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The colour of Os: Naturally biased associations between shape and colour

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Abstract. Many letters of the alphabet are consistently mapped to specific colours by English-speaking adults, both in the general population and in individuals with grapheme – colour synaesthesia who perceive letters in colour. Such associations may be naturally biased by intrinsic sensory cortical organisation, or may be based in literacy (eg 'A' is for 'apple', apples are red; therefore A is red). To distinguish these two hypotheses, we tested pre-literate children in three experiments and compared their results to those of literate children (aged 7 – 9 years) and adults. The results indicate that some colour – letter mappings (O white, X black) are naturally biased by the shape of the letter, whereas others (A red, G green) may be based in literacy. They suggest that sensory cortical organisation initially binds colour to some shapes, and that learning to read can induce additional associations, likely through the influence of higher-order networks as letters take on meaning.

1 Introduction

Adults do not generally have strong colour associations to letters. However, when asked to make a choice, they consistently map some letters to specific colours (Marks 1975; Rich et al 2005; Simner et al 2005). Interestingly, adults with grapheme – colour synaesthesia, who actually perceive black-and-white letters in colour, show the same consistent colour – letter associations for those specific letters (eg A tends to be red, G tends to be green, Z tends to be black, etc) despite the variability between synaesthetic individuals in the mapping of other letters. Synaesthesia, which occurs in about 5% of adults (Simner et al 2006), refers to the phenomenon in which stimulation of one sense elicits a concrete experience in that sense and in another sense, or on a different dimension of the same sense, as in the most common form — grapheme – colour synaesthesia (Cytowic 2002). These synaesthetic colours sometimes behave similarly to real colours in influencing perception. For example, when asked to search for a group of black numbers (eg 2s) among black numbers of a similar shape (eg 5s), grapheme – colour synaesthetes who report different induced colours for the two numbers (eg red 2s and green 5s) are much faster than controls at finding the target number, much like controls asked to search among numbers painted in two different colours (Ramachandran and Hubbard 2001). When such grapheme – colour synaesthetes view black-and-white letters, there is activation in the colour-processing areas of the brain (V4/V8) (Hubbard et al 2005; Sperling et al 2006).

The common colour – letter mappings seen in adults may in part reflect common neural cortical connections that facilitate links between the senses and between sensory dimensions such as shape and colour. These links may be most likely to occur when the relevant sensory dimensions involve processing by contiguous brain areas. This hypothesis has been used to explain why grapheme – colour synaesthesia is more common than other forms of synaesthesia (eg coloured odours) (Ramachandran and Hubbard 2001). For example, the fusiform gyrus, which is implicated in the processing of letters, lies adjacent to V4 and V8 in the visual extrastriate cortex, which are implicated in the processing of colour (Hubbard et al 2005; Sperling et al 2006). If systematic mapping of colour to shape is determined by intrinsic sensory cortical organisation, then the same consistent associations should exist in young children as in adults. If, on the other hand, they reflect language-based colour associations that develop after a child learns to read (ie after the child realises, for example, that G is the first letter of green), then pre-literate children should not show consistent colour – letter associations.

In order to differentiate between these two hypotheses, we tested toddlers for colour associations to letters. Letters necessarily have to be learned, and while toddlers may recognise the letter A and may know that apples are red, they do not know that the word apple begins with the letter A. From the letters that are consistently mapped in adults, we chose two colour – letter pairs, each with one rounded and one angular letter (A/G, O/X) that are mapped to opposing colours (red/green, white/black). Crucially, we included one pair with potentially language-based colour associations (A for red, G for green), and one pair without an obvious language basis for the colour mappings (O for white, X for black). We developed a novel way to test for colour – letter associations in pre-literate children in which children are asked to find a letter in a box with two slots, each covered by one of the opposing colours. Experiment 2 served as a replication, with the experimenter blind to the location of the colour choices. In experiments 1 and 2, we also tested older literate children, aged 7 to 9 years, and adults on the same measures. Experiment 3 evaluated the contribution of the sound of the name of the letter (eg the sound of A is "ay", not "ah") versus its shape to the colour – letter mappings in toddlers. We provide the first evidence of naturally biased colour – letter mapping in pre-literate children. Furthermore, we provide evidence that the mapping is based on the shape of the letter and not its sound.

2 Method

The experiment consisted of a training session followed by alternating validity and experimental trials. We designed the training session to introduce the game and the validity trials to test for understanding of the task. The experimental trials were designed to test for letter – colour associations.

2.1 *Participants*

Toddlers and children were recruited from a file of parents who volunteered their children for testing during hospital visits shortly after birth. Adults were recruited when in the lab for another experiment. The final sample for experiment 1 included twenty toddlers (mean age = 32.4 months, range = 30 – 36 months, twelve male), twenty older children (mean age = 7.55 years, range = 7 – 9 years, eleven male), and ten adults (mean age = 22.1 years, range = 18 – 25 years, six male). The final sample for experiment 2 included twenty toddlers (mean age = 34.1 months, thirteen male), twenty older children (mean age = 7.55 years, eight male), and ten adults (mean age = 20.5 years, four male). The final sample for experiment 3 included forty toddlers (mean age = 31.3 months, twenty male). An additional eight toddlers from experiment 1, and six each from experiments 2 and 3 were excluded because they failed to pass the criterion of three-out-of-four-correct validity trials. No older children or adults failed the validity criterion. None of the toddlers correctly identified all four presented letters (OTBG or XCAY) on a test of alphabet knowledge (see procedure).

2.2 *Materials*

Cardboard boxes (16 cm × 31 cm × 18 cm) were covered with different colours of fabric on each half (red versus green, or black versus white) and contained an interior cardboard divider. On the front of the box were two slots through which participants could reach to remove stimuli from one side of the box. In experiments 2 and 3, the boxes had a cardboard occluder (41 cm × 61 cm) on the back to prevent the experimenter from seeing the colours.

The experimental stimuli consisted of transparent plastic letters approximately 10.5 cm wide and 12 cm long (experiments 1 and 2: A, G, O, X; experiment 3: O, X). Validity stimuli were made of the same plastic material and represented objects with known colours (eg tree for green, snowflake for white) (see table 1).

Table 1. Stimuli used for each colour on each kind of trial.

Trials	Green	Red	Black	White
Training				
level 1	leaf	cherry	crow	polar bear
level 2	frog	firetruck	bat	cloud
Validity	tree	heart	spider	snowflake
Letters	G	A	X	O

2.3 *Procedure*

This study was approved by the Research Ethics Board of McMaster University. Before testing, the procedure was explained and informed consent was obtained from each participant or from a parent if the participant was a minor. Verbal assent was obtained from older children.

Participants were presented with one coloured box at a time, and asked to look for each stimulus on the side of the box in which they thought it was 'hiding'. Toddlers learned the task during a training session with two levels of four trials each (one for each colour in the experiment). In the first training level, the experimenter explained the game by asking the toddler to look for certain colour-specific objects in the appropriately coloured side of the box (eg "We are looking for a frog, frogs are green, can you look in the green side of the box for the frog?"). In the second level, the experimenter asked the toddler what colour each object was, and what side of the box it was hiding in (eg "Now we are looking for a firetruck. Do you know what colour a firetruck is? Great, what side of the box do you think the firetruck is hiding in?"). If the child made an error on either level, the experimenter explained the task in a different way (eg "Hmmm, what colour is a firetruck? OK, so do you think the firetruck is hiding in this side or this side?" The experimenter would point to the red side, then the green side). Older children and adults were given an explanation of the task in lieu of the training session.

After training on both colour pairs, each participant received a test sequence of four trials in which validity and experimental trials alternated within the first colour pair (eg red/green) (see table 1 for specific stimuli). They were then tested on the other colour pair. The order of colour pairs and stimulus presentation was counterbalanced across participants.

Each validity stimulus was placed in the appropriate coloured side of the box. For example, the tree was placed on the green side of the box and the child was asked: "I am looking for my friend the tree, what side of the box do you think the tree is hiding in?" To be included in the analysis, participants needed to respond correctly on at least three out of the four validity trials.

For each experimental trial, two letter stimuli were placed in the box, one on either side. In experiments 1 and 2, participants were shown the letter as it was spoken out loud. In experiment 3, half of the participants were shown the letter with no verbal label (eg "I am looking for my friend who looks like this..."), and half of the participants were given a verbal label and not shown the letter [eg "I am looking for my friend A (ay)..."].

In experiment 1, stimuli were placed in the boxes by the experimenter at the beginning of every trial. In experiments 2 and 3, stimuli were placed in the boxes prior to testing by a second experimenter to ensure that the experimenter was unaware of the side with the expected answer.

To assess knowledge of the alphabet, toddlers were shown a card with four letters on it (either OTBG or XCAY) and asked to identify each letter on the card (eg "Can you show me the letter O?"). No toddlers correctly identified all four letters.

3 Results

3.1 *Data analysis*

Each participant was given a score based on the proportion of associations made in the expected direction for each pair of letters. For each colour pair, a one-sample t-test (one-tailed; $\alpha = 0.05$) was performed to see if the proportions were significantly higher than a chance value of 0.5.

3.2 *Experiment 1*

For the O/X colour pair, participants chose in the expected direction (X black, O white) at all ages [toddlers: mean (M) = 0.75, $t_{19} = 3.25$, $p < 0.01$; older children: M = 0.75, $t_{19} = 3.68$, $p < 0.01$; adults: M = 0.85, $t_9 = 4.58$, $p = 0.001$] (figure 1). For the A/G colour pair, older children and adults chose the expected colours (red/green) significantly more often than chance (children, M = 0.80, $t_{19} = 4.49$, $p < 0.001$; adults, M = 1.0. However, toddlers chose colours randomly (M = 0.53, $t_{19} = 0.27$, $p = 0.789$) (figure 2).

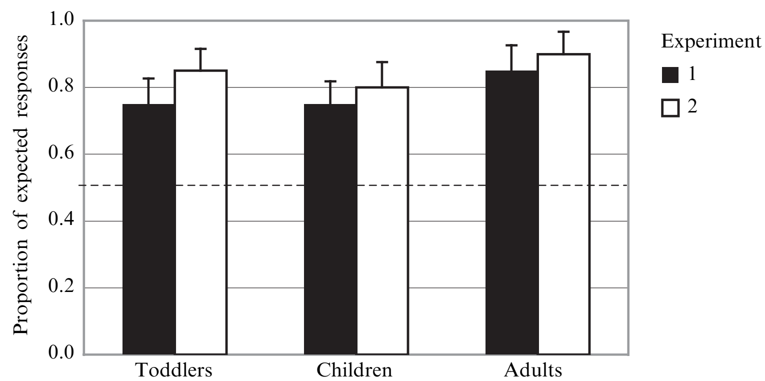

Figure 1. Mean proportion of responses in the expected direction for the O/X colour pair (O white, X black) in experiments 1 and 2. All three age groups made colour choices in the expected direction in both experiments. The dashed line indicates the level expected by chance. The bars denote 1 SEM.

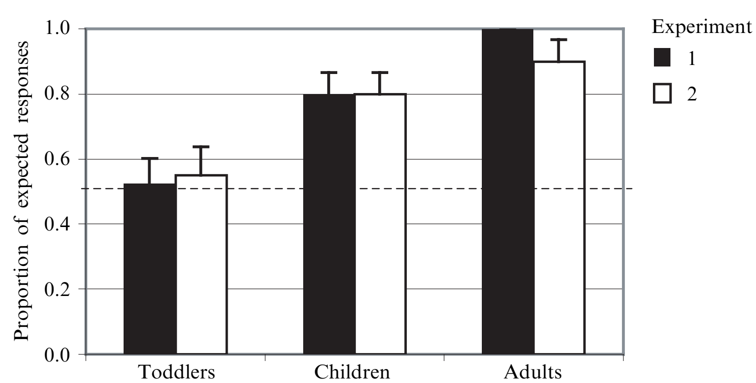

Figure 2. Mean proportion of responses in the expected direction for the A/G colour pair (A red, G green) in experiments 1 and 2. In both experiments, older children and adults made colour choices in the expected direction, while toddlers did not. The dashed line indicates the level expected by chance. The bars denote 1 SEM.

3.3 *Experiment 2: Replication with blind observer*
The findings were replicated. For the O/X colour pair, participants chose in the expected direction (X black, O white) at all ages (toddlers: $M = 0.85$, $t_{19} = 4.95$, $p < 0.001$; older children: $M = 0.80$, $t_{19} = 3.94$, $p = 0.001$; adults: $M = 0.90$, $t_9 = 6.0$, $p < 0.001$) (figure 1). For the A/G colour pair, older children and adults consistently chose the expected colours (red/green) (older children, $M = 0.80$, $t_{19} = 3.94$, $p = 0.001$; adults, $M = 0.90$, $t_9 = 6.0$, $p < 0.001$). However, toddlers chose colours randomly ($M = 0.55$, $t_{19} = 0.57$, $p = 0.577$) (figure 2).

3.4 *Experiment 3: Sound versus shape for O/X in toddlers*
Toddlers chose in the expected direction (X black, O white) when presented with the letter shapes alone ($M = 0.70$, $t_{19} = 2.63$, $p < 0.05$), but not when presented with the letter's sound alone ($M = 0.50$, $t_{19} = 0.000$, ns) (figure 3).

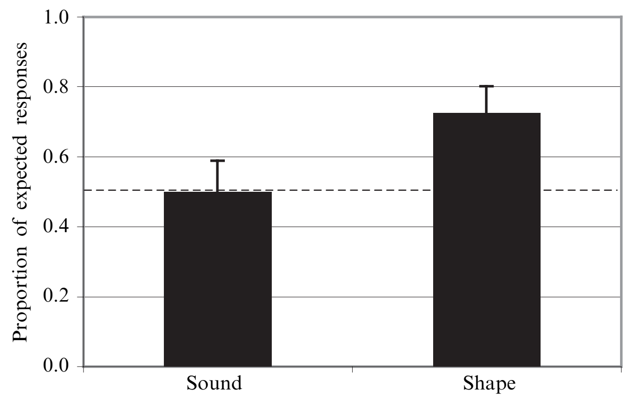

Figure 3. Mean proportion of toddlers' choices in the expected direction (O white, X black) for the shape only and sound only conditions in experiment 3. Toddlers made choices in the expected direction when they were only shown the shape of the letter but not when they only heard its sound. The dashed line indicates the level expected by chance. The bars denote 1 SEM.

4 Discussion
The findings indicate that there are natural biases to associate certain shapes with specific colours: in all three experiments, toddlers searched for the X in the black side of the box, and for the O in the white side. There is no obvious literary basis for this mapping and, even if there were, it is unlikely to influence the associations of children who have not yet learned to read. In contrast, the results for A/G suggest that literacy associations may induce additional colour – letter associations. Toddlers did not consistently map A to red and G to green, whereas literate children and adults did. These results suggest that cross- and intra-modal sensory associations in adulthood result from the joint influence of naturally biased sensory cortical organisation and of the experience of specific associations.

Our findings for X and O are consistent with evidence of other sensory associations that do not appear to be learned. A classic example is Benham's disc with a black-and-white pattern that induces the perception of colour when rotated (eg von Campenhausen and Schramme 1995). Similarly, adults report seeing colours and forms when their visual field is filled with flickering light, with the specific associations consistent across subjects and dependent on the frequency and phase of the flicker (Becker and Elliott 2006). Moreover, specific colours and forms are consistently reported to co-occur with one another, providing additional support for the systematic binding of colour to form in adults' perceptual system. Toddlers systematically map lower pitch to darker objects (Mondloch and Maurer 2004), a pattern matching cross-modal influences on adults' reactions and the percepts of synaesthetic adults (Marks 1975, 1996), but not evident in the statistics of the environment (darker objects do not consistently make lower-pitched sounds). Toddlers, like adults, also map nonsense words with non-rounded and rounded vowels (kiki versus bouba) to jagged and rounded shapes, respectively (Lindauer 1990; Maurer et al 2006; Ramachandran and Hubbard 2001).(1) Like the current results for X and O, these recent findings suggest that humans have intrinsic biases to make specific cross-dimensional and cross-modal associations.

Although the current research does not indicate which pathways mediate colour – letter associations at any stage of development, the results of experiment 3 indicating that toddler's associations for X and O are based on shape and not sound suggest that the colour – letter associations may be based initially on interactions between the colour and form pathways within the extrastriate visual cortex. This interaction could involve interactions within or among V4 cells that respond to both colour and form (Desimone et al 1985), or it could be mediated by the posterior parietal cortex, given its documented role in the binding of colour to shape (Donner et al 2002). Learning to read may induce a processing shift for colour – letter associations from the perceptual level (shape-based) to the cognitive level (letter-based). In synaesthetes with coloured graphemes, some aspects of colour – letter associations may remain at the perceptual level, which is consistent with imaging evidence of visual cortical activation of V4/V8 in synaesthetes when perceiving black-and-white graphemes in colour (Hubbard et al 2005; Sperling et al 2006). Evidence that deactivation of the posterior parietal cortex by TMS interferes with grapheme – colour synaesthesia suggests that the same perceptual binding mechanisms underlie synaesthetic percepts and non-synaesthetic percepts (Esterman et al 2006). This conceptualisation is consistent with the idea that synaesthesia stems from an exaggeration of sensory mechanisms that are common to everyone, what Mulvenna and Walsh (2006) term "supernormal integration" (eg Esterman et al 2006; Simner et al 2005; Ward et al 2006).

Further research will help to elucidate the influence of different physical characteristics of shapes and letters on colour associations. For example, the letters O and X may be associated with white and black, respectively, because they contain mostly empty space versus a solid middle. Alternatively, they might be associated with shapes with continuous versus jagged contours, respectively. Testing letters that have different shapes but are associated with the same colours (eg I white, Z black) will address this question, as will testing colour mapping to contrasting shapes that are not letters (eg rounded versus angular; with and without a solid middle). Finally, red and green lie on opposite sides of the colour wheel, whereas black and white lie at the extreme ends of a unidimensional colour axis. This fundamental difference between black and white versus other colours may result in naturally biased associations of shape to black and white only. Thus, it is important to clarify whether black and white hold a special distinction in initial sensory organisation. To do this, we will test toddlers on letters that have consistent non-literacy-based mapping in adults to colours other than black and white (eg C for yellow). Regardless of the various influences of shape and colour, our results provide intriguing evidence that sensory cortical organisation may initially determine the binding of colour to shape in a systematic manner that changes with the development of literacy.

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(1) Although most researchers characterise the crucial distinction as between rounded and non-rounded vowels, some have identified, instead, a distinction between stop and continuous consonants (Westbury 2005). Whichever interpretation is correct, the results indicate that there are sensory associations between sound and shape that do not appear to be learned.

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