Several pieces of evidence support these conclusions. First, replicating Wagner, Dobkins, and Barner (2013), a color word production task found that when children made color labeling errors, they were highly systematic. For example, when children made errors, they were often overextensions: when children used a word like *red* to label orange, they very often also used the same word to correctly label its target hue (e.g., the color red). Also, children's errors were often to hues that were directly adjacent to the target color, again consistent with the hypothesis that they initially overextend their color words beyond the adult color boundaries. Like the data from Wagner et al., these findings suggest that the delay between color word production and acquisition of adult-like meanings is due primarily to a gradual inductive process of identifying adult-like category boundaries.

A second piece of evidence came from parental report. On average, parents reported that children comprehended more color words then they produced. Only 6 of our participants produced color words but were reported by parents as not comprehending them. In contrast, parents of 12 children reported that their children comprehended color words without producing them. This was not simply because we sampled from children who were too old, and thus had advanced color word knowledge: We also found 20 children who neither produced nor comprehended color words according to parent report. These data are clearly at odds with previous claims that children use color words randomly for months before mastering adult-like meanings (Pitchford & Mullen, 2003; Sandhofer & Smith, 1999; Soja, 1994). However, our data also suggest that parent report data should be interpreted with caution. Although we found that children frequently had meanings for color words before they produced them – consistent with what parents reported – it is very unlikely that these children had acquired full, adult-like, meanings at this stage. As noted above, children in the production-only and comprehension-only groups did not accurately use color words to label colors in our in-lab labeling task (often overextending to adjacent hues), but *did* systematically look to the appropriate target color for these same words in the eye-tracking task and many also fixated perceptually close distractor colors. In sum, our findings suggest that although parents are likely right that their children have acquired *some* meaning for their color words, their judgments should not be interpreted as evidence for full adult-like meanings.

Our eye-tracking data support the conclusion that partial meanings often precede color word production. Consistent with parent report, children whose parents indicated that they both produced and comprehended color words looked significantly longer to target hues when target words were presented. Likewise, we found that children who did not produce color words but whose parents said they comprehended them also showed evidence of comprehension in the eye-tracking task. Finally, the small group of children who produced color words but were reported by parents as not understanding them also tended to look more towards the target hues when target words were presented, though this result was only marginally significant due to the limited number of parents who classified their children as only producing color words – a fact which itself is consistent with the hypothesis that production only rarely precedes comprehension.

In sum, evidence from parental report, an in-lab production task, and an eye-tracking comprehension measure together suggest that, contrary to the conclusions of many previous reports, color words resemble other early-acquired words: in most children, meanings emerge before children produce color words in speech though it takes some time before children's meanings become adult-like. Also, our data raise questions about other cases in which researchers have argued that production precedes comprehension, such as number and time. Emerging evidence, consistent with our study, suggests that children may acquire early partial meanings for a variety of abstract words before they acquire full adult-like meanings, including object labels (Ameel, Malt & Storm, 2008), number words (Barner & Bachrach, 2010; Brooks, Audet, & Barner, 2012; Condry & Spelke, 2008; Sarnecka & Gelman, 2004), time words (Tillman & Barner, 2013) and emotion words (Widen & Russell, 2003). While children are able to fast map words to their referents, they may require

[1] Unfortunately, increasing the number of Production-Only children by even 10 participants would require running at least 100 additional children given their relative rarity. In the overwhelming majority of cases, parents who report that their children produce a word also believe that their children comprehends that word, too – an intuition which is strongly supported by our data.

considerable time to converge on full-fledged adult meanings (Carey & Bartlett, 1978).

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