Early Colour Word Learning in British Infants

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Abstract

Colour word learning has traditionally been viewed as a difficult task. Previous accounts have focussed on infants' ability to show an adult-like understanding of colour terms. Here we examine whether infants understand colour terms at a basic level, using two different methods: first, evidence from parental reports that British infants can comprehend colour terms early, second from experimental data using eye-tracking. These finding show that colour word learning is a process that begins much earlier than previously thought, and develops slowly as infants learn where the boundaries of each term are located. Due to their abstract properties, colour words present a unique opportunity to assess category learning in infants, as well as the mechanisms that control word learning in general.

Keywords: Word learning; language acquisition; colour

Introduction

It has long been documented that colour words are difficult for children to learn (Kowalski & Zimiles, 2006; O'Hanlon & Roberson, 2006; Soja, 1994; Sandhofer & Smith, 1999). They are learned late (Heider, 1971; Franklin, 2006) and even when infants do learn to say colour words, they are riddled with errors (Pitchford & Mullen, 2003). But just how difficult are colour words to learn? Studies to date have had difficulty establishing a time-line for when colour words are learned, leading to various theories about why colour words are more difficult to learn, such as the inability to put categorical terms on a continuous spectrum of colour (Andrick & Tager-Flusberg, 1986), or their ability to abstract colour as a relevant domain of linguistic meaning (Kowalski & Zimiles, 2006; O'Hanlon & Roberson, 2006; Sandhofer & Smith, 1999). In the present study, it is demonstrated that in fact infants have some degree of colour word knowledge much earlier than previously shown, and that they are able to recognise typical colours when named. This finding suggests that the difficulties that infants have with understanding colour terms correctly may be due more to an inability to recognise the category boundary, rather than a complete lack of understanding of the basic terms.

Research into colour word learning in infants has shown that the age of acquisition has dropped dramatically over time (Franklin, 2006; Shatz, Behrend, Gelman, & Ebeling, 1996). While early studies had colour words learned as late as 7;0 (Heider, 1971), more recent studies have concluded that they are learned successfully around three years of age (Pitchford & Mullen, 2002) or earlier (Mervis, Bertrand, & Pani, 1995). While there may be an actual drop in age of colour term acquisition due to a rise in coloured plastic goods or other such environmental influences, it is also possible that an infant's comprehension of colour terms has been underestimated.

It is clear that infants have difficulty grasping an adult-like understanding of the meaning of a colour word, but this does not necessarily imply that they have failed to grasp the meaning of the term. Research into the slow inductive process of colour word learning has shown that it is possible for toddlers from around 30 months to 40 months to comprehend basic colour terms while still making errors (Wagner, Dobkins, & Barner, 2013; Wagner, Jergens, & Barner, 2014). This suggests that colour words are similar to most other classes of word, in that children first acquire a partial meaning for the colour terms, and start producing the terms, before then later slowly acquiring a fuller, adult-like meaning. In this case, proper, adult-like comprehension follows only after production, further raising questions about what it is to comprehend in such an abstract category of words. While this account may provide some insight into how colour words are learned, the participants are old enough that they may have already comprehended colour words to a degree. This raises two questions: when are colour words learned, and what is meant in this instance by "learned?"

The present study employs two different means to answer these questions: a parental word-learning survey, and an eye tracking paradigm. While word-learning surveys are particularly useful for measuring production (Fenson et al., 1994), measuring comprehension in this way has been debated (Tomasello & Mervis, 1994; Houston-Price, Mather, & Sakkalou, 2007), despite test showing that if anything, they could even be an underestimate of the child's ability (Styles & Plunkett, 2009). In the case of colour terms, which are a much more abstract category of word than concrete nouns, this doubt might be magnified. The aim of the present study is to investigate when colour word learning is occurring, and in doing so, establish where the process of colour term acquisition might begin. The results of the parental survey are then to be compared to eye-tracking data, in order to confirm the measures of early comprehension, and compare them to measures of production from the survey.

Parental Reports

Method

Participants 2692 8-30 month-old participants' details were filled out by parents either on paper or online before visiting the lab. Participants were always visiting either Ply-

mouth Babylab or Oxford BabyLab as part of an experiment. Participants for whom there was incomplete descriptive data of age and gender were not included in the analysis. As a number of participants visited more than once, the total was $N = 3413$ samples (1653 female). Figure 1 shows participant information by age and gender.

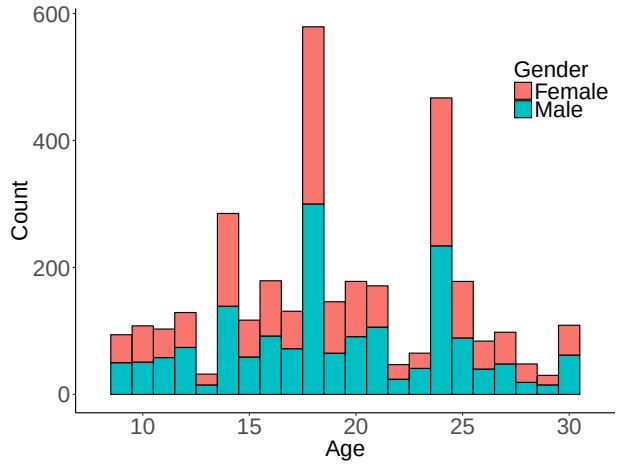

Figure 1: Histogram of participant samples in each age group by gender.

Procedure Parents were asked to fill out the Oxford Communicative Development Inventory (Oxford CDI, Hamilton, Plunkett, & Schafer, 2000). The Oxford CDI is a British adaptation of MacArthur-Bates CDIs (Fenson et al., 1994), which contains 416 terms. The Oxford CDI differs from the MacArthur-Bates CDIs in that it measures comprehension and production for the full age range of participants. Parents or caregivers were asked to check if their child does not comprehend, comprehends, or comprehends and produces each word. Thus an infant was marked as producing a term only if they were thought to "comprehend and produce" the term, while selecting either "comprehends" or "comprehends and produces" saw them marked as comprehending.

The Oxford CDI contains four colour terms: red, blue, green, and yellow. Only data from these four terms are included in the analysis.

Data was analysed in two separate binomial regressions, one for the comprehension data, and another for the production data, where the outcome was a binary response for the colour term in question (yes or no for either comprehension or production). Both models had fixed effects of which colour term was being recorded, as well as age of participant and the gender of the participant. Gender and colour were both dummy coded in each model.

Results

A summary of the model coefficients of each model can be seen in Table 1 and Table 2. Effects were added into the model individually and compared by measuring reduction in deviance compared to degrees of freedom, distributed as a χ^2. Colour improved model fit in comprehension $dev(3) = 15.95, p = 0.0012$ and in production $dev(3) = 21.58, p < 0.0001$, as did gender, both in comprehension $dev(1) = 43.2, p < 0.0001$, and in production $dev(1) = 59.89, p < 0.0001$.

Table 1: Standardized values of comprehension model effects. Colours are as compared to Blue.

	Estimate	Std. Error	z value	Pr($>\|z\|$)
(Intercept)	-8.42	0.20	-41.51	0.000
Age	0.39	0.01	41.56	0.000
Green	-0.25	0.07	-3.75	0.000
Red	-0.04	0.07	-0.68	0.499
Yellow	-0.11	0.07	-1.67	0.095
Male	0.66	0.27	2.42	0.016
Age:Male	-0.05	0.01	-3.61	0.000

Table 2: Standardized values of production model effects. Colours are as compared to Blue.

	Estimate	Std. Error	z value	Pr($>\|z\|$)
(Intercept)	-9.24	0.23	-39.59	0.000
Age	0.40	0.01	39.07	0.000
Green	-0.34	0.07	-4.65	0.000
Red	-0.17	0.07	-2.34	0.019
Yellow	-0.19	0.07	-2.55	0.011
Male	-0.60	0.34	-1.77	0.077
Age:Male	0.01	0.01	0.60	0.549

The results from Table 1 show that there was a large difference between green and the other colours, both in speaking and comprehension, while yellow and red were both slightly behind blue in both areas. Male infants learned the colour words significantly slower than female infants, suggesting that the general advantage that has been seen in word learning for female infants also applies to colour word learning, although it is possible that there is an effect of the higher rates of colour vision problems in males.

The results show that the four basic colour terms measured in this report are learned at a similar age, as reported by parents. All four colour terms are learned mostly within a month of each other, however the data suggests that green may be learned significantly after the other three, with blue generally the first colour term learned. Green may in many cases be learned after the other three colours, but only by a short amount of time. Around three months on average separates learning the colour word and producing it – a gap that suggests that there is a very short time in between basic learning and production.

The colour word learning shown here suggests both comprehension and production at a much earlier age than has been previously shown. By 24 months, around 75% of infants have learned the four colour terms, and around 50% were already producing the terms. This result is in stark contrast to previous studies that suggested that at the earliest, some children

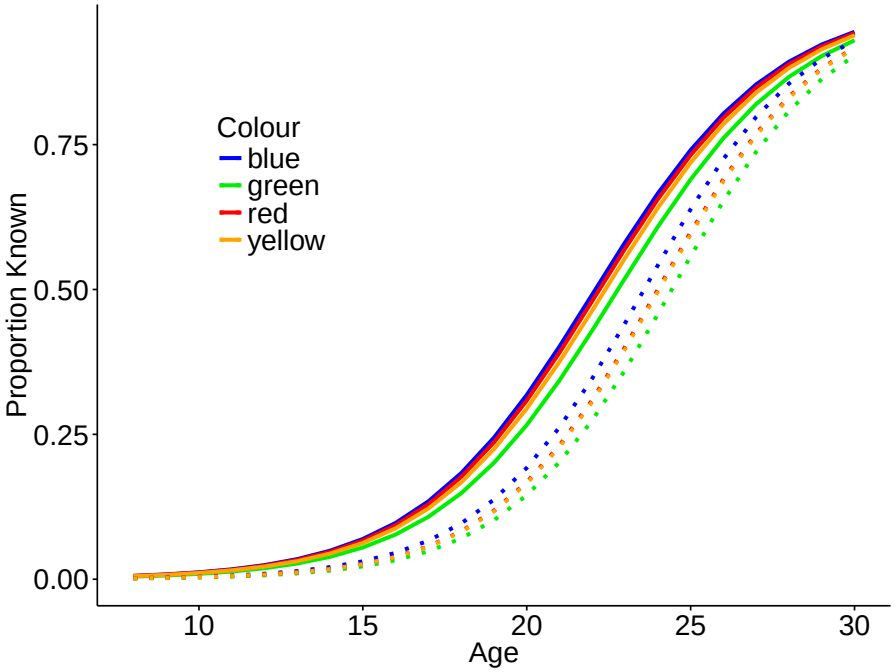

Figure 2: CDI estimates of proportion of British infants who understand colour terms at each age.

comprehended colour terms around 30 months (Sandhofer & Smith, 1999; Pitchford & Mullen, 2002). Here, parents report that roughly all of the children have learned the terms by this age.

The above results make startling claims about when colour word learning occurs. However, parental surveys have long been called into question, particularly in the case of measuring comprehension (Tomasello & Mervis, 1994; Houston-Price et al., 2007). Additionally, the parental reports only contain data from the four basic colour terms, which may not capture the full picture of colour word learning. In order to test the veracity of the claims made by the parental questionnaire, and to expand the scope of colours used from four to six, a second study was designed, using eye tracking data.

Eye-tracking Study

Method

Participants $N = 146$ participants were recruited for this study, either online or from the local maternity ward. A further $N = 23$ participants were excluded for fussiness or for failing to complete the experiment, while $N = 5$ participants were excluded from the experiment for failing to complete at least one trial with each colour as both target and distractor. Full participant information can be seen in Table 3. Participants were in 5 age groups, with the oldest age group as a control group who have likely learned colour words (and thus were not selected to be a specific age), and the youngest age group a control group who likely have not yet learned colour terms. All participants were monolingual and were learning English as their first language.

Table 3: Descriptive statistics for participants in Exp 2

Group	*N*	Mean Age (months)	SD (months)
12	30	11.84	0.70
16	29	15.96	0.70
19	31	19.69	0.73
24	28	24.30	0.36
48	28	53.46	18.78

Procedure Participants were seated on the lap of the caregiver, around 75cm from the eye tracker and presentation screen. Participants first completed a nine-point calibration sequence, and following that the trials began. In each trial, participants saw an attractive attention-getter for 2 seconds, and then were presented with two objects. The objects were identical in every way, except for colour. The objects on the screen were coloured one of red, blue, green, yellow, black, or white. All colours were considered to be typical examples of that colour category by three independent observers, and not too dark or light. 2 seconds after the test objects appeared on the screen, participants heard a colour term corresponding to one of the objects, in the format of "look, red," "look at the red one" or "look at the red chair." The objects that made up the stimuli were all regular items that would be seen around the household by the infants, such as furniture or items of clothing. The trial would continue for another 5 seconds after colour label onset.

Each participant saw 18 trials, 3 of each colour, and all trials were left right randomised. Presentation was counter-

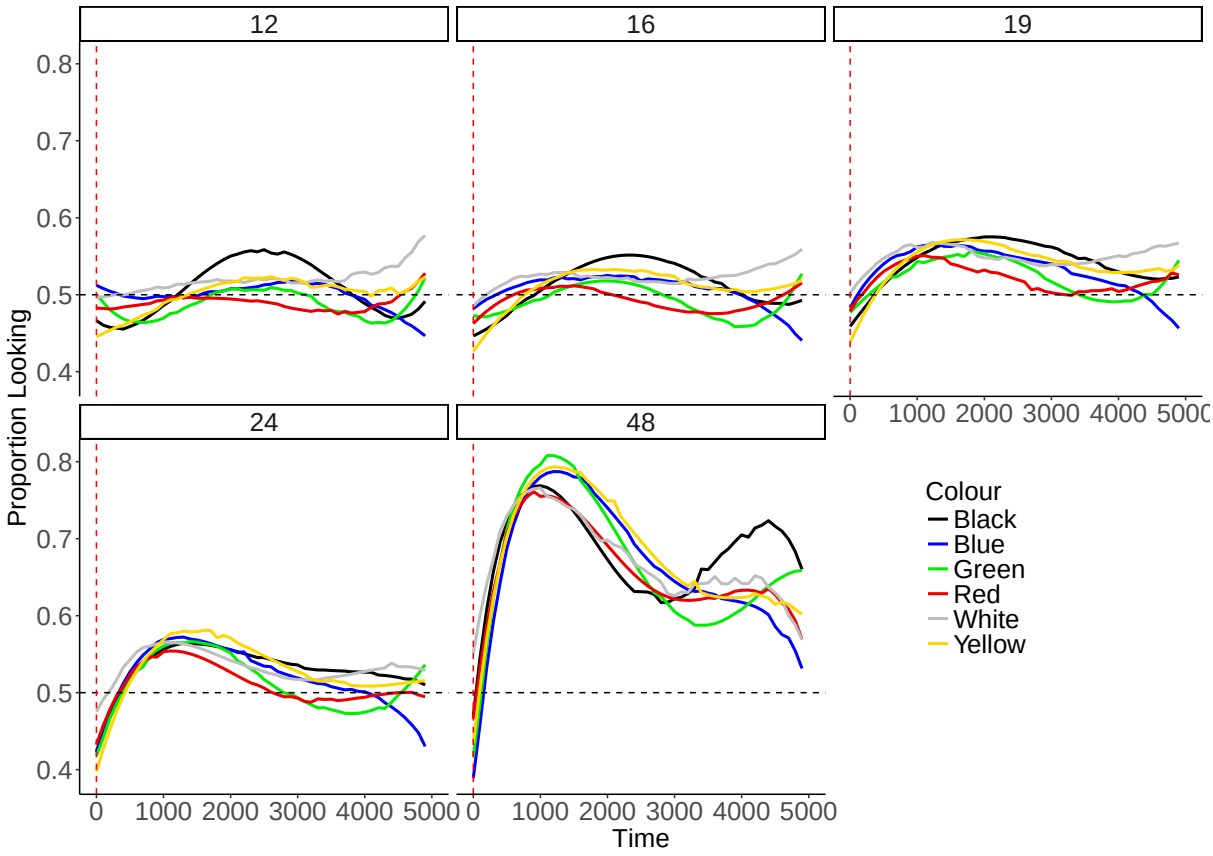

Figure 4: Fitted growth curve of looking to each colour after target word onset, separated by age group. Dotted red line indicated target word onset, dotted black line indicates chance looking.

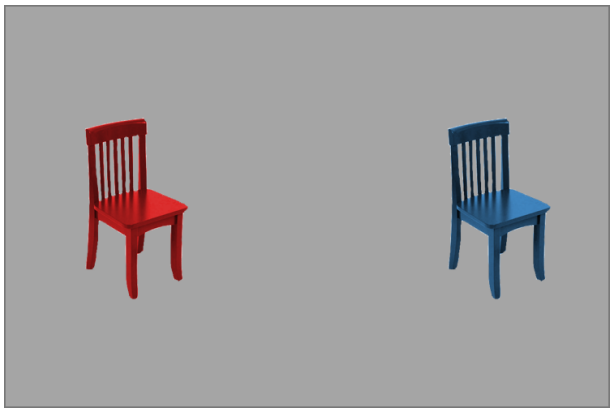

Figure 3: A typical trial as seen by participants.

balanced so that any pairing that participants saw with one of the stimuli (e.g. the red chair) as a target, they would then see again with that as a distractor, and the stimulus that had been the distractor (e.g. the white chair) then became the target. All stimuli were presented on a neutral grey background, and trials were presented in a randomised order. Infant fixations were recorded using a Tobii eye tracker sampling at 120Hz.

The data was modelled with a hierarchical binomial growth curve, using the function glmmPQL, with quartic orthogonal polynomials (Mirman, 2014), with a random effect of subject. Age and time were treated as continuous numeric variables, and target colour was dummy coded. Rather than modelling the raw data, which allows infant colour preferences to override the effect of the label, trials were aggregated for each participant, such that the proportion of looks to target was defined by using the target and distractor for the same colour i:

$$Proportion = \frac{TargetLooks(i)}{TargetLooks(i) + DistractorLooks(i)}$$

Results

The fitted model can be seen in Figure 4. The results indicate that there is very little colour word understanding at either 12 or 16 months, but by 19 months most of the participants understand all six colour words being examined. The effect of the label becomes more defined in the 24 month age group, until almost all participants react to the colour label by looking to the target in the 48 month group. The key fixation period is during the first two seconds after label onset. After that initial effect of the target label, it is likely that the infants return to random looking or looking by preference.

The results of this experiment also show that there is very little difference in the word learning of individual colour terms. Over the three month period between 16 months and 19 months, infants progress from knowing little of any of the colour terms to displaying some abilities in all of them. This shows that any differences in colour word learning must be of a smaller difference than three months.

The model output showed a significant effect of all four polynomials ($p < 0.0001$), of age ($p < 0.0001$) and of the interaction between age and each of the polynomials ($p < 0.0001$). The differences between colour terms had no significant effects on the model output (all $p > 0.05$). This suggests that general patterns of looking at the target vary over the course of the trial by age, but do not really vary by colour.

Finally, the proportion of looks to the target was collapsed so that for each colour and each participant any participant with a proportion of looks to target over 0.55 (above chance) in the first two seconds after target word onset were coded as "looking to target," while any participant looking at a proportion lower than 0.55 were coded as "not looking." These answers were then compared with the responses given by parents in the Oxford CDI for those participants by way of a Chi-squared test with Yates' continuity correction. $N = 6$ participants were excluded from this analysis as they did not fill out the Oxford CDI. Results showed a significant relationship between CDI answers and infants performance in the eye-tracking task, $\chi^2(1, N = 560) = 22.974$, $p < 0.0001$.

General Discussion

Two experiments were presented in order to measure colour word learning, the first using parental reports of whether their children were understanding and producing the terms, the second an experimental study using eye-tracking to measure whether infants looked to the coloured object upon hearing the colour label. Both methods have shown that there is early comprehension of colour terms, before 24 months in many participants according to the CDI results. The purpose of the second study was to verify the early comprehension that was evidenced in the parental reports. In the parental reports, the majority of participants were thought to have comprehended all four colour terms in the Oxford CDI by around 24 months. At 19 months, however, only 25% of participants were reported to have understood the colour terms. It is clear from the eye-tracking data that there is some understanding of the colour terms already by 19 months. Not only does the experimental evidence confirm that colour words are learned early, but it suggests that parents may in fact be underestimating how much their children know with respect to colour terms.

The results of each study showed that although there maybe patterns in the order of acquisition of colour terms in English, the differences between those colour terms are not great – in the parental reports green was seen to be significantly behind the other three colour terms, but only by a difference of around a month, while in the eye-tracking study, none of the colours were learned by the majority of participants at 16 months, while at 19 months all were learned. This suggests that there is a great deal of consistency as to when colour words are learned, and follow the assertion of Mervis et al. (1995) that following the learning of the first colour term, others quickly follow.

The results of the present study show that colour word learning occurs as young as 18 months, significantly earlier than has been shown by previous studies (Kowalski & Zimiles, 2006; O'Hanlon & Roberson, 2006; Pitchford & Mullen, 2002; Sandhofer & Smith, 1999; Soja, 1994). However, both elements of the present study only addressed typical examples of the colours in question, not a full adult-like understanding of colour terms. Previous studies focussed on atypical examples of the colour categories in order to examine colour word learning, but evidence presented here suggests that it is highly likely that this may have led to an underestimation, as the participants may have understood typical examples, but been unable to extend the colour categories in the same way an adult would (Wagner et al., 2013).

In the present study evidence is given for an early comprehension around 19 months of age, in contrast to this, Wagner et al. (2013, 2014) have shown that errors are still consistently made by participants around three years of age when presented with atypical examples of the colour category. This suggests that colour words are learned slowly over a long period of time, where an early comprehension precedes production, and that comprehension develops slowly until they have achieved an adult-like understanding (Wagner et al., 2014).

In this sense, colour words behave the same as other classes of word, including concrete nouns (Andersen, 1975), where children begin with typical examples of the word, but take time to learn the words closer to the boundary (Wagner et al., 2014; Yurovsky, Wagner, Barner, & Frank, 2015). Often the examples closer to the category boundary could be learned after production, while the typical examples will be learned before production. Very similar examples have been seen in the case of time words (Tillman & Barner, 2015), where children understand the order of time words, but not the exact meaning until much later.

The present study also compared the results of a parental report with those of an experimental eye-tracking study. The eye-tracking data successfully corroborates the results of the parental reports, with results suggesting a close relationship between both measures. Measuring comprehension through the use of questionnaires has long been questioned (Houston-Price et al., 2007; Tomasello & Mervis, 1994), despite evidence that it is a successful measure of comprehension at least in the case of object labels (Dale, 1991; Styles & Plunkett, 2009). The data evidenced here suggests that parents estimate colour word comprehension conservatively, possibly due to comprehension of a colour term being more abstract and thus harder to observe than a more concrete term. Even in the abstract case of colour terms, parental reports provide a useful estimate of comprehension, but parents are sensitive to small improvements that children make in their vocabularies

at a young age, and as such this captures comprehension at an early stage of the process. While parental reports are found here to be largely consistent with CDI reports of their understanding of these individual terms, little is known about how the rest of the colour vocabulary will develop after they learn their first few terms.

Colour words in many respects behave like other classes of words; they are learned early, but it takes infants some time to establish where the boundaries are located, and find an adult-like definition. We have provided strong evidence that colour word comprehension occurs much earlier than thought, preceding production and slowly developing for a number of years. It is worth noting all participants in this study were British monolingual infants and toddlers, learning English. The order and timing of early comprehension of colour words at this stage is only known for British English; it remains to be seen whether the same trends apply to colour word learning globally.

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