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Is the acquisition of basic-colour terms in young children constrained?

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Abstract. We investigated whether the learning of colour terms in childhood is constrained by a developmental order of acquisition as predicted by Berlin and Kay [1969 *Basic Color Terms* (Berkeley, CA: University of California Press)]. Forty-three children, aged between 2 and 5 years and grouped according to language ability, were given two tasks testing colour conceptualisation. Colour comprehension was assessed in a spoken-word-to-colour-matching task in which a target colour was presented in conjunction with two distractor colours. Colour naming was measured in an explicit naming task in which colours were presented individually for oral naming. Results showed that children's knowledge of basic-colour terms varied across tasks and language age, providing little support for a systematic developmental order. In addition, we found only limited support for an advantage for the conceptualisation of primary (red, green, blue, yellow, black, white) compared to non-primary colour terms across tasks and language age. Instead, our data suggest that children acquire reliable knowledge of nine basic colours within a 3-month period (35.6 to 39.5 months) after which there is a considerable lag of up to 9 months before accurate knowledge of the final two colours (brown and grey) is acquired. We propose that children acquire colour term knowledge in two distinct time frames that reflect the establishment of, first, the exterior (yellow, blue, black, green, white, pink, orange, red, and purple) and, second, the interior structure (brown and grey) of conceptual colour space. These results fail to provide significant support for the order predicted by Berlin and Kay, and suggest, instead, that the development of colour term knowledge is largely unconstrained.

1 Is the acquisition of basic-colour terms in young children constrained?

For more than a hundred years there has been substantial interest in the developmental difficulties young children experience when learning colour terms (Baldwin 1893; Darwin 1877, cited in Bornstein 1985; Nagel 1906). Initially, children may name many different colours with only one colour term and, even when they have acquired several colour terms, their naming of colour sensations is often inappropriate (eg Cruse 1977; Modreski and Goss 1969). Reliable colour naming has previously been reported to appear surprisingly late, at around 4 – 7 years (eg Bornstein 1985; Heider 1971; Johnson 1977; Mervis et al 1975), and may only be learned through a prolonged period of explicit instruction (Rice 1980). In contrast, the process by which young children learn the names for everyday objects appears effortless and often occurs within a single episode of hearing the word spoken in context (eg Carey 1978). The marked disparity between children's naming of everyday objects and colours suggests that the systematic process of fast mapping between novel labels and their referents that characterises early object word learning (eg Markman 1989; Nelson 1991) does not apply to the learning of colour words.[1]

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[1] Although colour terms may appear late compared to the names of many everyday objects, colour terms differ from object labels in that colour terms describe a particular object feature, whereas object labels define particular objects. In a previous study we showed that colour terms do not appear to be delayed when compared to other object attributes such as size (big and small) and speed (fast and slow) (Pitchford and Mullen 2001). We suggested that the developmental delay in colour term acquisition may form part of a more general delay in the acquisition of abstract object attributes.

The apparent difficulty children exhibit in acquiring colour terms does not arise from a deficit in colour perception, as substantial psychophysical evidence suggests that the ability to perceive and discriminate colour is established in early infancy (eg Allen et al 1993; Maurer and Adams 1987; Morrone et al 1993; Teller 1998; Teller and Bornstein 1987). Colour term acquisition may, however, be constrained cognitively by a systematic developmental order of acquisition. Berlin and Kay (1969) proposed the existence of, at most, eleven basic-colour terms, which, they predicted, would appear in a specific temporal order both (i) across different languages (an evolutionary hierarchy) and (ii) by children within a particular language (a developmental order). The eleven basic-colour categories identified by Berlin and Kay (1969) were predicted to appear in a specific 7-stage order of acquisition: stage 1 (black and white); stage 2 (red); stages 3 and 4 (green and yellow in either order); stage 5 (blue); stage 6 (brown); stage 7 (purple, pink, orange, grey). Berlin and Kay (1969) speculated that the developmental and evolutionary order of colour term acquisition would correspond as both reflected the underlying physiological structure of perceptual and conceptual colour space.

Substantial empirical evidence from a diverse range of disciplines supports the existence of up to eleven universal perceptual colour categories on which conceptual colour categories are based (see Hardin and Maffi 1997 for a comprehensive review). Six of these eleven categories are considered to be perceptually unitary or unique; there are four unitary hues (red, green, blue, and yellow) which are unique in their appearance and cannot be described in terms of any other colour combination, and there are two achromatic colours (black and white). It is believed that these six terms are perceptual 'building blocks' that can be used to describe all colours, either by applying them singly or in their various combinations. There is good evidence that these six unitary percepts are mediated at a cortical level by colour opponent processes, although little is known about the exact physiological mechanisms involved (Billock 1997; De Valois and De Valois 1993; De Valois et al 1997; Hurvich 1981; Hurvich and Jameson 1957; Ratliff 1976) or whether the neural representations of unitary and non-unitary hues differ. To be consistent with previous literature, we will refer to these six terms as the 'primary' colour terms.

Several variations of Berlin and Kay's (1969) order of colour term acquisition have been proposed (Kay 1975; Kay et al 1991; Kay and McDaniel 1978), but in general the six primary colour terms have been reported to appear first (Boynton and Olson 1990; Corbett and Davies 1992; Kay and McDaniel 1978; Miller and Johnson-Laird 1976). It has been predicted that children would initially anchor the different colour term categories to primary colour sensations (Millar and Johnson-Laird 1976) and consequently primary colour terms would appear at an earlier stage of acquisition than terms referring to the non-primary colours (Bornstein 1985; Millar and Johnson-Laird 1976).

Support for the development of the six primary colour terms before the five non-primary terms is mixed. Cross-cultural studies of languages other than English have shown that children will select and name primary colours more accurately than non-primary colours (eg Davies and Corbett 1998; Davies et al 1994; Dougherty 1978; Istomina 1963). In addition, some cross-sectional (Johnson 1977) and longitudinal (Cruse 1977) studies of English-speaking children have reported better naming of primary colours than non-primary colours in preschool children. Heider (1971) also found an advantage for the naming of primary colours; however, she found no evidence for this advantage from children's performance on other, non-production, tasks of colour term knowledge. Likewise, Andrick and Tager-Flusberg (1986) reported children's ability to produce colour terms correlated significantly with the earlier appearance of primary compared to non-primary colour terms, but their ability to comprehend colour terms did not. Furthermore, Bartlett (1978), from her study of preschoolers' comprehension and naming of the eleven basic colours, found no evidence to support Berlin and Kay's (1969) prediction. More recently, Shatz et al (1996) found no evidence from 2-year-olds on both tasks of colour comprehension and colour naming to support the notion that primary colour terms are learned prior to non-primary colour terms.

The contradictory evidence concerning the influence of the developmental order of colour term acquisition raises the possibility that other environmental or cultural factors may affect the early conceptual development of colour, such as maternal input on colour word learning (Andrick and Tager-Flusberg 1986). Furthermore, Western culture has been shown to influence Japanese children's usage of non-primary colour terms, although it has little effect on their naming of primary colours (Zollinger 1988). Environmental factors, such as these, should have little influence on the development of colour term knowledge if the order of colour term acquisition is governed by physiological mechanisms.

Comparisons across previous developmental studies are problematic, however, because studies testing the acquisition of colour term knowledge have not been sufficiently comprehensive. If the development of colour term acquisition is systematic, the order in which children acquire knowledge of the eleven basic-colour terms should be similar across children at different points of language development and also between different tasks of colour conceptualisation. However, most studies to date have tested knowledge of less than the full complement of eleven basic-colour terms (eg Andrick and Tager-Flusberg 1986; Davidoff and Mitchell 1993; Heider 1971; Johnson 1977; Shatz et al 1996). In addition, some studies have used only one task to assess colour term knowledge and the nature of the task used varies across studies (eg Cruse 1977; Heider 1971; Johnson 1977). Furthermore, other studies have tested colour term knowledge in only one age group of children (eg Heider 1971; Shatz et al 1996).

A further methodological problem evident in the literature is the measure of performance used, which is typically mean number (or percentage) correct (eg Andrick and Tager-Flusberg 1986; Bartlett 1978; Heider 1971). Such a measure is potentially inappropriate for developmental data because it does not account for a child's bias in responding when the correct answer is not known. For example, at an early stage in colour term acquisition, children typically pass through a stage when they use one colour term to name many different colours (eg Cruse 1977; Modreski and Goss 1969). Hence, a calculation of the mean number (or percentage) correct would thus give a misleadingly high measure of the child's ability to accurately apply this colour term, as it only calculates the proportion of times the term was accurately applied ('hits'), and ignores the inappropriate applications of the term (false alarms). To avoid this problem, we use d' as a dependent variable, because it measures discrimination independently of the response bias. In addition, d' on one task is directly comparable to d' on another task, enabling comparisons across tasks to be made.

In this study we address three questions about the developmental order of colour term acquisition to see if colour term acquisition is constrained:

(i) *Is there a systematic order to the development of colour term knowledge?* By 'knowledge' we mean children's ability to comprehend and name basic-colour terms (as measured by their performance on our tasks). To be considered systematic, children's pattern of acquisition of the eleven basic-colour terms should not be task-dependent, but should be similar across the tasks of comprehension and naming, and also should be consistent across children at different stages of language acquisition.

(ii) *Do the six primary colours develop before the others?* If children's acquisition of colour terms mirrors the evolutionary order by which colour terms are added to languages (Berlin and Kay 1969), primary colour terms referring to the unitary hues may be expected to appear first. Thus, an advantage for primary, compared to non-primary, colours should be shown by children of different language abilities and across different conceptual tasks.

(iii) *At what age do children show reliable knowledge of the eleven basic-colour terms?* We examine the developmental time frame in which children learn colour terms reliably. We consider children to have reliable colour term knowledge when their performance (as measured in terms of d') is significantly above chance (ie the point at which $p < 0.05$). Variations in the age at which children's knowledge of different colour terms becomes accurate may shed light onto the underlying mechanisms that govern their temporal appearance.

We measured the development of colour term knowledge using d' as the dependent variable across four groups of preschool children aged between 2 and 5 years in relation to their general language skills. Language age (LA) was assessed by means of a standardised measure of language functioning (including measures of both receptive and expressive language skills). Children were given two tasks to assess colour term knowledge. The same stimuli, which were focal examples of each of the eleven basic colour categories, were used in both tasks. In the first, colour comprehension was assessed with a spoken-word-to-colour-matching task and without the need for a verbal response. Children were required to match a spoken colour word to one of three different colour samples, one of which was the target colour and the other two acted as distractor colours. In the second task colour naming was assessed with children being required to produce basic-colour terms in response to individually presented colour stimuli.

2 Methods

2.1 *Participants*

Children were recruited from three different daycare settings in Montréal and represented the range of race and socioeconomic backgrounds that is typically found within a multicultural society. Parental consent was obtained for each of the forty-three children (twenty-three girls and twenty boys) that participated in the study. There was no family history of colour deficiencies (as reported by parents) for any of the children that participated in the study. All of the children were normally developing speakers of English (as judged by their parents) with normal or corrected-to-normal vision and hearing. Children were divided into four groups according to their language age (see below).

2.2 *Language assessment*

Each child's language development was assessed with the Preschool Language Scale-3 (Zimmerman et al 1992), a standardised psycholinguistic scale that has two subscales. The first subscale to be administered, auditory communication, measured receptive language abilities and required the child to point to specific pictures in response to questions asked by the experimenter. The second subscale given, expressive communication, assessed expressive language skills and required the child to produce spoken answers to questions asked by the experimenter. For each child a language-age-equivalent score was determined from her/his overall language score, which was calculated by summing the raw scores obtained from each of the subscales. The lowest possible age-equivalent score was 0 years 0 months and the highest was 7 years 0 months. The mean (M), standard deviation (SD), and range for each of the four language-age groups was: 2 years ($n = 10$), $M = 33.1$ months, SD $= 2.4$ months, range 28–35 months; 3 years ($n = 13$), $M = 43.2$ months, SD $= 2.7$ months, range 40–47 months; 4 years ($n = 10$), $M = 52.8$ months, SD $= 4.0$ months, range 48–58 months; and 5 years ($n = 10$), $M = 68.8$ months, SD $= 9.3$ months, range 60–84 months.

We used language age rather than chronological age to compare children because comparisons of comprehension and naming tasks based on language age have much less variance than comparisons based on chronological age (Pitchford and Mullen 2001), probably because the tasks used to assess colour conceptualisation are closely related to general language ability (Johnson 1977). In addition, comparisons based on language age control for the sex differences that have been reported in children's colour naming (eg Anyan and Quillian 1971; Bernasek and Haude 1993; Johnson 1977), as the advantage for colour naming that girls exhibit over boys is likely to result from a more general superiority in language skills commonly exhibited by girls (eg Maccoby 1966; McGlone 1980).

2.3 *Apparatus and stimuli*

Stimuli were computer-generated 8-bit images, generated with custom software developed in our laboratory, and were presented under control of an Apple Macintosh PowerBook G3 computer connected to a Dell CRT colour monitor (refresh rate of 67 Hz and resolution of 640×480 pixels). Stimuli are shown in figure 1. The background of the screen was set to a light grey (see appendix). Stimuli were the eleven basic colours identified by Berlin and Kay (1969) (red, pink, orange, brown, yellow, green, blue, purple, black, white, and grey). Clear examples of each of these colours were chosen from a range of colour chips provided in the *Munsell Book of Color*[(2)] that corresponded closely to the chips identified by Heider (1972) as the most 'focal' examples of each of the basic-colour categories. The analogous computer-generated colour stimuli were adjusted until each matched the Munsell chip exemplars, as judged perceptually by the two authors. The corresponding Munsell chip coordinates of each of the eleven colour stimuli and the background are listed in the appendix along with their CIE coordinates.

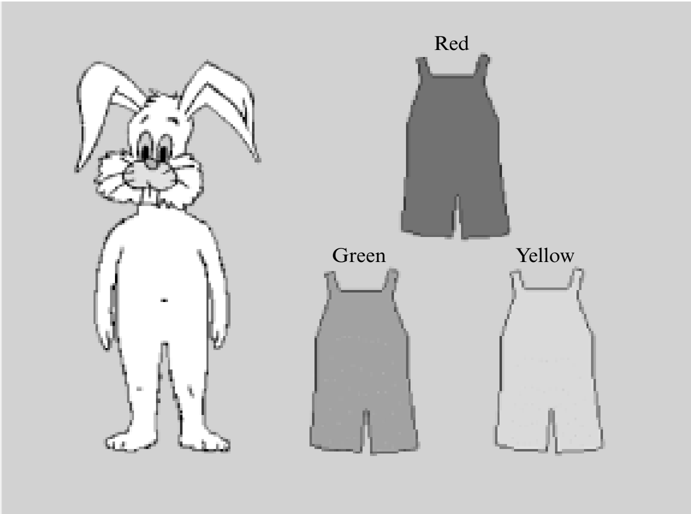
Stimuli were a series of five cartoon animals to be dressed in each of eleven items of clothing (underwear, undershirt, hat, coat, overalls, T-shirt, shorts, pants, dress, socks, and shoes) as shown in figure 1. Each animal was 469 pixels high and 158 pixels wide (17.5 cm $\times$ 5.9 cm), subtending 32.5 deg $\times$ 11.2 deg at a typical sitting distance of 30 cm. The five cartoon characters were neutrally coloured and were easy to discriminate from the eleven basic-colour stimuli as well as the grey background. Each of the eleven garments was coloured with each of the eleven basic colours.

2.4 *Procedure*

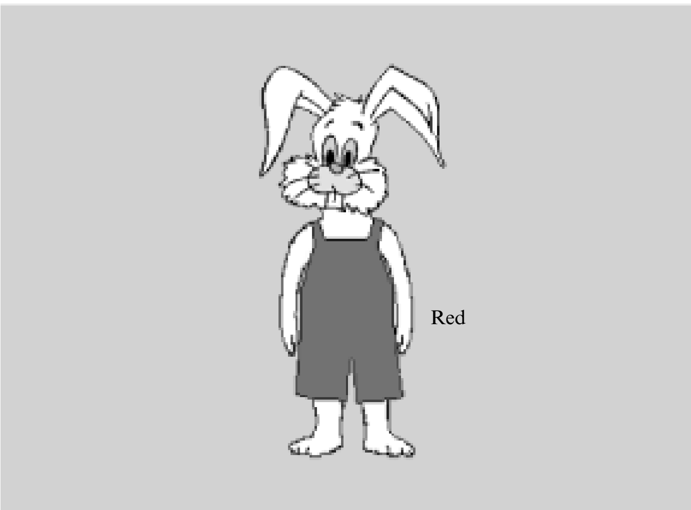
Each child was tested individually in a quiet area of the daycare by the same experimenter (the first author). During the testing of some of the younger children a familiar educator was also present. The child sat on a chair facing the monitor at a distance that enabled the child to touch the screen easily. The experimenter explained to the child that she/he was going to play some games on the computer. Two tasks were given: the first task assessed colour comprehension and the second task assessed colour naming.

2.4.1 *Colour comprehension task.* This spoken-word-to-colour-matching task measured children's ability to comprehend the eleven basic colours as a function of language age. The task started with the appearance of a cartoon animal presented to the left of the screen and three choices of the same garment each coloured with a different basic colour presented to the right of the screen (see figure 1a). One garment was coloured with the target colour and the other two acted as distractors. To control for the influence of perceptual adjacency (neighbourhood) on colour comprehension (Pitchford and Mullen, in press) equal numbers of distractor colours were presented from distant (eg blue to red) and adjacent (eg pink to red) colour categories to the target in perceptual colour space. The position of the target stimulus was randomised across trials. Task instructions were presented via computer voice-over, for example: "Point to the *red* overalls". Stimuli remained on the screen until the child responded and her/his response was recorded. The coloured garment selected by the child then appeared on the animal, irrespective of whether or not the child had responded correctly. A short beep

[(2)] *Munsell Book of Color* (Baltimore, MD: Macbeth Division of Kollmorgen Corporation).



(a) Colour comprehension



(b) Colour naming

Figure 1. Schematic illustration of stimulus display used in the tasks of (a) colour comprehension and (b) colour naming. In (a) children were asked to point to a colour named by the cartoon character. The cartoon character was then dressed in the garment selected by the child. In (b) children were requested to name the coloured garment worn by the cartoon character. In both tasks, stimuli remained on the screen until the children had made their response. The written colour terms shown in the greyscale figure indicate the colour used and were not present on the screen. A colour version of this figure can be viewed on the *Perception* website at http://www.perceptionweb.com/misc/p3405/.

marked the end of each trial, after which the following trial was presented. A trial could be repeated if the child did not make a response and in these rare instances, the position of the target colour was re-randomised. Each trial took about 10 s to complete. Each of the eleven basic colours was presented once for comprehension with the same cartoon animal with each of the eleven items of clothing. The order of colour presentation was randomised across trials. In addition, the combination of colours and garments was randomised over trials, as was the order of garment presentation.

After each of the eleven basic colours had been presented as targets, a lively piece of music played and the cartoon animal was dressed in the coloured garments selected by the child. Computer voice-over said: "Thanks for helping to dress me. You were very good". The next cartoon animal was presented, and the procedure was repeated for one block of 55 trials, during which each of the five cartoon animals (11 trials per animal) was presented once. Four blocks of 55 trials were presented producing a total of 220 trials (20 per colour). The order of animal presentation was randomised across blocks. Children completed the task over several sessions, each lasting approximately 10 min.

2.4.2 *Colour naming task.* This task measured children's ability to name accurately each of the eleven basic colours as a function of language age. The task started with the appearance of a cartoon animal centred in the screen that was dressed in one of the coloured garments (see figure 1b). As before, the order of colour, and also garment, presentation was randomised across trials, as was the colour and garment combination. A computer voice-over presented the task instructions, for example: "Hi. I'm Benji the Bunny. Can you tell me what I'm wearing? What's the colour of my overalls?" and the experimenter pointed to the item of clothing worn by the cartoon animal, the colour of which was to be named. Stimuli remained on the screen until the child responded and the experimenter recorded the child's response. The end of each trial was indicated by a short beep following which the next trial was presented. Again, a trial could be repeated if the child failed to respond, although this rarely happened. Correct naming was considered to be production of the basic-colour name that corresponded to the target colour (eg the name "red" for a red target). After each of the eleven colours had been presented once for oral naming, a lively piece of music played and the animal was dressed in the coloured garments that had been presented to the child. This procedure was repeated for two blocks of 55 trials, producing a total of 110 trials. Again, the order of animal presentation was randomised within each block of trials. Children completed the task over several sessions lasting 10 min.

2.5 *Results*

2.5.1 *The measure of discrimination (d').* We use d' as a dependent variable because it takes into account the fact that a child may have a bias in responding, having a tendency to select one particular colour when the correct answer is not known. d' is a standard measure of discrimination that enables the child's ability to discriminate each colour to be measured independently of her/his response bias (eg see Macmillan and Creelman 1991). For the comprehension task, d' refers to a child's ability to identify correctly a colour presented as a target (maximum of 20 hits), taking into account the child's tendency to select the colour in error when presented as a distractor (maximum of 40 false alarms). For the naming task, d' refers to a child's ability to apply a particular colour term correctly (maximum of 10 hits), compared to her/his erroneous application of that colour term (maximum of 100 false alarms).

A d' of 0 corresponds to chance discrimination and perfect discrimination produces a theoretical upper limit of infinity. However, following standard procedure, when our children obtained a perfect score we converted proportions of 0 and 1 to $1/(2N)$ and $1 - 1/(2N)$, respectively (eg see Macmillan and Creelman 1991, page 10). This adjustment yielded a maximum d' of 6.24 for colour comprehension and 6.39 for colour naming.

2.5.2 (i) *Is there a systematic order to the development of colour term knowledge?* We compared the ability of each of the four language-age (LA) groups to comprehend and name each of the eleven basic colours. The mean d' performance of the four LA groups on the tasks of colour comprehension and colour naming is reported in table 1. As can be seen, for each of the eleven basic colours on both of the experimental tasks, the standard deviations for the two younger LA groups are larger than those of the

Table 1. Mean and standard deviation (in parentheses) d' performance on the tasks of colour comprehension (CC) and colour naming (CN) for each of the four LA groups.

Colour	2 years 3 years		4 years 5 years					
	CC	CN	CC	CN	CC	CN	CC	CN
White	1.22	1.43	5.43	5.65	6.24	6.03	6.24	6.15
	(1.08)	(2.24)	(1.33)	(1.23)	(0.00)	(0.78)	(0.00)	(0.51)
Black	1.36	1.08	5.29	5.57	5.74	5.74	5.97	5.89
	(1.79)	(2.31)	(1.18)	(0.83)	(1.17)	(1.18)	(0.83)	(1.07)
Red	1.38	0.98	5.02	4.97	6.08	6.24	5.97	6.39
	(1.41)	(2.48)	(1.90)	(2.11)	(0.49)	(0.5)	(0.56)	(0.0)
Green	1.52	2.7	5.13	5.01	6.09	6.24	6.01	6.39
	(1.54)	(2.56)	(1.75)	(2.01)	(0.46)	(0.5)	(0.50)	(0.0)
Yellow	2.24	2.87	5.04	5.21	6.09	6.24	6.24	6.24
	(1.94)	(2.38)	(1.57)	(1.52)	(0.46)	(0.5)	(0.00)	(0.5)
Blue	1.44	2.84	4.85	6.14	6.12	6.39	5.95	6.39
	(1.31)	(2.78)	(1.75)	(0.89)	(0.37)	(0.0)	(0.62)	(0.0)
Brown	1.40	1.37	4.59	2.26	5.00	3.64	5.68	5.44
	(1.07)	(1.97)	(1.61)	(2.74)	(1.60)	(2.64)	(1.01)	(1.73)
Purple	0.92	1.68	4.86	4.54	6.24	6.11	5.74	5.89
	(1.26)	(2.38)	(1.95)	(2.11)	(0.00)	(0.59)	(0.90)	(1.12)
Pink	1.60	2.41	5.20	4.8	5.89	6.11	5.68	5.87
	(1.71)	(2.57)	(1.57)	(1.73)	(0.74)	(0.59)	(0.72)	(0.84)
Orange	1.76	2.74	4.77	4.26	5.94	6.15	5.86	6.01
	(2.01)	(2.64)	(1.48)	(1.87)	(0.64)	(0.51)	(0.62)	(0.82)
Grey	0.91	0.45	4.15	2.63	5.03	3.76	5.71	3.46
	(1.03)	(1.3)	(1.68)	(2.09)	(1.56)	(3.03)	(0.92)	(3.19)

two older LA groups. In addition, the performance of the 4-year and 5-year LA groups was close to ceiling for some colours. To avoid violating the assumptions of homogeneity of variance, in each of the following analyses, data from the 2-year and 3-year LA groups were analysed separately from those of the 4-year and 5-year LA groups. In each analysis, the d' for each child of a particular LA group, for each of the eleven basic colours, on both of the experimental tasks, was entered into the analysis.

Younger children: 2-year and 3-year LA groups. Differences in the mean d' performance for the two younger LA groups at comprehending and naming each of the eleven basic colours were investigated by a $2 \times 2 \times 11$ mixed ANOVA, where LA group (2) was the between-subjects factor, and task (2), and colour (11) were within-subject factors. Results revealed significant main effects of LA group ($F_{1,21} = 86.7$, $p < 0.0001$) and colour ($F_{10,210} = 11.05$, $p < 0.0001$). Only the interactions between LA group and colour ($F_{10,210} = 4.71$, $p < 0.0001$) and task and colour ($F_{10,210} = 3.8$, $p < 0.0001$) were significant.

A posteriori analyses (with Tukey's HSD, $p < 0.05$ at least) were conducted to explore further the significant interaction between LA group and colour (shown in figure 2). Results revealed that, when collapsed across task, the performance of the 3-year LA group was significantly higher than that of the 2-year LA group for all colours except orange and brown. The 3-year LA group performed significantly poorer on brown and grey than all of the other basic colours. Within the 2-year LA group some colours were better known than others as the children's performance on grey was significantly poorer than on yellow, green, blue, pink, and orange, but their performance on yellow was significantly higher than on black, white, red, purple, and grey.

The interaction between task and colour, shown in figure 3a, was also explored with a posteriori analyses (with Tukey's HSD, $p < 0.05$ at least). Results showed no difference in the younger children's comprehension of the eleven basic colours, but, when collapsed across LA group, their naming of brown and grey was inferior to that of all other colours. In addition, the younger children were significantly better at naming blue than red, brown, orange, purple, and grey.

Older children: 4-year and 5-year LA groups. As above, a 2 (LA group) × 2 (task) × 11 (colour) mixed ANOVA was performed to explore differences in the mean performance of the 4-year and 5-year LA groups on each of the eleven basic colours in both of the experimental tasks. Results revealed a significant main effect of colour ($F_{10,180} = 12.3$, $p < 0.0001$) and a significant interaction between task and colour ($F_{10,180} = 4.59, p < 0.0001$).

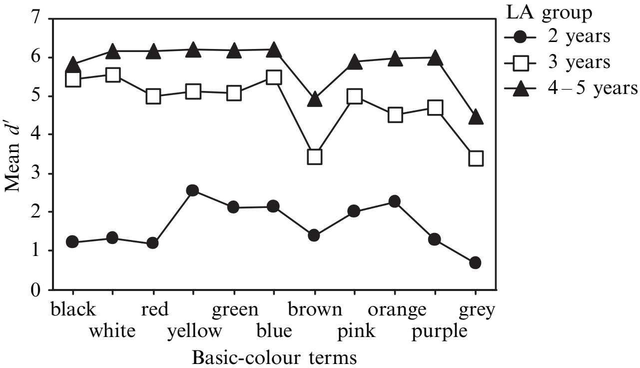


Figure 2. Development of colour term knowledge as a function of language age: mean d' for performance collapsed across colour comprehension and naming tasks. The interaction between LA group and colour is shown for the 2-year and 3-year LA groups and the main effect of colour is shown for the older children. See text for results of the statistical analysis of the data.

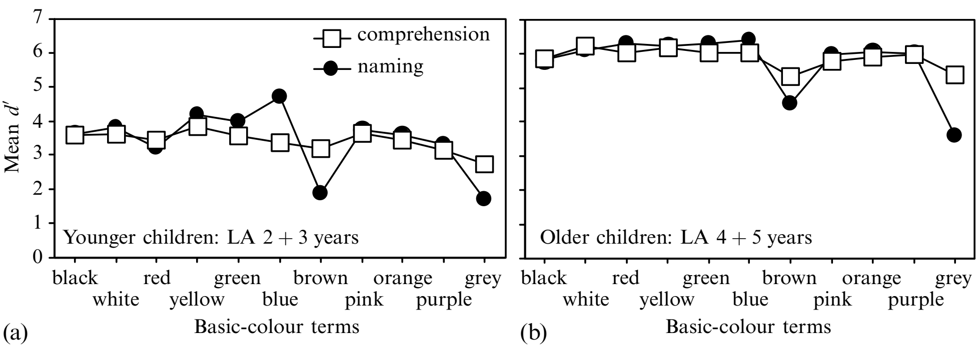


Figure 3. Children's comprehension and naming of the eleven basic colours: mean d' for performance, collapsed across LA groups. (a) The interaction between task and colour for the younger children; (b) interaction between task and colour for the older children. See text for results of the statistical analysis of the data.

A posteriori analyses (with Tukey's HSD, $p < 0.05$ at least) were conducted to explore further the significant main effect of colour (shown in figure 2) and the task by colour interaction (shown in figure 3b). As figure 2 shows, when collapsed across LA group and task, the older children's knowledge of brown and grey was significantly poorer than that of all other colours. However, the interaction between task and colour (shown in figure 3b) shows that the older children named only brown and grey significantly less accurately than the other basic colours as their comprehension of these two colours relative to the other nine basic colours did not differ significantly. In addition, the older children's comprehension of grey was significantly better than their naming of this colour.

These results indicate that colour term acquisition follows a typical developmental progression in that children with advanced language skills outperformed those of a relatively younger language age (see figure 2). However, the acquisition of colour terms does not appear to be systematic. The interactions reported above suggest that the pattern of performance exhibited across the eleven basic colours is dependent upon the task used to measure colour term knowledge and the developmental point at which colour term knowledge is assessed. In particular, there is a marked distinction between the performance of the youngest children (the 2-year LA group) and those with more advanced language skills. Whilst the performance of the 2-year LA group across the different colours appeared unsystematic, the performance of children with a language age of 3 years or above appeared to be characterised by one common feature. That is, the older children performed poorly on brown and grey compared to the other basic colours. The interaction between task and colour showed this resulted mostly from the poorer naming (and not comprehension) of these two colours. When collapsed across LA groups, only children's naming (and not the comprehension) of brown and grey was inferior to that of the other basic colours. Thus, the inferior naming of these two colours compared with the use of the other nine basic-colour terms appears to be a characterising feature of children's colour term acquisition after a language age of about 3 years. This suggests that children may acquire knowledge of these two colours at a distinctly later point in development.

2.5.3 (ii) *Do the six primary colours develop first?* We compared the mean d' performance of each of the four LA groups for primary and non-primary colours on the tasks of colour comprehension and colour naming. A mean d' for the six primary colours (white, black, red, green, yellow, and blue) and a mean d' for the five non-primary colours (brown, purple, pink, orange, and grey) was calculated for each child and was entered into the following analyses.

Younger children: 2-year and 3-year LA groups. To explore how the young children's knowledge of primary and non-primary colours developed with increasing language age and across tasks, a $2 \times 2 \times 2$ mixed ANOVA was conducted, where LA group (2) was the between-subjects factor, and task (2), and primacy (2) were the within-subject factors. Results (shown in figures 4a and 4b) revealed significant main effects of LA group ($F_{1,21} = 28.65$, $p < 0.0001$) and primacy ($F_{1,21} = 32.62$, $p < 0.0001$). Significant interactions were found between LA group and primacy ($F_{1,21} = 13.57$, $p < 0.01$), task and primacy ($F_{1,21} = 11.66$, $p < 0.01$), and the 3-way interaction between LA group, task, and primacy was also significant ($F_{1,21} = 10.14$, $p < 0.01$).

An analysis of simple effects was conducted to explore the significant 3-way interaction between LA group, task, and primacy. As expected, the 3-year LA group performed significantly better than the 2-year LA group on the comprehension of primary ($F_{1,42} = 17.08$, $p < 0.001$) and non-primary colours ($F_{1,42} = 15.18$, $p < 0.001$), and also the naming of primary ($F_{1,42} = 15.61$, $p < 0.001$) and non-primary colours ($F_{1,42} = 5.1$, $p < 0.05$). More importantly, results showed no difference between knowledge of primary and non-primary colours for the 2-year LA group on either the comprehension (figure 4a) or naming (figure 4b) tasks. The 3-year LA group also comprehended primary colours to the same extent as non-primary colours (figure 4a), but their naming (figure 4b) of primary colours was superior to their naming of non-primary colours ($F_{1,21} = 66.03$, $p < 0.0001$). In addition, the 3-year LA group comprehended non-primary colours significantly better than they named these colours ($F_{1,21} = 6.79$, $p < 0.05$).

Older children: 4-year and 5-year LA groups. A separate 2 (LA group) $\times$ 2 (task) $\times$ 2 (primacy) mixed ANOVA was conducted to investigate differences in the older children's comprehension and naming of primary and non-primary colours. Only the main effect

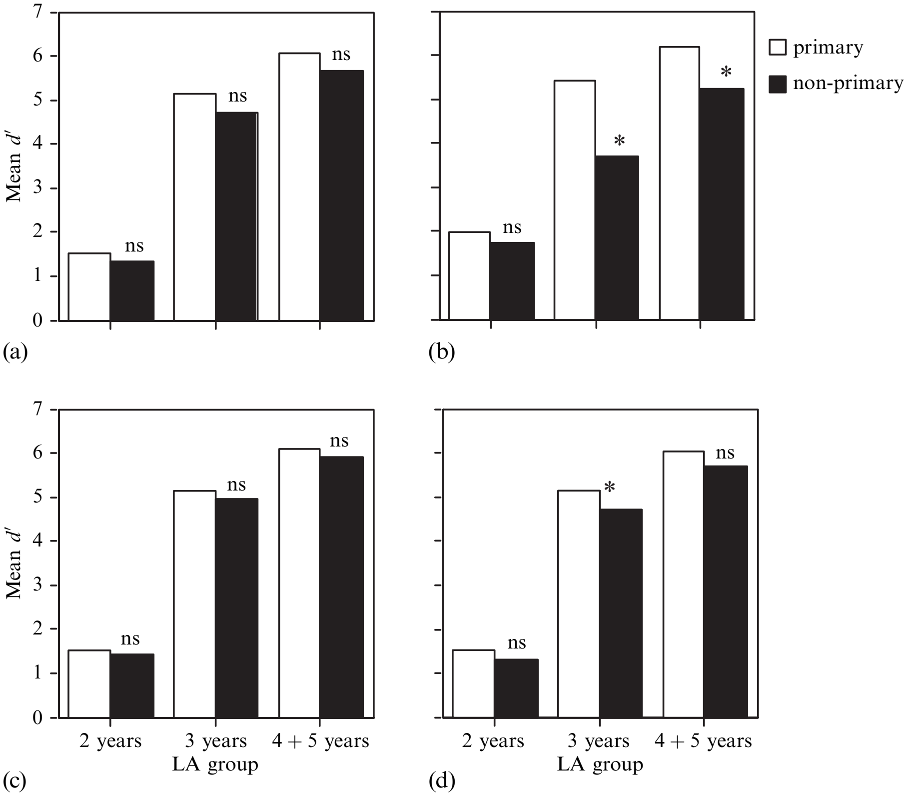


Figure 4. Mean d' for children's comprehension and naming of primary compared to non-primary colours as a function of language age. (a) Children's comprehension, and (b) children's naming of primary and non-primary colours for the eleven basic-colour terms. (c) Children's comprehension, and (d) children's naming of primary and non-primary colours for the nine basic-colour terms (excluding brown and grey). See text for results of the statistical analysis of the data.

of primacy ($F_{1,18} = 15.84$, $p < 0.001$) and the interaction between task and primacy ($F_{1,18} = 6.29$, $p < 0.05$) were significant. Exploration of the interaction between task and primacy was conducted with Tukey's HSD ($p < 0.05$ at least). Results revealed no difference in the older children's comprehension of primary and non-primary colours (figure 4a), but their naming of primary colours was superior to their naming of non-primary colours (figure 4b). In addition, the older children comprehended non-primary colours significantly better than they named these colours.

These results suggest that any advantage for primary over non-primary colour terms depends upon the task used to measure colour term knowledge and also the age at which colour term knowledge is assessed. Significant effects of primacy were shown only on the colour naming task and only by children with a language age of 3 years and above. Interestingly, two of the five non-primary colour terms are brown and grey, and as the results reported in section 1 showed, brown and grey were named (but not comprehended) significantly less accurately than other basic colours by children with a language age of 3 years and above. It may be possible that the late acquisition of brown and grey relative to the other nine basic colour terms contributed to the significant primacy effect shown on the colour naming task by the children with more advanced language skills. To test this hypothesis, for each child we recalculated her/his mean d' performance for non-primary colours based on pink, orange, and purple alone, thus excluding brown and grey. We then ran the above analyses again, in which we compared the mean d' for the six primary and three non-primary colours, on both tasks, for the two younger and two older LA groups. Results are shown in figures 4c and 4d.

Younger children: 2-year and 3-year LA groups. As before, a 2 (LA group) $\times$ 2 (task) $\times$ 2 (primacy) mixed ANOVA was conducted to investigate an advantage for primary over non-primary colours (excluding brown and grey), on the tasks of colour comprehension and naming, in the 2-year and 3-year LA groups. The only results that were consistent with the previous primacy analysis were a significant main effect of LA group ($F_{1,21} = 70.05$, $p < 0.0001$), a significant interaction between LA group and primacy ($F_{1,21} = 8.47$, $p < 0.01$), and a significant 3-way interaction between LA group, task, and primacy ($F_{1,21} = 7.66$, $p < 0.05$). In contrast to the previous analysis, both the main effect of primacy and also the interaction between task and primacy were found be to insignificant.

An analysis of simple effects was once again used to investigate the 3-way interaction. A similar pattern of results was found as with the previous analysis; however, with brown and grey excluded from the non-primary mean d', the comprehension of non-primary colours was no longer significantly better than the naming of non-primary colours by the 3-year LA group. Interestingly, children with a language age of 3 years continued to show superior naming of primary compared to non-primary colours ($F_{1,21} = 19.27$, $p < 0.001$), even when brown and grey no longer contributed to the mean d' for non-primary colours (figure 4d).

Older children: 4-year and 5-year LA groups. Data from the two older LA groups were subjected to a separate 2 (LA group) $\times$ 2 (task) $\times$ 2 (primacy) mixed ANOVA, to investigate if an advantage for primary colours would still be shown when brown and grey were excluded from the non-primary d' mean. In contrast to the original analysis, this analysis revealed no significant main effects or interactions. Thus, the older children's comprehension (figure 4c) and naming (figure 4d) of primary colours was comparable to that of non-primary colours, when the contribution from brown and grey was removed.

These results suggest that the significant primacy effect originally shown on the colour naming task by children with advanced language skills may, in part, result from the late acquisition of brown and grey, two non-primary colours, relative to the other nine basic-colour terms. When brown and grey are removed from the analyses, a significant primacy effect is shown only by the 3-year LA group and only on the colour naming task. Although few of the pairwise comparisons between primary and non-primary colours reached statistical significance, our data show a consistent yet insignificant bias towards better performance on primary colours across tasks and LA groups. Overall, our results lend some (albeit weak) support for a consistent advantage of primary over non-primary colours, when compared across different conceptual tasks, and different points of language acquisition.

2.5.4 (iii) *At what age do children show reliable knowledge of the eleven basic-colour terms?* We wanted to determine the developmental time frame in which children's knowledge of the eleven basic-colour terms becomes reliable, as variations in the age at which children accurately know colours has implications for the underlying mechanisms governing their temporal appearance.

In order to generate an overall measure of colour term knowledge (referring to both receptive and expressive abilities) for each child, we calculated the children's mean d' performance on the colour comprehension and colour naming tasks for each of the eleven basic-colour terms. This yielded a maximum d' of 6.315. To produce a learning curve for each of the eleven basic colours, we plotted the mean d' for each measure of language age shown in our sample of children, and fitted a Weibull function to each plot. The learning curves for each of the eleven basic colours are shown in figure 5.

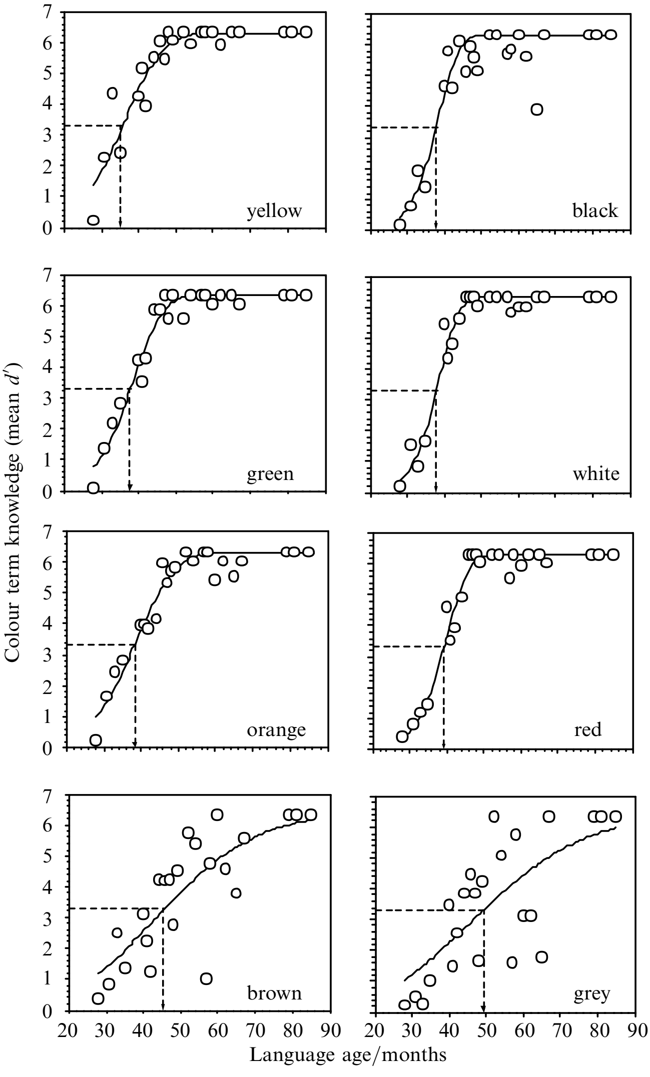


Figure 5. Learning curves for each of the eleven basic-colour terms. In each panel data points show mean d' for colour term knowledge (combined comprehension and naming performance) for a colour as marked as a function of language age. Solid line shows a Weibull fit to the data.

As can be seen in figure 5, typical learning curves were found for each of the eleven basic colours, with some colours showing a more rapid rate of acquisition (indicated by a steeper curve) than others. To determine the language age at which children show accurate colour term knowledge, for each colour we calculated the language age that corresponded to the point on the learning curve at which a d' of 3.28 was achieved. This corresponds to a level of performance where children can significantly discriminate a particular colour term (at $p < 0.05$), and thus the corresponding language age indicates the point at which their colour term knowledge is correctly established. The following 'age-of-acquisition' sequence of colour term knowledge was found and is shown in figure 6: yellow (35.6 months), blue (36.4 months), black (37.7 months), green (37.8 months), white (37.8 months), pink (37.9 months), orange (38.1 months), red (39.2 months), purple (39.5 months), brown (45.7 months), and grey (48.9 months).

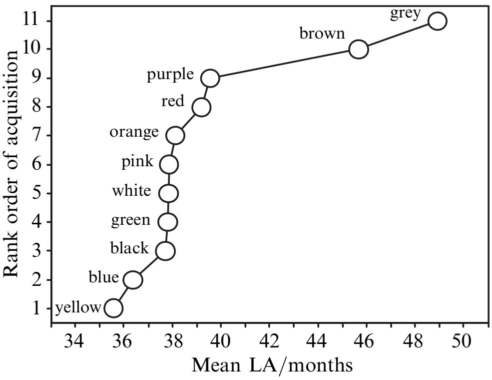


Figure 6. Age at which children acquire reliable knowledge of each of the eleven basic colours. The Weibull fits of figure 5 were used to determine the average language age at which each of the eleven basic colours could be reliably discriminated (a d' of 3.28, $p < 0.05$); the developmental sequence is plotted above.

As can be seen from figure 6, children's knowledge of nine of the eleven basic colours becomes reliable within a narrow time frame of 3 months, starting at a language age of 35.6 months (for yellow) and ranging to 39.5 months (for purple). There is then a considerable lag of between 6.2 months and 9.4 months before children's knowledge of the final two colours (brown and grey, respectively) becomes reliable. This suggests that accurate colour term knowledge develops over two distinct periods of time and is thus dichotomous: first, children acquire knowledge of yellow, blue, black, green, white, pink, orange, red, and purple (presumably in any order); second, knowledge of brown and grey is acquired. An unpaired t-test confirmed that reliable knowledge of the first nine basic colours is acquired at a significantly younger age than reliable knowledge of brown and grey ($t = 9.522$, $p < 0.0001$). The mean age of acquisition for the first nine basic colours is 37.8 months (SD = 1.21) compared to 47.3 months (SD = 2.26) for the last two colours acquired.

Considerable support for this dichotomous developmental order was found amongst the individual children's data. For each child, her/his knowledge of each of the eleven basic colours was categorised as either reliable ($d' = 3.28$) or not reliable ($d' < 3.28$). Children that showed reliable knowledge of at least one of the other basic colours when their knowledge of brown and/or grey was not reliable provide support for our developmental order. In contrast, children that showed reliable knowledge of brown and/or grey when their knowledge of at least one of the other basic colours was not reliable provide support against our prediction. To test these predictions we excluded children who showed no reliable colour term knowledge or who showed reliable knowledge of all the basic colour terms. Of the remaining twenty-four children, twenty-one (87.5%) supported our prediction that brown and grey would be the last two colours to be acquired, a significantly higher proportion than would be expected on the basis of chance ($\chi^2 = 13.5$, $p < 0.0001$), thus supporting a dichotomous order of development.

3 Discussion

In this study we investigated whether the acquisition of basic-colour terms by young children is constrained. Berlin and Kay (1969) hypothesised that children would acquire basic-colour vocabulary in a systematic order that is analogous to the evolutionary hierarchy by which colour terms are added to languages, as both reflected the underlying physiological structure of perceptual and conceptual colour space. Of the eleven basic-colour terms, the first six to appear in the evolutionary hierarchy refer to the unique hues plus the two achromatic colours. Consequently, it has been predicted that children would acquire the six primary-colour terms at an earlier developmental stage than the five non-primary basic-colour terms (Bornstein 1985; Miller and Johnson-Laird 1976). This prediction has received contradictory support, however, from previous developmental studies (Andrick and Tager-Flusberg 1986; Bartlett 1978; Cruse 1977; Heider 1971; Johnson 1977; Shatz et al 1996), which raises doubts about the supposition that children's developing colour vocabulary and the evolution of colour language across cultures are both governed by the same underlying physiological mechanisms.

We measured the development of colour term knowledge across four language-age groups using two tasks of colour conceptualisation (comprehension and naming). Our results show, first, that children's colour term acquisition does not appear to be systematic, as has previously been proposed (Berlin and Kay 1969), except for the delayed development of brown and grey compared to the other nine basic-colour terms. Second, we find only weak support for the development of the six primary colour before the other non-primary colour terms. Third, the order in which children acquire accurate knowledge of the eleven basic-colour terms appears to be dichotomous and is characterised by the late appearance of brown and grey.

Our results provide little support for the proposition that the development of young children's basic-colour term knowledge is systematic (Berlin and Kay 1969). We argued that, to be considered systematic, the pattern of performance across the eleven basic colours should be similar for children at different stages of colour term acquisition and across different conceptual tasks. The cross-sectional design of our study, that employed four language-age groups and two tasks of colour conceptualisation, revealed that the pattern of performance depended both on age and task. Different patterns of performance for the eleven basic colours were exhibited across the different language-age groups, and within the colour comprehension and colour naming tasks.

The most marked distinction in performance patterns across colours was between the 2-year LA group and the other three, older, LA groups. The unsystematic performance across colours exhibited by the youngest LA group appears to characterise colour-term acquisition in the early stages and does not reflect children's inability to perform the tasks. If task mastery was a limiting factor, we should not have found a significant interaction between LA group and colour in the younger children's data. However, the significant interaction between LA group and colour shown by the younger children indicates that performance develops differentially across colours. Furthermore, there are clear examples from individual children within the 2-year LA group that their knowledge of some colours was reliable (as indicated by a d' of 3.28 or above) when their knowledge of other colours was not yet accurate. For example, one child (MB) with a language age of 2 years could comprehend accurately the colours black, red, yellow, blue, pink, and orange, but his comprehension of the others was unreliable. MB also named green and blue accurately, but his naming of the other basic colours was not yet reliable (see figure 7).

One feature that did emerge from our data, however, was the significantly poorer performance of brown and grey relative to other basic-colour terms. The interaction between LA group and colour shown by the younger LA groups and the main effect of colour shown by the older children suggest that, when children reach a language age of 3 years and above, their knowledge of brown and grey is inferior to that of other basic colours. However, the interaction between task and colour showed it was the naming, and not the comprehension, of brown and grey that was relatively impaired. Differences in task difficulty may have contributed to this finding, however, as children may have succeeded at comprehending brown and grey by a process of exclusion when the other two distractor colours were known. Clearly, this strategy would not have been available on the colour-naming task in which only the target colour to be named was presented. It is clear, however, from these results that colour term acquisition by young children does not appear to follow an invariant 7-stage order, as suggested by Berlin and Kay (1969).

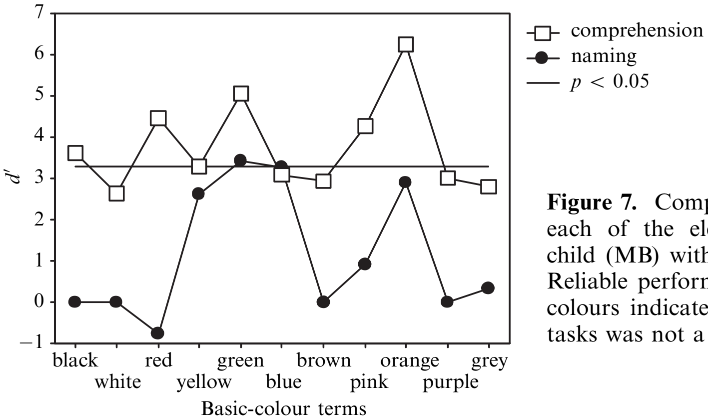


Figure 7. Comprehension and naming of each of the eleven basic colours by one child (MB) with a language age of 2 years. Reliable performance for some, but not all, colours indicates the ability to perform the tasks was not a limiting factor.

Our results also lend only weak support for the prediction that children will acquire the six primary colour terms at an earlier developmental stage than the five non-primary colour terms (Berlin and Kay 1969; Bornstein 1985; Miller and Johnson-Laird 1976). A small but consistent bias towards better performance on primary compared to non-primary colours was shown by each of the LA groups across both of the conceptual tasks; however, this advantage for primary over non-primary colour terms only reached statistical significance when children had reached a language age of 3 years and was shown only on the colour naming task. No significant effect of primacy on colour term knowledge was shown by the 2-year LA group. The advantage for primary over non-primary colours appeared to be attributed, in part, however, to the later acquisition of brown and grey relative to the other nine basic-colour terms. The primacy effect originally shown by the 4-year and 5-year LA groups on the colour naming task was no longer significant when the contribution of brown and grey was removed. However, the advantage for better naming of primary than non-primary colours remained for the 3-year LA group, even when the contribution of brown and grey was removed. The most likely reason for this advantage in the 3-year LA group is that, at this stage of development, primary colours are more salient linguistically than non-primary colours, probably because they occur more frequently than non-primary colours in children's book and games (Corbett and Davies 1997; Hays et al 1972).

Our results are consistent with previous developmental studies. For example, significantly better naming of primary compared to non-primary colours has been reported in preschool children (Andrick and Tager-Flusberg 1986; Cruse 1977; Heider 1971; Johnson 1977), although no effect of primacy on colour comprehension has been found (Andrick and Tager-Flusberg 1986; Bartlett 1978; Heider 1971; Shatz et al 1996). Furthermore, 2-year-olds have been shown to exhibit no effect of primacy on comprehending and naming six of the basic-colour terms (Shatz et al 1996). These results are intriguing, as they suggest that the existence of the six unitary percepts does not significantly influence the conceptual development of the corresponding primary colour terms. Thus, despite their perceptual uniqueness, only a slight advantage for the conceptualisation of primary colours is shown. Interestingly, this finding is consistent with a recent study of adult colour naming which found no difference in the 'nameability' of primary and non-primary terms (Guest and Van Laar 2000). Overall, these results fail to provide very strong evidence in support of the notion that the development of colour terms by young children is physiologically constrained in the manner suggested by Berlin and Kay (1969).

In addition, our age-of-acquisition sequence shows that children acquire accurate knowledge of the first nine basic-colour terms at a much earlier age (between 35.6 to

39.5 months) than has previously been suggested. Earlier generations of children could reportedly name the four unique hues only by the age of 7 years in the 1900s (eg Binet and Simon 1908/1916) and 4 years in the 1970s (Miller and Johnson-Laird 1976). However, the accurate knowledge of the first nine colour terms exhibited by our 3-year-olds is consistent with the findings of Shatz et al (1996) who reported better knowledge of the four unique hues in 2-year-olds than has been shown by previous generations. Various experiential factors may account for these cohort effects. For example, preschool attendance has been shown to refine colour-term knowledge (Shatz et al 1996) and contemporary children are more likely than the children of previous generations to attend preschool. As today's generation of young children is typically exposed to highly coloured stimuli from a very early age, such as coloured toys, TV, books, crayons, etc, it is possible that colour is a more salient attribute for contemporary 2-year-olds and 3-year-olds than it has commonly been in the past. Cohort effects, such as these, would not be expected if physiological constraints govern colour term acquisition.

Our analysis of the developmental time frame in which colour term knowledge becomes reliable revealed that children acquire an accurate knowledge of the first nine basic-colour terms all within a narrow time frame of 3 months. This time frame is so short that we assume any sequence of these first nine terms is possible. After this period, there is a considerable gap of 6 to 9 months until knowledge of the final two basic colours (brown and grey) becomes accurate. We thus propose that children acquire reliable knowledge of the eleven basic-colour terms in two distinct time periods: first, knowledge of yellow, blue, black, green, white, pink, orange, red, and purple (in any order) becomes accurate; then, reliable knowledge of brown and grey (in either order) is acquired. Considerable support for this proposition is provided by the analysis of our individual children's data. Of the twenty-four children who showed neither reliable nor unreliable knowledge of all basic-colour terms, twenty-one (87.5%) supported our prediction that knowledge of brown and grey would be the last to become accurate. This was a significantly higher proportion of children than would be expected on the basis of chance.

Reliable comprehension and naming of colour terms is indicative of the systematic mapping of perceptual colour categories to the corresponding conceptual colour space. Studies of adult colour naming have shown that conceptual colour space is categorically organised in a manner that reflects the arrangement of perceptual colour space (eg Boynton and Olson 1987, 1990; Guest and Van Laar 2000; Sturges and Whitfield 1995), as depicted in figure 8. As can be seen in figure 8, nine of the eleven basic colours lie to the outside of perceptual colour space and two of the basic colours (brown and grey) form the interior structure. In another study, we showed that young children gradually acquire this system of perceptually based conceptual colour categories during the developmental period in which they learn about colour terms (Pitchford and Mullen, in press). The results of the present study suggest that the order in which children acquire accurate knowledge of the eleven basic-colour categories is based on the structure of perceptual colour space. The main dichotomy seems to be between the systematic mapping of the nine colours that lie to the exterior and the two colours that lie to the interior of perceptual and conceptual colour space.

Our results suggest that initially the external structure of conceptual colour space becomes established during the 3-month period (35.6 months to 39.5 months) in which reliable knowledge of the first nine basic colour terms is acquired. We propose that initially the nine colour categories that lie to the outside of perceptual colour space (see figure 8) become consistently mapped to the corresponding conceptual representations in any order. The lag in the acquisition of reliable knowledge of brown and grey suggests that the internal structure of conceptual colour space becomes consistently mapped at a later point in development. Consequently, this dichotomous developmental

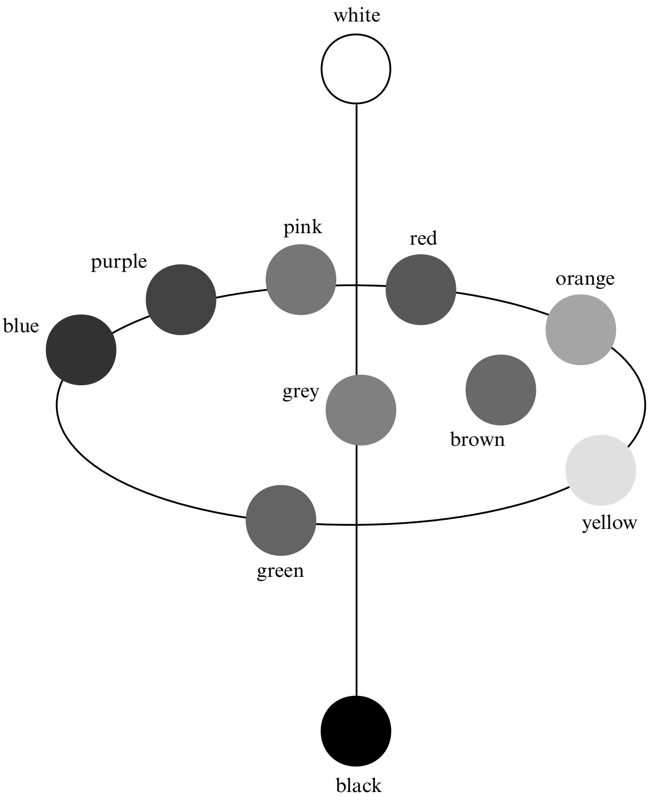


Figure 8. Schematic illustration of conceptual colour space. A colour version of this figure can be viewed on the *Perception* website at http://www.perceptionweb.com/misc/p3405/.

order of colour term acquisition appears to be constrained only by the later mapping of the internal structure of conceptual colour space. Aside from brown and grey, the order of acquisition of the other nine colour terms appears to be unconstrained, and might be shaped by environmental factors specific to any individual child, such as parental input (Andrick and Tager-Flusberg 1986), or may simply occur randomly within the given time frame. This proposal is consistent with recent studies that have suggested that adult colour naming is unconstrained (Davidoff et al 1999; Roberson et al 2000; Saunders and van Brakel 1997).

If, as we propose, colour term acquisition is constrained only by the later mapping of the internal structure of conceptual colour space, we might expect children to acquire names for non-basic colours that, like brown and grey, lie to the inside of colour space at a later point in development. This hypothesis is open to test; however, a recent study of children's colour conceptualisation by Braisby and Dockrell (1999) provides incidental support for this prediction. These authors compared young children's comprehension and naming of colours that were high-frequency and low-frequency terms according to adult word frequency counts. All of the high-frequency colour terms were basic colour terms, mostly lying on the exterior of perceptual colour space. In contrast, most of the low-frequency terms referred to non-basic colours (such as beige, olive, and burgundy) that lie in the interior of perceptual colour space. Results showed that children had particular difficulty with low-frequency colour terms, most of which referred to internal, non-basic colours. A control experiment with animal terms showed that the differential deficit for low-frequency colours could not be explained in terms of a general deficit for low-frequency terms, but implied it was specific to colour. It is thus likely that these findings resulted from the comparison of colours that form the exterior and internal structure of perceptual colour space, as suggested by our study. Furthermore, we predict that, when equated for frequency, children should find it easier to map new non-basic colour terms, such as 'scarlet', to colours that lie to the exterior of perceptual colour space than new colour terms, such as 'taupe', referring to colours located to the interior of perceptual colour space. We are currently exploring this interesting hypothesis.

It is not clear why the acquisition of the internal basic colours, brown and grey, appears to be constrained, although there are several reasons why brown and grey may be difficult colours to conceptualise. One possibility is that the psychological or linguistic salience of these two colours is less than that of the other basic-colour terms. Studies of adult colour naming have suggested that psychological or linguistic salience, evidenced by the frequency with which colour terms appear within written texts, is the most reliable measure at distinguishing between primary and non-primary colour terms (Corbett and Davies 1997). Thus, it may be that children find brown and grey difficult to conceptualise because they appear less frequently in children's texts than the other nine basic-colour terms. To test this hypothesis we consulted the database of children's early reading vocabulary reported by Stuart et al (personal communication) to determine children's written word frequency of each of the eleven basic-colour terms. This database is restricted to the frequency for written words that children aged 5 to 7 years are exposed to in the United Kingdom, but we assume it provides a reasonable estimate of the frequency of colour terms for preschool children in North America. The frequency counts for brown (113) and grey (28) were lower than those of some of the other basic colours, but the frequency counts of orange (30), pink (16), and purple (10) were either comparable to, or lower than, those of brown and grey. Thus, psychological or linguistic salience cannot account adequately for the late appearance of brown and grey.

Other possible suggestions for the delayed acquisition of brown and grey are that these two colours are perceptually more similar than the others in terms of their brightness or other aspects of their appearance, or are of low visibility compared to the other samples, and may thus be more difficult to establish conceptually. The luminance contrasts of the samples are given in the appendix, which shows that red is more similar to grey in terms of brightness than is brown, and blue is more similar in brightness to brown than is grey. Furthermore, in terms of appearance, purple is similar to pink, and orange is similar to yellow. As these colour terms were all used accurately before brown and grey, we conclude that perceptual similarity is unlikely to account for the difficulty children experience with conceptualising brown and grey. Moreover, there is no reason to assume that the viewing conditions of the experiment failed to elicit strong sensations of the colours brown and grey since these two stimuli were both of high luminance contrast (93% and 59%, respectively).

A more likely possibility is that brown and grey are perceptually less salient than the other basic colours. Many of our everyday surroundings and background objects are brown or grey, such as the surfaces of roads, pavements, and buildings. If these two colours are perceptually less salient than the other basic colours, this may limit their conceptualisation. A related issue is that these colour terms may lack functional significance for identifying objects that is typical of the other basic colours. The first nine basic-colour terms to appear may have greater functional significance than brown and grey because they are more relevant for defining distinctive features of particular objects, such as yellow for a banana and white for snow. Clearly, any one particular colour may be a defining feature of several different objects (eg yellow is the characteristic colour of a banana, a lemon, a canary, and a daffodil) but brown and grey may characterise many more objects than each of the other nine basic colours. It is very likely that initially children use functional significance as a basis for conceptualising object properties (Au and Markman 1987; Macario 1991; Soja 1994). In a previous study we argued that the disparity between children's ability to form conceptual representations of colours compared to objects resulted from the nature of colour as an abstract property that can be applied to any object (Pitchford and Mullen 2001). However, it is also plausible that within the general attribute of colour, the functional significance of particular colours may limit their relative ease of conceptualisation.

Thus, it appears that explanations of children's colour term acquisition based on anthropological studies of the evolution of colour terms across languages (Berlin and Kay 1969) seem largely inappropriate. We found only weak support for the appearance of primary-colour terms referring to the unique hues at an earlier stage of colour term acquisition than the non-primary colour terms, suggesting that colour term acquisition is unlikely to be physiologically constrained. Instead, we propose a dichotomous developmental order for reliable colour term acquisition, in which we suggest that first the external and then the internal structure of conceptual colour space becomes systematically mapped to perceptual colour categories. Semantic constraints may hinder the acquisition of some internal colours, such as brown and grey, but, in general, colour term acquisition by young children appears to be unconstrained.

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Appendix

Munsell chip coordinates and CIE 2° x, y; and u', v' chromaticity coordinates and brightness for the eleven basic-colour stimuli and background measured with a Photo Research PR-645 SpectralCal Colorimeter. Luminance is reported as the percentage difference (plus or minus) from the background (49 cd m^{-2}).

Colour	Munsell chip coordinate	Chromaticity coordinates (x, y; u', v')	Luminance/% difference from background
White		0.273, 0.289; 0.185, 0.439	+78.6
Black			
Red	7.5R 5/16	0.634, 0.328; 0.447, 0.521	−57.5
Green	2.5G 7/10	0.302, 0.552; 0.134, 0.551	−6.1
Yellow	5YR 8.5/10	0.441, 0.489; 0.221, 0.551	+30.6
Blue	5PB 4.5/12	0.148, 0.069; 0.167, 0.177	−69.4
Brown	5YR 3/6	0.570, 0.328; 0.393, 0.510	−93.1
Purple	3.75P 5/10	0.214, 0.106; 0.223, 0.247	−70.2
Pink	2.5RP 8/6	0.321, 0.267; 0.230, 0.432	−6.1
Orange	5YR 7/14	0.522, 0.422; 0.297, 0.541	−28.6
Grey	N5.5/1	0.268, 0.281; 0.184, 0.434	−59.2
Background	N8/1	0.277, 0.297; 0.185, 0.444	0