VISUAL COGNITION, 2003, *10* (1), 51–77

The development of conceptual colour categories in pre-school children: Influence of perceptual categorization

Nicola J. Pitchford and Kathy T. Mullen
McGill University, Montreal, Quebec, Canada

This study investigates the influence of perceptual colour categorization on the development of conceptual colour space in 43 pre-school children as a function of language-age. Knowledge of the 11 basic colour terms identified by Berlin and Kay (1969) was assessed in comprehension and naming tasks. Children's ability to comprehend basic colour terms was assessed in a spoken word-to-colour matching task in which a target colour was presented with two distracters from either distant or adjacent perceptual colour categories. Children's ability to name basic colour sensations was measured in an explicit naming task. Results showed that children's comprehension of basic colour terms was influenced by the perceptual relationship between the target and distracter colours. Most importantly, at a language-age of 3 years and above, naming errors were more likely to be made to adjacent, rather than distant, perceptual colour categories. These results are consistent with the prediction that categorical colour perception influences the underlying structure of developing conceptual colour space during the period in which children acquire basic colour terms.

Young children appear to have difficulty establishing conceptual representations of colour sensations. For example, they can learn colour words without knowing the colour to which they refer, they will use a single colour word to name many different colours, and they often apply colour terms in a haphazard and inconsistent manner (e.g., Baldwin, 1893; Cruse, 1977; Darwin, 1877, cited in Bornstein, 1985; Modreski & Goss, 1969; Nagel, 1906). In addition, colour

---

Please address all correspondence to: Dr N. Pitchford, School of Psychology, University of Nottingham, University Park, Nottingham, NG7 2RD, UK. Email: nicola.pitchford@nottingham.ac.uk

This research as supported by a Royal Victoria Hospital Research Institute Postdoctoral Fellowship awarded to NJP and a Medical Research Council Project Grant (no. MT-10819) awarded to KTM. We are particularly grateful to the children, staff and directors at the Royal Victoria Hospital, Montreal General Hospital, and McGill University daycares (Ellen Unkrig Staton, Carole Montpetit, and Maggie Descent, respectively) that kindly participated in this research. We would also like to thank Dr Tim Ledgeway for the software development and Rebecca Achtman for recording the task instructions.

http://www.tandf.co.uk/journals/pp/13506285.html DOI:10.1080/13506280143000629

terms appear at a later developmental stage than labels for familiar objects (e.g., Bornstein, 1985; Heider, 1971; Johnson, 1977; Mervis, Catlin, & Rosch, 1975; Pitchford & Mullen, 2001a; Shatz, Behrend, Gelman, & Ebeling, 1996). Unlike colour terms, children learn the words for many everyday objects with apparent ease and with remarkable speed during the early stages of lexical acquisition, often within a single occurrence of hearing the word spoken in context (e.g., Carey, 1978). The nature of early word learning is thus considered to be principally referential, involving the mapping of words to objects, actions, and events in the world (e.g., Markman, 1989; Nelson, 1991). The striking disparity in the nature by which young children learn the names for everyday objects and colours suggests that colour terms may not be systematically mapped to colour sensations during the initial stages of colour term acquisition.

There is substantial evidence to suggest that the processing of human colour sensations is categorical in nature. Berlin and Kay (1969) were the first to propose that there exist, at most, 11 universal basic perceptual colour categories on which, they claimed, colour terms are systematically mapped. The 11 basic colour categories identified by Berlin and Kay are *white*, *black*, *red*, *green*, *yellow*, *blue*, *brown*, *purple*, *pink*, *orange*, and *grey*, each of which is defined by a focal region, representing the most typical example of its category. The perceptual focal point of each colour category is remarkably concordant across all languages that use a particular colour term, indicating that the underlying internal conceptual representation of focal colour regions is universal in structure (e.g., Boynton, Fargo, Olson, & Smallman, 1989; Collier, 1976; Harkness, 1973; Heider, 1972; Uchikawa & Boynton, 1987; Uchikawa & Shinoda, 1990; Uchikawa & Sugiyama, 1993).

The focal regions of basic colour categories have been shown repeatedly to have perceptual and cognitive distinctiveness. For example, cross-cultural studies have shown that focal colours are recognized more accurately and rapidly, and become associated with colour names more reliably, than non-focal colours (Heider, 1972; Rosch, 1973). In addition, developmental studies have shown that children are more likely to select and are better at matching (Heider, 1971), comprehending, and naming (Andrick & Tager-Flushberg, 1986), focal colours than non-focal colours. The consistency by which studies report evidence for focal colour regions of the basic perceptual colour categories strongly suggests that there is an underlying physiological basis for categorical colour perception, on which colour concepts are based, that appears to be independent of genetic or cultural differences (Uchikawa & Boynton, 1987).

In addition, studies of colour naming in normal-sighted adults have shown that conceptual colour space is categorically organized in a manner that correlates with the arrangement of perceptual colour space (e.g., Boynton & Olson, 1987, 1990; Guest & Van Laar, 2000; Sturges & Whitfield, 1995). The ability to name colours is taken as an indicator of colour cognition, as accurate colour naming involves the transference of information from conceptual colour-processing mechanisms to stored phonological lexical colour codes (Davidoff, 1991). A recent study of adult colour naming by Guest and Van Laar (2000) provides evidence for the categorical representation of colour concepts. They asked each of 10 adults to name 1044 unique stimulus–background colour combinations (each of which was presented on three occasions). Unlike previous studies of colour naming in adults that have used restricted naming vocabularies (Boynton & Olson, 1987; Sturges & Whitfield, 1995), subjects were able to use an unrestricted vocabulary to name the different colour samples. Interestingly, the basic colour terms (as defined by Berlin & Kay, 1969) were still predominantly used in colour naming and were applied to the majority of the stimuli. Moreover, compared to non-basic colour terms, basic colour names were used more consistently and confidently, and were produced at a faster rate, hence confirming their distinctness from other non-basic colour terms. The results of these studies have been interpreted to suggest that there is a perceptual basis to colour categorization and the corresponding nomenclature (Boynton & Olson, 1987, 1990; Guest & Van Laar, 2000).

Over the course of development, the immature brain of the child must acquire this system of mappings of colour percepts to colour concepts, although exactly when, and how, this system becomes implemented is presently unclear. Developmental studies have shown young children's perceptual colour space is organized in a similar manner to that of the adult. For example, infants as young as 4 months of age can categorize the four primary chromatic hues in a perceptually similar manner to that of adults (Bornstein, Kessen, & Weiskopf, 1976). In addition, a study by Offenbach (1980) showed that basic perceptual colour space is invariant across age (from age 4 years to old age) in normally sighted individuals. Thus, when children engage in the learning of colour terms, they already possess colour percepts on which colour concepts can be mapped.

In this study we investigate how the system of perceptual mappings between colour percepts and colour concepts becomes implemented during the development period in which children learn to use colour terms. Initially, young children clearly lack a systematic mapping between colour concepts and colour percepts in the initial stages of colour term acquisition, because they often consistently use only one colour term to name a range of different colours (e.g., Istomina, 1963; Soja, 1994). In addition, they are likely to know more colour labels than colour referents (Bartlett, 1978). However, over the course of development, the underlying organization of colour concepts must come to reflect the categorical arrangement of perceptual colour space.

Very few developmental studies have investigated systematically the underlying structure of conceptual colour space in children. Examinations of the errors children make in comprehending and naming colours can be used to investigate how colour concepts are organized in the developing brain. Some studies have suggested that young children's colour concepts may be organized according to a warm–cool perceptual boundary. For example, 3-year-old children reportedly rarely make errors in colour naming that violate a perceptual boundary between warm (red, orange, and yellow) and cool (green, blue, and purple) colours (Park, Tsukagoshi, & Landau, 1985, also cited in Shatz et al., 1996). Furthermore, 2-year-old children appear to show an awareness of this perceptual boundary. Shatz et al. (1996) showed that on a task of spoken word-to-colour matching, in which a target colour is paired with a distracter colour from either within or between the warm–cool boundary, 2-year-olds made more within- than across-boundary errors. However, the within-across boundary distinction drawn by Shatz et al. is confounded with perceptual adjacency as within-boundary distracters were either adjacent or non-adjacent to the target colour, whereas across-boundary distracters were never adjacent to the target colour. Adjacent colours can lie either side of the warm–cool boundary (e.g., yellow and orange are both ''warm''; yellow and green are ''warm'' versus ''cool'' respectively), as can non-adjacent colours (e.g., yellow and red are both ''warm''; yellow and blue are ''warm'' versus ''cool'' respectively). Interestingly, Bartlett (1978) noted that when children have acquired around four colour terms, their naming errors appear to be based, in part, on perceptual adjacency. Thus, it is possible that a perceptual influence to the development of colour concepts may reflect structuring according to perceptual adjacency rather than a warm–cool perceptual boundary, although this specific hypothesis has not yet been tested formally.

In this study we investigate the underlying structure of developing conceptual colour space in four groups of children at different stages of language acquisition to determine the organization of the developing conceptual colour space. We compare children's knowledge of the 11 basic colour terms over two experimental tasks, as a function of language-age. Children's comprehension of basic colour terms was assessed in Experiment 1 using a spoken word-to-colour matching task. The accuracy of children's colour naming of the 11 basic terms was assessed in Experiment 2 with an explicit colour naming task. The influence of perceptual adjacency on colour comprehension was explored systematically by manipulating the nature of the relationship between the target and distracter colours over two experimental conditions. In condition 1, distracter colours were distant to the target colour in visual colour space, and in condition 2 distracter colours were adjacent colours to the target colour. The influence of perceptual adjacency on developing colour concepts was further explored in the colour naming task, by examining the distribution of naming errors made to distant and adjacent colour categories. If perceptual colour categorization influences the development of conceptual colour space, we argue that:

(1) Children will be significantly better at comprehending target colours presented with distant, rather than perceptually similar adjacent, distracters (Experiment 1); and

(2) children will generate significantly more adjacent (e.g., ''pink'' to a red target) than distant (e.g., ''blue'' to a red target) errors in colour naming

(Experiment 2). Our results generally support these predictions and suggest that perceptual colour categorization influences the nature by which conceptual colour categories are acquired.

GENERAL METHODS

Participants

Forty-three normally developing English-speaking children from three different day-care settings participated in the study. The socio-economic status and race of our sample of children was representative of a multi-cultural society such as Montreal. Prior consent was obtained from their parents or guardians. All of the children had normal or corrected to normal vision and hearing and had experienced normal language acquisition up to the time of testing, as judged by their parents. The 20 boys and 23 girls were divided more or less equally into four groups on the basis of their language-age (see later).

Language assessment

As the tasks used to assess the development of colour concepts are intimately related to general language skills (Johnson, 1977), language-age was considered to be a more reliable metric than chronological-age on which to compare children of similar ability. We use language-age rather than chronological-age, as analyses based on language-age produced less variance than those based on chronological-age, and thus allow differences between groups to be more clearly delineated (Pitchford & Mullen, 2001a). Furthermore, several studies have reported sex differences in colour naming, with girls outperforming boys of the same chronological-age (e.g., Anyan & Quillian, 1971; Bernasek & Haude, 1993; Johnson, 1977), a difference most likely due to a general superiority in linguistic skills commonly exhibited by girls (e.g., Maccoby, 1966; McGlone, 1980). Basing comparisons on language-age rather than chronological-age should therefore reduce the potential effects of sex differences on the overall pattern of results.

Language development was assessed using the Pre-School Language Scale—3 (Zimmerman, Steiner, & Pond, 1992). This standardized psycholinguistic scale has two sub-scales: (1) auditory comprehension measured receptive language abilities, and (2) expressive communication assessed expressive language skills. For auditory comprehension, children were required to point to specific pictures, and for expressive communication to produce spoken answers, in response to questions asked by the experimenter. The auditory comprehension sub-scale was administered first. Raw scores obtained from each of the sub-scales were summed to form a total language score from which age-equivalent scores were determined that ranged from a possible lower limit of 0 years 0 months to a possible upper limit of 7 years 0 months.

The mean (*M*), standard deviation (SD), and range (in months) for each of the four LA-groups was: 2 years (n = 10) M = 33.1, SD = 2.4, range 28–35; 3 years (n = 13) M = 43.2, SD = 2.7, range 40–47; 4 years (n = 10) M = 52.8, SD = 4.0, range 48–58; and 5 years (n = 10) M = 68.8, SD = 9.3, range 60–84.

Apparatus and stimuli

Stimuli were computer-generated 8-bit images, generated using 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 colour Plate 1, situated between pp. 64 and 65. The background of the screen was set to a light grey. Stimuli were the 11 basic colours, that is, red, pink, orange, brown, yellow, green, blue, purple, black, white, and grey. Clear examples of each of the 11 colours were chosen from a range of colour chips provided in the *Munsell Book of Colour*[1] 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 and CIE co-ordinates of each of the 11 colour stimuli and the background are listed in Appendix 1. Luminance is given as a percentage difference from the background.

Stimuli were a series of five cartoon animals to be dressed in each of 11 items of clothing (underwear, undershirt, hat, coat, overalls, T-shirt, shorts, pants, dress, socks and shoes) an example of which is shown in Plate 1, situated between pp. 64 and 65. Each animal was approximately 469 pixels high and 158 pixels wide (17.5 × 5.9 cm), subtending 32.5 and 11.2 degrees of visual angle at a typical sitting distance of 30 cm. The five cartoon characters were neutrally coloured and were easy to discriminate from the 11 basic colour stimuli as well as the grey background. Each of the 11 garments was coloured with each of the 11 basic colours.

Procedure

Each child was tested individually in a quiet area of the day-care centre. One experimenter (the first author) tested all of the children. A familiar educator was present during the testing of some of the younger children. 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 they were going to play some games on the computer. Two experiments were administered to assess

[1] Macbath Division of Kollmorgen Corporation, Baltimore, MD 21218, USA.

colour comprehension (Experiment 1) and colour naming (Experiment 2). Experiment 1 was given before Experiment 2.

EXPERIMENT 1: COLOUR COMPREHENSION

Method

This task measured children's ability to select a target colour corresponding to a spoken colour word. The target colour was presented in a group of three colours, with the two other colours both chosen from either distant (condition 1) or adjacent (condition 2) colour categories to the target.

Plate 1a (situated between pp. 64 and 65) shows the stimulus display. The experiment started with the appearance of a cartoon animal and three different colour choices of the same garment, one of which was the target colour and the other two colours acted as distracters. The position of the target stimulus was randomized across trials. Task instructions, spoken by a female, were recorded and presented via the cartoon animals as computer voice-over. The game was introduced to the child via the cartoon character computer voice-over. For example, ''Hey there. I'm Benji the Bunny and I need to get dressed. Can you help me?'' and the child was asked by the computer voice-over, for example, to ''Point to the RED overalls.'' The stimuli remained on the screen until the child responded and the response was entered into the computer. The cartoon animal was then dressed in the coloured garment selected by the child, irrespective of whether or not they had selected the correct colour (see Plate 1b, situated between pp. 64 and 65). A short beep after the child's response had been entered marked the end of each trial, and then the next trial was presented. For each new trial the previous garment disappeared and the animal appeared undressed. The same cartoon animal appeared for 11 trials, so that each of the 11 basic colour stimuli were presented once (i.e., using each of the 11 items of clothing once). For each animal, the 11 colour stimuli were presented in a random order. The combination of colours and garments was randomized. At the end of each presentation of 11 colours a lively piece of music played and the animal was re-dressed in the 11 coloured garments that had been selected. The computer voice-over the said ''Thanks for helping to dress me. You were very good.'' The next cartoon animal was then presented and the same procedure was repeated. Hence, over one block of 55 trials 11 colours were presented with each of the five animals. A second block of trials was then given, producing a total of 110 trials. The order in which the five cartoon animals were presented was randomized within each block of trials. Each child completed the experiment over several sessions lasting approximately 10 min.

To investigate the effect of perceptual adjacency on colour comprehension the relationship between the target and distracter colours was systematically manipulated over two experimental conditions. Distracter colours were selected that were considered to be either distant (condition 1) or adjacent (condition 2) neighbours to the target colour according to the Munsell colour space (see Appendix 2). As can be seen in Appendix 2, the number of adjacent and distant distracters varied for the different basic colours. In each condition there were 110 trials, thus over the whole experiment a total of 220 trials were presented.

Each of the 11 colour stimuli was presented with the same frequency, both as a target and as a distracter, over each condition. Thus, within each condition of 110 trials, each of the 11 basic colours was presented on 10 occasions as a target colour and on 20 occasions as a distracter. To ensure that each of the colour stimuli were presented on the same number of occasions within each of the experimental conditions, specific combinations of target to distracter colours were created (see Appendix 3). The two experimental conditions were counterbalanced across participants within each of the language-age groups to avoid order effects.

Results

The measure of discrimination (d′). d′ is a standard measure of discrimination that takes into account the fact that a child may have a predisposition (bias) to generate a particular response (e.g., ''orange'' in the colour comprehension task or ''blue'' in colour naming). d′ allows the child's ability to discriminate each colour to be calculated independently of their response bias. Chance discrimination corresponds to a d′ of 0, 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 (e.g., see Macmillan & Creelman, 1991, p. 10). This adjustment yielded a maximum d′ of 5.52, in which d′ refers to a child's ability to identify correctly a colour presented as a target (maximum of 10 hits), taking into account their tendency to select the colour in error when presented as a distracter (maximum of 20 false alarms). A d′ of 3.28 corresponds to a level of performance where children can significantly discriminate a particular colour term (at $p < .05$) and thus indicates the point at which their colour comprehension becomes accurate.

The aim of this experiment was to assess children's ability to comprehend each of the 11 basic colour categories, as a function of language-age. The mean d′ performance for each of the four LA groups on both of the experimental conditions is reported in Table 1.

Inspection of Table 1 shows there is considerable variation in performance for each of the 11 basic colours (as shown by the standard deviations) on this task amongst the two youngest LA groups. In contrast, the two older LA groups show very little variation in performance and for most of the 11 basic colours their performance is close to ceiling. So as to uphold assumptions about homogeneity of variance, two separate analyses were conducted in which differences in the mean performance of the 2- and 3-year LA groups were analysed

TABLE 1

Experiment 1: Mean d′ performance and standard deviation (SD) for each of the 11 basic colours presented when distractor colours were either distant (condition 1, C1) or adjacent (condition 2, C2) to the target colour in perceptual colour space, for each of the four language-age (LA) groups

Colour	*LA-group mean d′ (SD)*							
	2 years		*3 years*		*4 years*		*5 years*	
	C1	*C2*	*C1*	*C2*	*C1*	*C2*	*C1*	*C2*
Red	1.64 (1.87)	1.52 (1.8)	5.02 (1.09)	4.4 (2.03)	5.52 (0.0)	5.36 (0.53)	5.39 (0.44)	5.4 (0.39)
Pink	1.8 (1.73)	1.75 (2.17)	5.19 (0.67)	4.61 (1.58)	5.52 (0.0)	5.19 (0.72)	5.52 (0.0)	4.99 (0.69)
Orange	1.94 (1.98)	1.71 (2.03)	5.0 (0.7)	4.36 (1.52)	5.52 (0.0)	5.21 (0.7)	5.4 (0.39)	5.26 (0.55)
Brown	1.12 (0.87)	2.28 (2.28)	4.1 (1.66)	4.95 (1.11)	4.29 (1.6)	5.39 (0.44)	5.01 (0.91)	5.39 (0.44)
Yellow	2.25 (2.02)	2.5 (2.34)	5.13 (0.78)	4.76 (1.34)	5.52 (0.0)	5.39 (0.44)	5.52 (0.0)	5.52 (0.0)
Green	1.46 (1.63)	1.67 (1.92)	4.94 (1.3)	4.81 (1.54)	5.52 (0.0)	5.39 (0.44)	5.28 (0.51)	5.52 (0.0)
Blue	2.25 (1.92)	1.31 (2.02)	4.81 (1.04)	4.39 (1.8)	5.52 (0.0)	5.4 (0.39)	5.39 (0.44)	5.39 (0.44)
Purple	1.08 (1.76)	1.2 (2.08)	4.85 (1.26)	4.39 (2.08)	5.52 (0.0)	5.52 (0.0)	5.39 (0.44)	5.16 (0.59)
Black	1.53 (1.56)	1.07 (2.38)	5.0 (0.7)	4.95 (1.23)	5.13 (0.89)	5.22 (0.96)	5.52 (0.0)	5.26 (0.82)
White	1.79 (1.53)	1.27 (1.93)	5.37 (0.55)	4.85 (1.19)	5.52 (0.0)	5.52 (0.0)	5.52 (0.0)	5.52 (0.0)
Grey	0.69 (1.18)	1.36 (1.78)	3.87 (1.7)	4.43 (1.81)	4.49 (1.41)	5.23 (0.94)	5.26 (0.55)	5.26 (0.82)

independently from the 4- and 5-year LA groups. In each analysis, each child's d′ score of a particular LA group was entered into the analysis for each of the 11 basic colours on both experimental conditions.

Younger children; 2- and 3-year LA groups. Differences in mean d′ performance of the two youngest LA groups for each of the 11 basic colours presented in condition 1 (distant distracters) and condition 2 (adjacent distracters) were investigated by subjecting the data to a 2 × 2 × 11 mixed ANOVA, in which language-age (2) was the between-subject factor, and condition (2) and colour (11) were within-subject factors. A significant main effect of language-age, $F(1, 21) = 36.49$, $p < .0001$, was found, indicating that overall the performance of the 3-year LA group was better than that of children with a language-age of 2 years. A significant main effect of colour, $F(10, 210) = 4.09$, $p < .0001$, was found but the main effect of condition failed to reach significance. However, the interaction between condition and colour was significant, $F(10, 210) = 4.49$, $p < .0001$, suggesting that perceptual colour categorization influences colour comprehension to some extent. Post hoc analyses (using Tukey's HSD, $p < .05$) were conducted to explore the interaction between condition and colour (see Figure 1a). Results revealed that when presented with distant distracters (condition 1) brown was comprehended significantly less than pink, orange, yellow, blue and white, and grey was comprehended significantly less than the other colours except for brown and purple. In contrast, there was no significant difference in the children's ability to comprehend the 11 basic colours within condition 2 (adjacent distracters). None of the other interactions were significant.

Older children: 4- and 5-year LA groups. As with the younger children, a 2 × 2 × 11 mixed ANOVA was conducted to explore differences in the mean d′ performance of the 4- and 5-year LA groups for each of the 11 basic colours presented in condition 1 (distant distracters) and condition 2 (adjacent distracters). As before, the between-subject factor was language-age (2), and the within-subject factors were condition (2) and colour (11). Results revealed the main effect of language-age was not significant, indicating that the older children's comprehension of basic colour categories was very similar. The main effect of colour was significant, $F(10, 180) = 3.46$, $p < .001$, and although the main effect of condition did not reach significance, the interaction between condition and colour (shown in Figure 1b) was significant, $F(10, 180) = 3.75$, $p < .0001$. Post hoc analyses (using Tukey's HSD, $p < .05$) showed that when presented with distant distracters, brown was comprehended significantly less than all other colours expect grey, and grey was comprehended significantly less than the other basic colours, except for brown, black, and green. In addition, pink was comprehended significantly better when presented with distant, rather than adjacent, distracters. In contrast, brown and grey were comprehended

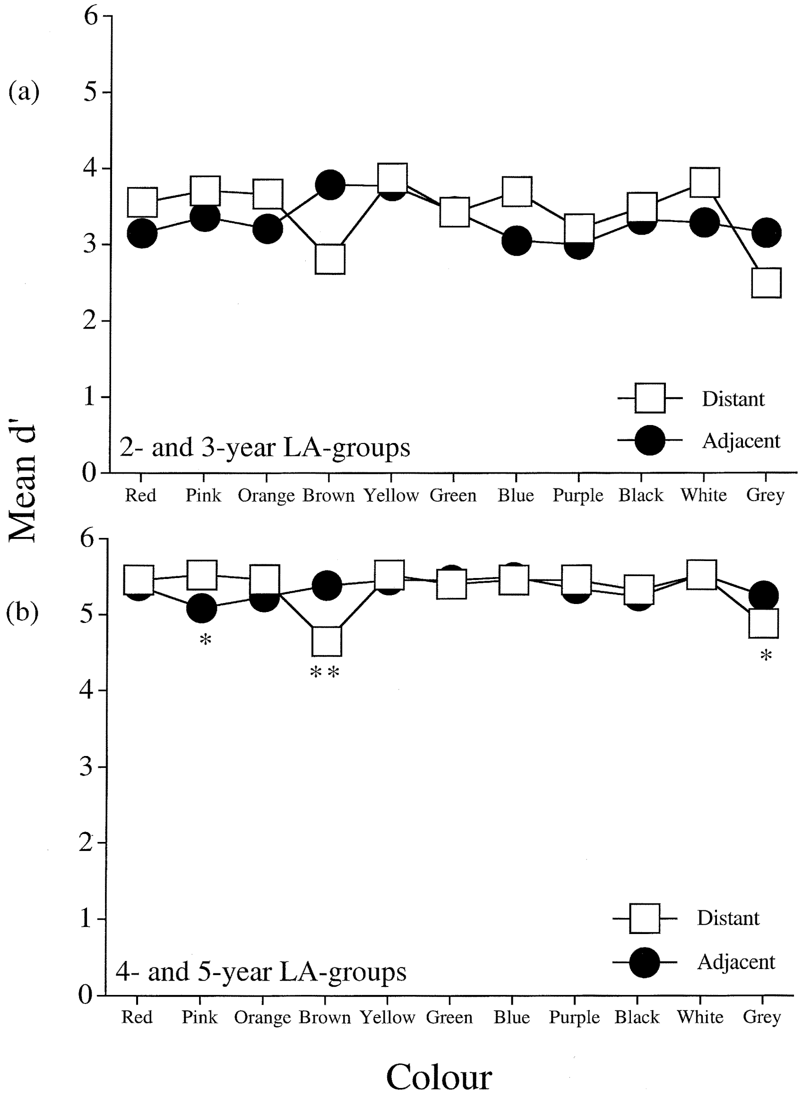

Figure 1. Experiment 1: Interaction between condition and colour for (a) the younger children (2- and 3-year LA groups) and (b) the older children (4- and 5-year LA groups).

significantly better when presented with adjacent, rather than distant, distracters. None of the other interactions were significant.

Discussion

The previous results suggest that perceptual adjacency has some influence on children's ability to comprehend the 11 basic colour categories, as in each analysis the interaction between condition and colour was significant. Furthermore, Figures 1a and 1b show a slight advantage in comprehension when target colours are presented with distant, rather than adjacent, distracters for some of the basic colour categories, although very few pairwise comparisons reached significance. Specifically, post hoc analyses showed that the older children comprehended the colour pink significantly better when presented with distant, rather than adjacent, distracter colours. The finding, however, that the older children comprehended brown and grey significantly *better* when presented with adjacent, rather than distant, distracters appears to be inconsistent with our prediction, and raises the possibility that these two colours should be reclassified as perceptual neighbours.

In our experimental design, adjacent and distant colours were determined by their relationship to target colours according to the Munsell colour space (see Appendix 2). Thus, we considered adjacent colours to brown to be the chromatic colours red, pink, orange, and yellow, and adjacent colours to grey were considered to be the other two achromatic colours, black and white. The pairing of brown and grey to these adjacent colour categories resulted in grey acting as a distant distracter to brown and vice versa. Thus, in condition 1 (distant distracters), on 3 of the 10 trials in which brown was a target colour, grey was a distant distracter. Likewise, on 4 of the 10 trials that grey was a target colour, brown was a distant distracter (see Appendix 3a).

The pairing of brown and grey as perceptually distant distracters may have acted to depress the overall level performance for the distant distracter condition but raise the overall level of performance for the adjacent distracter condition. To test this we removed brown and grey from the data set and re-ran the analyses. We found that the main effect of condition becomes significant for the older children, $F(1, 8) = 6.84$, $p < .05$, and both the younger and older LA groups show a trend towards better comprehension with distant rather than adjacent distracters (2- and 3-years: Condition 1 (distant distracters) mean $d' = 3.61$, condition 2 (adjacent distracters) mean $d' = 3.29$; 4- and 5-years: Condition 1 (distant distracters) mean = 5.46, condition 2 (adjacent distracters) mean $d' = 5.35$).

In addition, the significant interactions reported above between condition and colour for both the younger and older LA groups showed that brown and grey were comprehended significantly less than other basic colours, but only when presented with distant distracters. Should brown and grey be considered as perceptual neighbours, as suggested by our results, a greater influence of perceptual adjacency on colour comprehension would be expected.

In other colour spaces, such as the OSA space, brown and grey lie adjacent to each other within the internal structure of the colour space, and the other nine basic colours form the exterior structure of the colour space (Boynton & Olson, 1987). The poorer performance on brown and grey relative to the other nine basic colour terms at each language-age is supported by a further study (Pitchford & Mullen, 2001b, 2002) and suggests that children acquire these two colour terms at a later developmental stage. The relatively late acquisition of brown and grey compared to the other nine basic colour terms may have also contributed to the pattern of results reported earlier. If, as our data suggest, children find brown and grey difficult to comprehend relative to the other nine basic colour terms, their performance on each of these two colours is likely to be poorer when the other is presented as a distracter, as in condition 1 (distant distracters). Given the nature of our results it seems more appropriate for brown and grey to be considered as perceptual neighbours in the later analysis of naming errors (Experiment 2).

EXPERIMENT 2: COLOUR NAMING

Method

This task measured the accuracy by which children of the four different LA groups could produce each of the 11 basic colour terms. The colour naming experiment started with the appearance of one of the five cartoon animals presented in the centre of the screen (see plate 1 c, situated between pages 64 and 65). The animal was dressed in one of the 11 items of clothing that had been assigned one of 11 basic colour stimuli. The computer voice-over asked the child, for example, ''Hi. I'm Danny the Dog. Can you tell me what I'm wearing? What's the colour of my shorts?'' As before, the stimuli remained on the screen until the child responded and the response was entered into the computer by the experimenter. Again, a short beep marked the end of each trial, and the following trial was presented. The animal appeared undressed for each new trial. When all of the 11 colour stimuli had been presented for oral naming, via the 11 items of clothing, the lively piece of music played and the cartoon animal was re-dressed in all of the coloured garments that had been presented to the child. The same procedure was repeated for two blocks of 55 trials, producing a total of 110 trials. As before, the order in which the five animals were presented was randomized within each block of trials. Children completed the experiment over several 10 min sessions.

Correct colour naming was considered to be the production of the basic colour label that corresponded with the target colour (e.g., the label ''red'' for a red target). Four types of errors were recorded: Distant naming errors (e.g., ‘‘blue’’ to a red target), adjacent naming errors (e.g., ‘‘pink’’ to a red target), errors of omission (‘‘don’t know’’), or others (e.g., non-basic colour terms such as ‘‘silver’’, ‘‘gold’’, or ‘‘beige’’).

Results

The maximum d′ for colour naming was 6.39. In this experiment, d′ refers to a child’s ability to name correctly a particular colour when presented as a target (maximum of 10 hits) taking into account their erroneous application of that colour name to the other colour stimuli (maximum of 100 false alarms). As before, a d′ of 3.28 indicates the point at which children can accurately name (where $p < .05$) a basic colour. This experiment measured children’s ability to name correctly each of the 11 basic colours. Table 2 reports the mean d′ naming performance of each of the four LA groups.

As with the colour comprehension task, there was considerable variation (see standard deviations in Table 2) in basic colour naming for the two younger LA groups, whereas much less variation is shown by the two older LA groups. Again, the performance of the two older LA groups is close to ceiling for most of the basic colour categories, indicating that for most colours their naming was accurate. Thus, as in Experiment 1, separate analyses were conducted to compare differences in the mean performance of the 2- and 3-year LA groups and also the 4- and 5-year LA groups. Again, in each analysis, each child’s d′ score of a particular LA group for each of the 11 basic colours on the colour naming task was entered into the analysis.

TABLE 2
Experiment 2: Mean d′ performance and standard deviation (SD) of each of the four LA groups

Colour	*LA group mean d′ (SD)*			
	2 years	*3 years*	*4 years*	*5 years*
Red	0.98 (2.48)	4.97 (2.11)	6.24 (0.5)	6.39 (0.0)
Pink	2.41 (2.57)	4.8 (1.73)	6.11 (0.59)	5.87 (0.84)
Orange	2.74 (2.64)	4.26 (1.87)	6.15 (0.51)	6.01 (0.82)
Brown	1.37 (1.97)	2.26 (2.74)	3.64 (2.64)	5.44 (1.73)
Yellow	2.87 (2.38)	5.21 (1.52)	6.24 (0.5)	6.24 (0.5)
Green	2.7 (2.56)	5.01 (2.01)	6.24 (0.5)	6.39 (0.0)
Blue	2.84 (2.78)	6.14 (0.89)	6.39 (0.0)	6.39 (0.0)
Purple	1.68 (2.38)	4.54 (2.11)	6.11 (0.59)	5.89 (1.12)
Black	1.08 (2.31)	5.57 (0.83)	5.74 (1.18)	5.89 (1.07)
White	1.43 (2.24)	5.65 (1.23)	6.03 (0.78)	6.15 (0.51)
Grey	0.45 (1.3)	2.63 (2.09)	3.76 (3.03)	3.46 (3.19)

Younger children: 2- and 3-year LA groups. To investigate the differences in mean d′ naming ability for each of the 11 basic colours for the two youngest LA groups, a 2 × 11 mixed ANOVA was performed, in which language-age (2) was the between-subject factor and colour (11) was the within-subject factor. A significant main effect of language-age, $F(1, 21) = 17.88$, $p < .001$, was found, indicating that overall the 3-year LA group were significantly better at colour naming than the 2-year LA group. In addition, the main effect of colour was significant, $F(10, 210) = 8.73$, $p < .0001$, as was the interaction between language-age and colour, ($F(10, 210) = 3.54$, $p < .001$.

The significant interaction between language-age and colour, shown in Figure 2, suggests that children learn to name different colours at different rates of acquisition. Post hoc analyses (using Tukey's HSD, $p < .05$) were conducted to explore the interaction. Results showed children with a language-age of 2 years were significantly poorer at naming grey than orange, yellow, green, and blue. By a language-age of 3 years, brown was named significantly less than all other

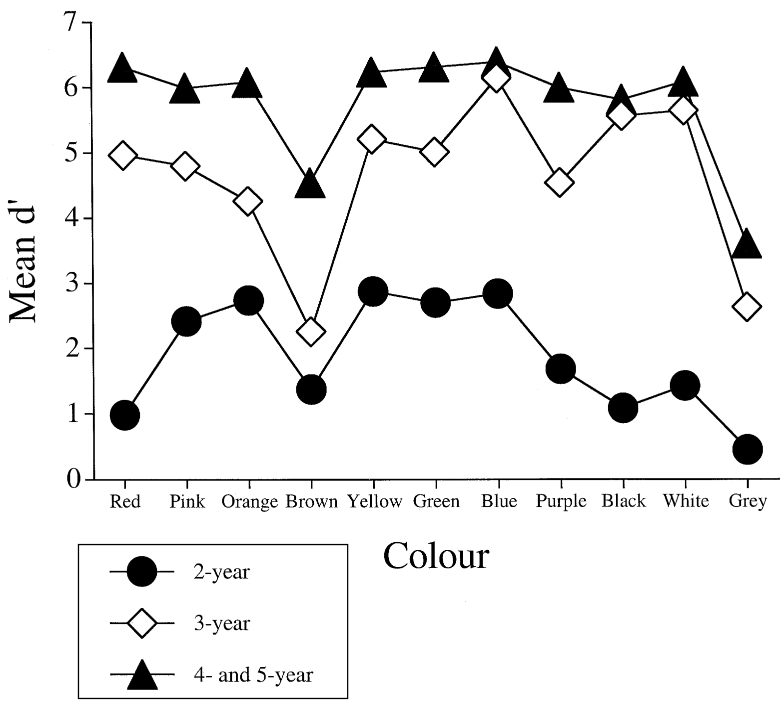

Figure 2. Experiment 2: Interaction between language-age and colour is shown for the younger children (2- and 3-year LA groups). Main effect of colour is shown for the older children (4- and 5-year LA groups).

colours except grey, grey was named significantly less than all other colours except brown and orange, and orange was named significantly less than blue.

Older children: 4- and 5-year LA groups. A separate 2 × 11 mixed ANOVA was conducted to explore the differences in mean d′ naming ability of the two older LA groups for each of the 11 basic colours. As before, language-age (2) was the between-subject factor and colour (11) was the within-subject factor. Only the main effect of colour was significant, $F(10, 180) = 10.53$, $p < .0001$. Post hoc analyses (using Tukey's HSD, $p < .05$) showed that brown and grey were named significantly less than all other colours except for grey and brown respectively (see Figure 2).

Error analysis

To explore the influence of perceptual adjacency on colour naming we performed an analysis of the naming errors made by the children in each of the four LA groups, as erroneous colour naming can shed light on the underlying organization of conceptual colour representations. We looked at the different types of naming errors made by children in the four LA groups across the colour naming task. We were interested to see if children more readily misnamed a target colour with a name of a colour that lies adjacent to, rather than distant from, the target colour in the Munsell colour space. As the results from Experiment 1 suggest that brown and grey are perceptual neighbours, we considered the misnaming of brown with ''grey'' and grey with ''brown'' to be adjacent naming errors. For each child, responses were categorized as either: Correct (e.g., ''red'' to a red target), distant naming error (e.g., ''blue'' to a red target), adjacent naming error (e.g., ''pink'' to a red target), error of omission (''don't know''), or other (e.g., non-basic colour terms such as ''silver'', ''gold'', or ''beige''). Two of the children in the 2-year LA group used only one colour term (blue) to name all of the 11 colour categories. Since this prevents any genuine differences between distant and adjacent naming errors being revealed we excluded these two children from the error analyses.

To investigate the influence of categorical colour perception on colour naming, only differences between the number of distant and adjacent error categories were explored. For each child, the number of errors made to each of the 11 basic colour categories was normalized to take account of differences in prior probabilities of making an adjacent or distant error across the different colour categories. Normalizing the number of errors made to take account of differences in guess rates is essential with such data because for most colours there are more distant than adjacent error names. Thus, for most of the 11 basic colours, there is a greater chance of producing a distant than adjacent naming error if children are randomly assigning colour names. For example, if the colour green is misnamed with a basic colour term, there are eight possible distant naming errors (red, pink, orange, brown, purple, black, white, and grey) but only two possible adjacent naming errors (yellow and blue). In this instance, the prior probability of misnaming the colour green is unequal (.8 for a distant error and .2 for an adjacent error) and biased towards making a distant error. In contrast, when the target colour brown is named erroneously with a basic colour term, there are five distant (green, blue, purple, black, white) and five adjacent (red, pink, orange, yellow, grey) colours to which an error can be made. Thus, there is an equal prior probability (.5) of making a distant or adjacent naming error to the colour brown. So as to avoid this problem, for each child the number of distant and adjacent naming errors made to each of the 11 basic colours was normalized to a common guess rate of 50% (probability of .5 for each of the two error categories). Thus, if children are randomly assigning basic colour names when misnaming any of the 11 target colours there should be no difference between the number of distant and adjacent errors made.

As with the previous analyses, for each child, the normalized number of distant and adjacent errors made to each of the 11 basic colours was entered into the following analyses. As before, the error data from the 2- and 3-year LA groups was analysed separately from the 4- and 5-year LA groups.

Younger children: 2- and 3-year LA groups. To investigate differences between the (normalized) mean number of adjacent and distant naming errors made by the 2- and 3-year LA groups to each of the 11 basic colours, a $2 \times 2 \times 11$ mixed ANOVA was conducted. Language-age (2) was the between-subject factor, and error category (2) and colour (11) were the within-subject factors. Significant main effects of language-age, $F(1, 19) = 9.67$, $p < .01$, and colour, $F(10, 190) = 3.23$, $p < .001$, were found, and the interaction between language-age and colour was significant, $F(10, 190) = 2.73$, $p < .01$. Post hoc analyses (using Tukey–Kramer, $p < .05$) of this interaction showed that the 2-year LA group made significantly more errors to purple than blue and green.

Although a significant main effect of error category was not found, the interaction between error category and language-age, $F(1, 19) = 4.82$, $p < .05$, was significant. This interaction is shown in Figure 3 and was explored further with post hoc analyses (using Tukey–Kramer, $p < .05$). As can be seen from Figure 3, the 2-year LA group made slightly more distant than adjacent naming errors, but this difference was not significant, suggesting that when misnaming target colours, children with a language-age of 2 years are likely to apply colour names randomly. However, the distribution of error categories shifted with development, as the 3-year LA group made significantly more adjacent naming errors than errors to distant colour categories. In addition, children with a language-age of 3 years made significantly fewer distant naming errors than the 2-year LA group. These results suggest that perceptual colour categorization has an influence on colour naming when children's colour naming begins to be

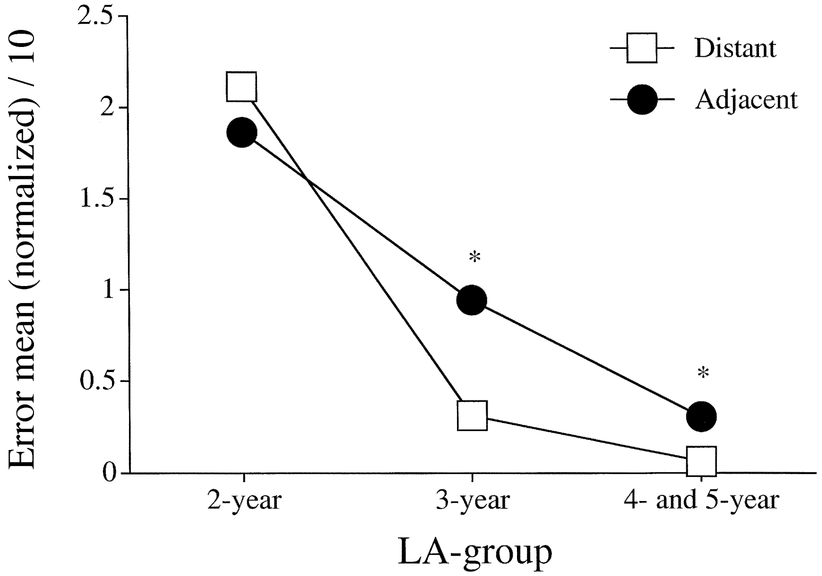

Figure 3. Experiment 2: Distribution (normalized mean) of distant and adjacent naming errors made by the different LA groups.

systematic at a language-age of around 3 years. The other interactions were not significant.

Older children: 4- and 5-year LA groups. A separate 2 × 2 × 11 mixed ANOVA was conducted to explore differences in the (normalized) mean naming errors of the 4- and 5-year LA groups for each of the 11 basic colour categories. As before, the between-subject factor was language-age (2) and the within-subject factors were error category (2) and colour (11). Results showed the main effect of language-age was not significant, indicating that the 4- and 5-year LA groups made a similar number of errors overall. Although the older children made very few naming errors, the main effect of error category was significant, $F(1, 18) = 5.64$, $p < .05$, and as shown in Figure 3, when collapsed across colours, significantly more naming errors were made to adjacent, rather than distant, colour categories by the older LA groups. The main effect of colour was also significant, $F(10, 180) = 5.18$, $p < .0001$, and the interaction between condition and colour was significant, $F(10, 180) = 6.89$, $p < .0001$. Post hoc analyses (using Tukey–Kramer, $p < .05$) of this interaction revealed that when naming the colour grey, the older children made significantly more adjacent than distant errors, and they made significantly more adjacent errors to grey than to all the other colour categories. None of the other interactions were significant.

Discussion

The results from the colour naming task support our prediction that children will make more adjacent naming errors compared to distant naming errors when conceptual colour space begins to reflect the categorical organization of human colour sensations. The two children in the 2-year LA group that named all of the 11 basic colour categories with the same colour label ''blue'' suggests that initially perceptual colour space is broadly mapped to a particular phonological colour code. However, our data suggest that as the size of the phonological colour lexicon increases with language-age, and children acquire more colour labels, the mappings between perceptual colour categories and conceptual colour space become increasingly refined.

The finding that the 2-year LA group made a similar number of distant versus adjacent naming errors (when normalized to take account of differences in guess rates) over the colour naming task suggests an early stage of colour term learning exists where the mappings between colour concepts and perceptual colour space are undefined. When misnaming a colour, children at this stage of colour term acquisition appear to apply colour terms randomly and their errors bare little relationship to the target colour. Conceptual colour space appears to be mapped broadly to perceptual colour categories, resulting in a pattern of inconsistent misnaming of colour sensations.

Results show that by a language-age of 3 years, significant effects of perceptual adjacency was found in colour naming as the 3-year LA group made significantly more adjacent than distant naming errors, when collapsed across colours. Although the 3-year LA group made fewer errors overall than children with a language-age of 2 years, the number of distant errors was dramatically reduced, resulting in the 3-year LA group making significantly fewer distant naming errors than the 2-year LA group. The finding that the 3-year LA group made significantly more adjacent than distant naming errors over all 11 basic colours suggests that the mappings between perceptual colour categories and conceptual colour space are becoming increasingly refined to perceptually adjacent colour categories.

The pattern of results from the 4- and 5-year LA groups suggest that the mappings between colour percepts and colour concepts are systematic, as their performance on the tasks of colour comprehension and colour naming was close to ceiling. This suggests that by a language-age of 4 years children have acquired the full complement of basic colour terms and each of the 11 basic colours can be comprehended and named largely without error. At this stage of development, if children make errors in colour naming they will most likely make adjacent errors that appear to be confined to the erroneous naming of grey with ''brown'', the last two colours to be acquired.

GENERAL DISCUSSION

In this study we investigated the process by which developing conceptual colour space becomes mapped to perceptual colour categories. We argued that in the initial stages of colour term acquisition colour terms are not systematically mapped to colour sensations because children will name perceptually different colours with only one colour term, and once they have acquired more than one colour term their application is initially haphazard and inconsistent (Baldwin, 1893; Cruse, 1977; Darwin, 1877, cited in Bornstein, 1985; Modreski & Goss, 1969; Nagel, 1906). However, studies of adult colour naming suggest that conceptual colour space is categorically structured in a manner that reflects the organization of perceptual colour categories (e.g., Boynton & Olson, 1987, 1990; Guest & Van Laar, 2000; Sturges & Whitfield, 1995). We argued that this system of perceptual mappings between colour percepts and colour concepts must become implemented during the developmental period in which children learn colour terms.

This is the first study to investigate systematically the influence of perceptual categorization on the development of conceptual colour space in pre-school children. We investigated the role of perception on the development of colour concepts by comparing children's knowledge of the 11 basic colour terms identified by Berlin and Kay (1969) in tasks of colour comprehension and colour naming. We predicted that, if perceptual colour categorization influences the development of conceptual colour space, children would be significantly better at comprehending target colours when presented with distant, rather than adjacent, perceptual colour categories, and would generate significantly more adjacent than distant errors in colour naming. The results of our study generally support our predictions.

We found that children's ability to comprehend basic colour terms was influenced by the nature of the distracter colours presented alongside the target. Our data showed a trend towards better comprehension when target colours were presented with distracter colours from perceptually distant, rather than adjacent, colour categories. However few of the pairwise comparisons reached significance (in line with our prediction, we found that pink was comprehended significantly better when presented with distant, rather than adjacent, distracters, by the two older LA groups). Further support for our prediction is provided by the colour naming task. Most importantly, we found that children with a language-age of 3 years and above made significantly more adjacent than distant errors in colour naming. Thus, our results support the notion that categorical colour perception influences the development of the underlying structure of conceptual colour space.

Not surprisingly, a typical developmental progression of colour term knowledge was revealed, as children's ability to both comprehend and name the 11 basic colour categories increased with language-age. The main stage of learning appears to take place between the language-ages of 2 and 3 years, as on each of the two tasks the 3-year LA group performed significantly better than the 2-year LA group. By a language-age of 4 years, children could comprehend and name most of the 11 basic colours without error, indicating their knowledge of basic colour terms had become accurate. We address the developmental order in which colour terms are acquired in two further papers (Pitchford & Mullen, 2001b, in press). We present evidence to suggest that colour term acquisition develops in two distinct time-frames that reflect the establishment of first the exterior and then the interior structure of conceptual colour space. Knowledge of the nine basic colours (yellow, blue, black, green, white, pink, orange, red, and purple) that form the outside of conceptual colour space become reliable, in any order, between the ages of 35.6 and 39.5 months. After a considerable lag of up to nine months, children acquire reliable knowledge, in any order, of the final two basic colours (brown and grey) that form the interior structure of conceptual colour space. Why children find brown and grey difficult to conceptualize remains to be determined, although interestingly, adults also appear to have more difficulty with brown and grey than other basic colour terms. The data presented by Guest and Van Laar (2000) show that adult's nameability (consistency, confidence, and speed of naming) of brown and grey is poorer than other basic colour terms. This dichotomous developmental order is consistent with the view that colour concepts become systematically mapped to perceptual colour space over the course of acquisition.

An alternative view has been recently revived by Davidoff and colleagues amongst others (Davidoff, Davies, & Roberson, 1999; Roberson, Davies, & Davidoff, 2000; Saunders & van Brakel, 1997) that is based on the original ideas of Whorf (1956), in which linguistic colour categories are believed to influence categorical colour perception. They propose that perceptual colour categories form by demarcations at boundaries that are driven by language and are thus culturally defined. A potential difficulty for this account comes from developmental studies that have demonstrated categorical colour perception in infants as young as 4 months (Bornstein et al., 1976; Catherwood, Crassini, & Freilberg, 1989). In addition, perceptual colour categorization appears to be invariant across age in normally sighted individuals (Offenbach, 1980) and has be shown in other primate species (Matsuzawa, 1985). These studies strongly suggest that perceptual colour categorization is not culturally defined. It is difficult to see how linguistic relativity can adequately account for categorical colour perception in pre-verbal infants and non-verbal primates. However, Roberson et al. (2000) point out that 4-month-old infants are capable of learning many different categories, so they argue that age alone cannot rule out the role of early linguistic experience on the shaping of perceptual colour categories, although this seems unlikely given the short time-frame involved. In addition, the present study shows that conceptual colour categories are forming prior to the fully developed adult usage of the colour name. Whether, as we suggest, perceptual categorization drives the development of colour term acquisition or, as Davidoff and colleagues suggest, the possession of pre-verbal linguistic colour categories drives categorical colour perception, is still an open question.

Our results are compatible with previous developmental studies that have suggested young children are aware of a warm–cool perceptual boundary (e.g., Shatz et al., 1996). If, as our results suggest, conceptual colour space becomes systematically mapped to perceptual colour categories, children should be expected to show an awareness of a warm–cool perceptual boundary because the ‘‘warm’’ colours red, orange, and yellow, are perceptually adjacent colour categories, as are the ‘‘cool’’ colours green, blue, and purple. In contrast, the results of our study cannot be accounted for by proposing that developing conceptual colour space is based on a warm–cool perceptual boundary as children made adjacent naming errors that fell across the warm–cool boundary. For example, they erroneously named red with ‘‘purple’’ and vice versa and they misnamed yellow with ‘‘green’’ and vice versa.

Our results are also compatible with a neuropsychological study of the erroneous patterns of colour naming made by an adult (JT) with colour agnosia (Woodward, Dixon, Mullen, Christensen, & Bub, 1999). Colour agnosia is a neuropsychological disorder that arises from focal brain damage in which colour concepts are selectively impaired while colour percepts and phonological colour codes remain intact (Davidoff, 1991). As the errors made by JT in colour naming reflected selective damage to the conceptual colour-processing mechanism they were thus informative as to the underlying structure of conceptual colour space. JT made a consistent pattern of errors across tasks of explicit colour naming and spoken colour-word-to-colour-chip matching, in which errors were constrained to adjacent areas of visual colour space (for example, naming pink as ‘‘purple’’ and orange as ‘‘yellow’’) rather than distal areas. The consistent pattern of naming errors made by JT in which target colours were readily confused with colours located adjacent in visual colour space is suggestive of damage to a categorically organized conceptual colour-processing mechanism that is directly based on perceptual colour categories.

As expected, our results appear to rest on genuine differences in hue rather than other factors known to contribute to colour appearance, such as luminance. For each of the 11 basic colours, distant and adjacent colours were determined on the basis of their relative hue location to target colours in the Munsell colour space, even though they may differ in luminance. Appendix 1 reports the physical characteristics of our stimuli. It can be seen that some adjacent colour categories are also similar in luminance (e.g., purple and blue) but others differ greatly in luminance (e.g., purple and pink). Furthermore, some colours that are similar in luminance were not considered to be perceptually adjacent colour categories (e.g., red and grey, and pink and green). Our results show that although children readily confused colours that are chromatically adjacent, irrespective of their similarity in luminance (such as purple with either pink or blue), children rarely confused distant colours that were similar in luminance but not hue (such as red and grey, and pink and green). This suggests that the mapping of colour concepts to colour percepts is based primarily on the location of the category in colour space, and not by luminance *per se*.

To conclude, this is the first study to investigate systematically how the underlying basis of perceptual mappings to developing colour concepts becomes implemented during the developmental period in which colour terms are learned. Our results suggest that the process by which human colour sensations are mapped to colour concepts is initially broad in nature, but becomes increasingly refined over the course of development to perceptually adjacent colour categories. Eventually, a system of mappings between colour percepts and colour concepts is established that reflects the categorical organization of the basic perceptual colour categories.

REFERENCES

Andrick, G.R., & Tager-Flushberg, H. (1986). The acquisition of colour terms. *Journal of Child Language*, *13*, 119–134.

Anyan, W.R., & Quillian, W.W. (1971). The naming of primary colours by children. *Child Development*, *42*, 1629–1632.

Baldwin, J.M. (1983). A new method of child study. *Science (Washington, D.C.)*, *21*, 213–214.

Bartlett, E.J. (1978). The acquisition of the meaning of colour terms: A study of lexical development. In P. Smith & R. Campbell (Eds.), *Proceedings of the NATO conference on the psychology of language*, New York: Plenum.

Berlin, B., & Kay, P. (1969). *Basic colour terms*. Berkeley, CA: University of California Press.

Bernasek, J.L., & Haude, R.H. (1993). Colour naming and colour-matching by pre-school children as a function of visual field and sex. *Perceptual and Motor Skills*, *77*, 739–747.

Bornstein, M.H. (1985). On the development of colour naming in young children: Data and theory. *Brain and Language*, *26*, 72–93.

Bornstein, M.H., Kessen, W., & Weiskopf, S. (1976). Colour vision and hue categorisation in young human infants. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 115–129.

Boynton, R.M., Fargo, L., Olson, C.X., & Smallman, H.S. (1989). Category effects in colour memory. *Colour Research and Application*, *14*, 229–234.

Boynton, R.M., & Olson, C.X. (1987). Locating basic colours in the OSA space. *Colour Research and Application*, *12*, 94–105.

Boynton, R.M., & Olson, C.X. (1990). Salience of chromatic basic colour terms conformed by three measures. *Vision Research*, *30*, 1311–1317.

Carey, S. (1978). The child as a word learner. In M. Halle, J. Bresnan, & G. Miller (Eds.), *Linguistic theory and psychological reality*. Cambridge, MA: MIT Press.

Catherwood, D., Crassini, B., & Freilberg, K. (1989). Infant response to stimuli of similar hue and dissimilar shape: Tracing the origins of the categorization of objects by hue. *Child Development*, *60*, 752–762.

Collier, G.A. (1976). Further evidence for universal colour categories. *Language*, *52*, 884–890.

Cruse, D.A. (1977). A note on the learning of colour names. *Journal of Child Language*, *4*, 305–311.

Davidoff, J.B. (1991). *Cognition through colour*. Cambridge, MA: MIT Press.

Davidoff, J.B., Davies, I., & Roberson, D. (1999). Colour categories in a stone-age tribe. *Nature*, *398*, 203–204.

Guest, S., & Van Laar, D. (2000). The structure of colour naming space. *Vision Research*, *40*, 723–734.

Harkness, S. (1973). Universal aspects of learning colour codes: A study of two cultures. *Ethos*, *1*, 175–200.

Heider, E.R. (1971). ''Focal'' colour areas and the development of colour names. *Developmental Psychology*, *4*, 447–455.

Heider, E.R. (1972). Universals in colour naming and memory. *Journal of Experimental Psychology*, *93*, 10–20.

Istomina, Z.M. (1963). Perception and naming of colour in early childhood. *Soviet Psychology and Psychiatry*, *1*, 37–46.

Johnson, E.G. (1977). The development of colour knowledge in pre-school children. *Child Development*, *45*, 308–311.

Maccoby, E.E. (1966). *The development of sex differences*. Stanford, CA: Stanford University Press.

Macmillan, N.A., & Creelman, C.D. (1991). *Detection theory: A user's guide*. Cambridge, UK: Cambridge University Press.

Markman, E.M. (1989). *Categorization and naming in children: Problems of induction*. Cambridge, MA: MIT Press.

Matsuzawa, T. (1985). Colour naming and classification in a chimpanzee (*Pan troglodytes*). *Journal of Human Evolution*, *14*, 283–291.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral and Brain Sciences*, *3*, 215–263.

Mervis, C.B., Catlin, J., & Rosch, E. (1975). Development of the structure of colour categories. *Developmental Psychology*, *11*, 54–60.

Modreski, R.A., & Goss, A.E. (1969). Young children's initial and changed names form-colour stimuli. *Journal of Experimental Child Psychology*, *8*, 402–409.

Nagel, W.A. (1906). Observations on the colour-sense of a child. *Journal of Comparative Neurology and Psychology*, *16*, 217–230.

Nelson, K. (1991). Concepts of meaning in language development. In N.A. Krasnegor & D.M. Rumbaugh (Eds.), *Biological and behavioral determinants of language development* (pp. 89–115). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Offenbach, S.I. (1980). Children's perception of Munsell colours. *Journal of Psychology*, *104*, 43–51.

Park, S., Tsukagoshi, K., & Landau, B. (1985). *Young children's misnaming of colours*. Paper presented at the biennial meeting of the Society for Research in Child Development, Toronto, Canada.

Pitchford, N.J., & Mullen, K.T. (2001a). Conceptualisation of perceptual attributes: A special case for colour? *Journal of Experimental Child Psychology*, *80*, 289–314.

Pitchford, N.J., & Mullen, K.T. (2001b). Young children's development of basic colour terms. O.S. of America, ''Vision and color meeting: Color workshop'', *Optics Express*, *9*, 1.

Pitchford, N.J., & Mullen, K.T. (in press). Is the acquisition of basic colour terms in young children constrained? *Perception*.

Roberson, D., Davies, I., & Davidoff, J.B. (2000). Colour categories are not universal: Replications and new evidence from a stone-age culture. *Journal of Experimental Psychology: General*, *129*, 369–398.

Rosch, E.H. (1973). Natural categories. *Cognitive Psychology*, *4*, 328–350.

Saunders, B.A.C., & van Brakel, J. (1997). Are there nontrivial constraints on colour categorization? *Behavioural and Brain Sciences*, *20*, 167–228.

Shatz, M., Behrend, D., Gelman, S.A., & Ebeling, K.S. (1996). Colour term knowledge in two-year-olds: Evidence for early competence. *Journal of Child Language*, *23*, 177–199.

Soja, N.N. (1994). Young children's concept of color and its relation to the acquisition of color words. *Child Development*, *65*, 918–937.

Sturges, J., & Whitfield, T.W.A. (1995). Locating basic colours in the Munsell space. *Colour Research and Application*, *20*, 364–376.

Uchikawa, K., & Boynton, R.M. (1987). Categorical colour perception of Japanese observers: Comparison with that of Americans. *Vision Research*, *27*, 1825–1833.

Uchikawa, K., & Shinoda, H. (1990). Effects of colour memory on colour appearance. In Y. Ohta (Ed.), *Colour vision deficiencies* (Proceedings of the symposium of the International Research Group on Colour Vision Deficiencies, Tokyo, Japan, 1990, pp. 35–43). Amsterdam: Kugler & Ghedini Publications.

Uchikawa, K., & Sugiyama, T. (1993). Effects of eleven basic colour categories on colour memory. *Investigative Ophthalmology and Visual Science*, *34*, 745.

Whorf, B.L. (1956). The relation of habitual thought and behavior to language. In J.B. Carroll (Ed.), *Language, thought and reality: Essays by B.L. Whorf*. Cambridge, MA: MIT Press.

Woodward, T.S., Dixon, M.J., Mullen, K.T., Christensen, K.M., & Bub, D.N. (1999). Analysis of errors in colour agnosia: A single-case study. *Neurocase*, *5*, 95–108.

Zimmerman, I.L., Steiner, V.G., & Pond, R.E. (1992). *The Pre-School Language Scale—3*. San Antonio, TX: Psychological Corporation.

Manuscript received January 2001
Revised manuscript received November 2001

APPENDICES

1. Munsell chip co-ordinates

Colour	*Munsell chip co-ordinate*	*CIE 2° chromaticity co-ordinates (x, y; u′, v′)*[1]	*Luminance (% difference from the background 2)*
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	N5.51/1	0.268, 0.281; 0.184, 0.434	−59.2
Background	N8/1	0.277, 0.297; 0.185, 0.444	0.0

[1] Measured with a Photo Research PR-645 SpectralCal Colorimeter.
[2] 49 cd/m^2.

2. Relationship between target (*T*) and distracter colours in condition 1 (D = distant distracters) and condition 2 (**A** = adjacent distracters) in Experiments 1 and 2

Target colour	*Distracter colours*										
	R	*Pi*	*O*	*Br*	*Y*	*G*	*B*	*Pr*	*Bl*	*W*	*Gr*
Red (R)	*T*	**A**	**A**	**A**	D	D	D	**A**	D	D	D
Pink (Pi)	**A**	*T*	**A**	**A**	D	D	D	**A**	D	D	D
Orange (O)	**A**	**A**	*T*	**A**	**A**	D	D	D	D	D	D
Brown (Br)	**A**	**A**	**A**	*T*	**A**	D	D	D	D	D	D*
Yellow (Y)	D	D	**A**	**A**	*T*	**A**	D	D	D	D	D
Green (G)	D	D	D	D	**A**	*T*	**A**	D	D	D	D
Blue (B)	D	D	D	D	D	**A**	*T*	**A**	D	D	D
Purple (Pr)	**A**	**A**	D	D	D	D	**A**	*T*	D	D	D
Black (Bl)	D	D	D	D	D	D	D	D	*T*	**A**	**A**
White (W)	D	D	D	D	D	D	D	D	**A**	*T*	**A**
Grey (Gr)	D	D	D	D	D	D	D*	D	**A**	**A**	*T*

* In Experiment 2, grey was considered to be an adjacent error to brown and vice versa.

3. Specific target and distracter combinations in Experiment 1

(a) Condition 1: Distant distracter colours

Colour	*Distracter combination*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Red (R)	Y Bl	Y G	Y W	Y Gr	G B	G Bl	G W	G Gr	B Gr	B Bl
Pink (Pi)	Y B	Y G	Y W	Y Bl	Y Gr	G B	G Bl	G W	B Gr	B Bl
Orange (O)	B Pr	B W	B Bl	B Gr	G Pr	G W	G B1	G Gr	Pr Gr	Pr W
Brown (Br)	G Pr	G B	G W	G Gr	Pr B	Pr Bl	Pr W	Pr Gr	B Gr	B Bl
Yellow (Y)	R Pr	R Pi	R Bl	R Gr	B W	B Bl	B Pi	Pi W	Pi Gr	Pi W
Green (G)	R Br	R Pi	R Gr	Pr Bl	Pr W	O Bl	O W	Pi Bl	Pi W	Br W
Blue (B)	R Br	R Pi	R Gr	Pi Bl	Pi W	Y Gr	Y Bl	O W	O Br	Br Bl
Purple (Pr)	Br O	Br G	Br Bl	Br Gr	Y Gr	Y Bl	Y W	O W	O Gr	G Gr
Black (Bl)	O Pi	O Pr	O B	O R	O Br	Br Y	Br Pr	Br Pi	R Pi	R Y
White (W)	O Y	O Pi	O Br	Br R	Br G	Pr R	Pr Pi	Pr Y	R Y	R Pi
Grey (Gr)	O Br	O B	O Pr	O R	Br Y	Br Pi	Br R	Pi R	Pi Y	Pr R

(b) Condition 2: Adjacent distracter colours

Colour	*Distracter combination*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Red (R)	O Pi	O Pi	O Br	O Br	O Pr	Pr Pi	Pr Pi	Pr Br	Pr Br	Pi Br
Pink (Pi)	O R	O R	O Br	O Br	O Pr	Pr R	Pr R	Pr Br	Pr Br	R Br
Orange (O)	Br R	Br R	Br Y	Br Y	Br Pi	Br Pi	Y Pi	Y Pi	Y R	R Pi
Brown (Br)	Y R	Y R	Y R	Y Pi	Y O	O R	O Pi	O Pi	Pi R	Pi R
Yellow (Y)	G O	G O	G O	G O	G O	G O	G Br	G Br	G Br	G Br
Green (G)	Y B	Y B	Y B	Y B	Y B	Y B	Y B	Y B	Y B	Y B
Blue (B)	Pr G	Pr G	Pr G	Pr G	Pr G	Pr G	Pr G	Pr G	Pr G	Pr G
Purple (Pr)	B R	B R	B R	B R	B R	B Pi	B Pi	B Pi	B Pi	B Pi
Black (Bl)	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr	W Gr
White (W)	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr	Bl Gr
Grey (Gr)	Bl W	Bl W	Bl W	Bl W	Bl W	Bl W	Bl W	Bl W	Bl W	Bl W