

Links between global and local shape perception, coloured backgrounds, colour discrimination, and non-verbal IQ

Patricia Dore, Ardian Dumani, Geddes Wyatt, Alex J Shepherd

Department of Psychological Sciences, Birkbeck College, University of London, U.K.

Corresponding author: Dr Alex J Shepherd, Department of Psychological Sciences, Birkbeck College, University of London, U.K.

Telephone: +44 20 7631 6212

Fax: +44 20 7631 6312

Email: a.shepherd@bbk.ac.uk

Running title: local and global shape perception; colour; non-verbal IQ

Keywords: local and global shape perception; colour; non-verbal IQ; WAIS; SPM+

Word count (main body): 8030

Abstract

This study explored associations between local and global shape perception on coloured backgrounds, colour discrimination, and non-verbal IQ (NVIQ). Five background colours were chosen for the local and global shape tasks that were tailored for the cone-opponent pathways early in the visual system (cardinal colour directions: L-M, loosely, reddish-greenish; and S-(L+M), or tritan colours, loosely, blueish-yellowish; where L, M and S refer to the long, middle and short wavelength sensitive cones). Participants also completed the Farnsworth-Munsell 100-hue test (FM100) to determine whether performance on the local and global shape tasks correlated with colour discrimination overall, or with performance on the L-M and tritan subsets of the FM100 test. Overall performance on the local and global shape tasks did correlate with scores on the FM100 tests, despite the colour of the background being irrelevant to the shape tasks. There were also significantly larger associations between scores for the L-M subset of the FM100 test, compared to the tritan subset, and accuracy on some of the shape tasks on the reddish, greenish and neutral backgrounds. Participants also completed the non-verbal components of the WAIS and the SPM+ version of Raven's progressive matrices, to determine whether performance on the FM100 test, and on the local and global shape tasks, correlated with NVIQ. FM100 scores correlated significantly with both WAIS and SPM+ scores. These results extend previous work that has indicated FM100 performance is not purely a measure of colour discrimination, but also involves aspects of each participant's NVIQ, such as the ability to attend to local and global aspects of the test, part-whole relationships, perceptual organisation and good visuomotor skills. Overall performance on the local and global shape tasks correlated only with the WAIS scores, not the SPM+. These results indicate that those aspects of NVIQ that engage spatial comprehension of local-global relationships and manual manipulation (WAIS), rather than more abstract reasoning (SPM+), are related to performance on the local and global shape tasks. Links are presented between various measures of NVIQ and performance on visual tasks, but they are currently seldom addressed in studies of either shape or colour perception. Further studies to explore these issues are recommended.

1. Introduction

The present study examined associations between performance on a global precedence task, display background colour, colour discrimination and non-verbal IQ (NVIQ). Global precedence refers to a bias towards processing the overall (global) structure of a stimulus over its individual (local) elements. Navon (1977), for example, asked participants to identify a large, global, letter (S or H), which was created from smaller, local, letters (also S or H) or to identify the smaller, local, letters that formed the larger, global, letter. The small component letters could be either congruent or incongruent with the larger ones. Navon (1977) found that participants were faster to identify the global letter correctly than when asked to identify the local letters (global precedence). Participants were also slower to identify the local letters when they differed from the global letter (incongruent trials) compared to when local and global letters were the same (congruent trials). There was an asymmetry, however, such that the identity of the small letters did not affect the time taken to identify correctly the large, global letters, whether the small component letters were congruent or not. This asymmetry was taken as evidence for a hierarchical model of perceptual processing that proceeds from the global level to the local. Navon (1977) suggested that the characteristics of a larger stimulus are broken down, as opposed to being built up from the smaller constituent elements. Subsequently, Navon (1981a,b) refined his proposal, suggesting that global shapes are processed rapidly and the smaller, detailed, components slightly more slowly, not necessarily sequentially. Navon (1977; 1981a,b) concluded that whilst participants can pay attention to the global level of a stimulus without attending to its local features, they were unable to pay attention to the local elements without attending to the global structure, resulting in the asymmetric difference in reaction time between the local and global, congruent and incongruent, displays.

Navon's account of managing shape identification in complex scenes is intuitively appealing. When perceiving our environment, we are often bombarded with a large number of different stimuli. In order to manage all this input, we need to select and focus our attention solely on the part/parts of the scene that is/are of interest. Perceiving a stimulus on a global level rapidly and then, later, on a local level allows us to do this, providing us with the ability to identify a stimulus and then focus on important details.

Navon's (1977) study, and his conclusions, have provoked considerable debate regarding: (1) the neural processes involved in the processing of such hierarchically organised shapes; (2) which other factors may influence performance; and (3) what types of stimuli, other than letters or geometric shapes, are susceptible to hierarchical

effects. Navon's (1977) study has been cited over 2,000 times in a broad range of basic, applied, clinical and comparative areas of research, from studies on memory to attention, perception of faces to natural scenes, autism to schizophrenia, and bees to primates (for reviews on particular areas see Kimchi, 1992; Amirkhiabani and Lovegrove, 1997; Blanca *et al.*, 2006; Poirel *et al.*, 2008; De Cesarei and Loftus, 2011). One area that has received relatively little research, however, is the effect background colour may have on global precedence and asymmetric global-local interference. In this study, the effect of background colour on the identification of local and global shapes was examined, together with tests of colour discrimination and NVIQ.

Three relevant studies are those of Lovegrove and Pepper (1994), Michimata *et al.* (1999) and Vidal *et al.* (2004). They examined the effects of colour on global precedence, however, their results are inconsistent, and the rationale for choosing colour has been questioned. The criticisms have centered on whether performance differences for local and global stimuli reflect processing in pathways sensitive to different spatial frequencies, or to activity in the magnocellular and parvocellular pathways in the visual system (Skottun, 2004; Vidal-López and Romera-Vivancos, 2009). Navon (1977) commented that differences in performance for global and local stimuli are unlikely to reflect processing in visual pathways sensitive to different spatial frequencies, as he reported performance asymmetries depended on the *relative* size of local and global elements, not their absolute size (see Experiment 4, Navon, 1977). He reported smaller elements were not processed less frequently, nor less accurately, than larger ones, unless they were also a local element in a global shape.

Nevertheless, there has been a line of research that has discussed global precedence in terms of spatial frequency channels and in terms of activity in the magnocellular and parvocellular pathways in the visual system. LaGasse (1993), for example, compared local and global diamond and square shapes that had been low- or high-pass filtered using a cut-off point at 1.75 cpd, thereby removing high or low spatial frequencies above or below that cut-off point, respectively. Lamb and Yund (1993) compared two types of global and local letter shape combinations. One type contained white global and local letters on a grey background, and so included a range of spatial frequencies. The second type were contrast balanced images, where each line segment of the local letters was flanked by darker lines. In these images, spatial frequencies below 3 cpd were virtually eliminated and those below 6 cpd were minimal. Both studies found that a global form advantage, measured by faster reaction times to global than local stimuli, required global stimuli that contained low spatial frequencies. LaGasse (1993) did not find asymmetric interference effects with unfiltered stimuli (e.g. the presence of a global

square interferes with the perception of local diamonds but the presence of local diamonds does not interfere with the perception of a global square), however, and neither LaGasse (1993) nor Yund and Lamb (1993) analysed this aspect with the filtered or contrast matched stimuli.

Lovegrove and Pepper (1994), Michimata *et al.* (1999) and Vidal *et al.* (2004) suggested that global shapes may be processed in the fast-acting magnocellular, or transient, pathway, which optimally responds to stimuli with low spatial and high temporal frequencies. They suggested that the processing of the local, smaller, components of a display could reflect processing in the slower-acting parvocellular, or sustained, pathway, which optimally responds to high spatial and low temporal frequencies (Livingstone and Hubel, 1988). Michimata *et al.* (1999) and Vidal *et al.* (2004) examined the effects of background colour (red or green) on the identification of local and global shapes or letters, even though background colour is irrelevant to the task. They selected red following reports that the activity of some neurons (Type IV) in the magnocellular pathway can be suppressed by narrowband long-wavelength light (peaks between 640-660nm) in primates at the levels of the retina (de Monasterio, 1978), the LGN (Wiesel and Hubel, 1966; Dreher *et al.*, 1976), and the striate cortex (Livingstone and Hubel, 1984). Behavioural studies in humans have also reported changes in performance on tasks ostensibly targeted to processing by the magnocellular pathway when stimuli were presented on similar narrowband long-wavelength backgrounds, such as a reduction in sensitivity to luminance flicker on intense red, compared to green, backgrounds (Stromeyer *et al.*, 1987), decreased metacontrast masking on red, compared to white or green backgrounds (Breitmeyer and Williams, 1990), increased reaction times to detect briefly flashed luminance increments on red, compared to green or blue, backgrounds (Breitmeyer and Breier, 1994) or increased motion coherence thresholds on red backgrounds (Chapman *et al.*, 2004). The results from these behavioural studies have been described as consistent with long-wavelength suppression of at least some neurons in the magnocellular pathway in primates (but see also Skottun, 2004, for a critical review of the evidence that activity in magnocellular pathways may, or may not, be suppressed by long-wavelength, or red, light, and Type IV neurons are also found in the parvocellular pathway, Spear *et al.* 1994).

Nevertheless, presenting hierarchical stimuli on red backgrounds may, it has been argued, suppress activity in the magnocellular pathways and reduce the global precedence effect, if processing in the magnocellular pathway underlies faster and more accurate processing for global stimuli over the small component elements. Michimata *et al.* (1999) found that their red background did indeed affect the time taken to respond to

their global shapes. They used large diamond and square shapes composed of either small squares or diamonds. They reported that their red background reduced the usual asymmetric interference in reaction times (where the presence of an incongruent global shape interferes with the time taken to identify the local shapes, but incongruent local shapes do not increase the time taken to identify the global shapes). Instead of asymmetrical interference, they found symmetrical interference when their stimuli were presented on a red background: there were comparable amounts of global-to-local and local-to-global interference on incongruent trials. Conversely, the asymmetric interference pattern in reaction times remained when a green background was used. They concluded that suppressed activation in the magnocellular pathway, from the red background, attenuated the processing of low spatial frequencies, which resulted in the reduced global shape processing advantage with incongruent global and local shapes.

Vidal *et al.* (2004) were interested in two aspects of global precedence: the effects of coloured backgrounds on their local-global shape task and group differences in three groups of children: normal readers, poor readers and children with dyslexia. They presented black hierarchical letters (C or U) on either red or green backgrounds. As found by Michimata *et al.* (1999) for reaction times, Vidal *et al.* (2004) reported that performance on their red background was worse for the global tasks than for the local, but for accuracy only, not reaction times, and equally for each reading group. They focused their discussion on the lack of evidence for a deficit in the magnocellular system in children with dyslexia. They did not comment on the overall pattern: the lowest error rates occurred for the local task on the red background, comparable error rates were found for the other three conditions (the global task on a red or green background, the local task on a green background), so performance was not, overall, worse for the global task on the red background. They did not report results for asymmetric interference between local and global tasks on either coloured background.

Lovegrove and Pepper (1994) coloured the *letters* rather than the background: on different trials their local and global letters could all be either red, green or blue, on a black background. They found the expected effects, overall: significant effects of global precedence (response times to global letters were faster than those to the local component letters); letter congruency (congruent letters were identified more rapidly than incongruent) and the asymmetric interference between local and global letter identification. The only effect of colour was a greater global precedence effect for blue letters (the increase in response time for local tasks). There were no significant effects involving letter congruency and colour, nor for accuracy. While they introduced their study by referring to transient and sustained visual pathways, and low and high spatial

frequencies, they considered their blue stimuli should favour the perception of low spatial frequencies and slow the perception of high spatial frequencies, whereas the red and green stimuli should favour the perception of high spatial frequencies and slow the perception of low spatial frequencies. Curiously, they concluded their data were consistent with their hypothesis that faster perception of the global letter is mediated by the transient visual pathways.

In a review of these studies (Michimata *et al.*, 1999; Lovegrove and Pepper, 2004; Vidal *et al.*, 2004), Vidal-López and Romera-Vivancos (2009) concluded that colour could affect the global precedence effect, but that it was unlikely to be due to the ability of red to suppress activity in the magnocellular pathway. They commented on the use of different stimuli (coloured letters vs coloured backgrounds), different participants (university vs secondary school students) and different measures (reaction times vs accuracy), and cited the review by Skottun (2004) who provides a discussion on the use of colour to isolate functioning in the magnocellular pathways. They recommended further research was necessary to determine how colour can affect the global precedence effect.

The colours that were chosen by Michimata *et al.* (1999), Lovegrove and Pepper (2004) and Vidal *et al.* (2004) did not take into consideration how colour is processed in the visual system. From the chromaticities of the red and green backgrounds used by Michimata *et al.* (1999), it appears they coloured their computer's CRT screen to create coloured backgrounds by activating only the red, or the green, phosphors, respectively, matched for luminance using heterochromatic flicker photometry [CIE (1931) $Y(x,y)$: 4.0 cdm^{-2} , red: (0.63, 0.35); green: (0.28, 0.59), see Figure 1]. Vidal *et al.* (2004) did not specify the chromaticities of their red and green backgrounds, they only stated that their luminances were equal, 5.4 cdm^{-2} . Lovegrove and Pepper (2004) also did not report the chromaticities of the colours used, simply that they were red, green and blue, each with a luminance of 15.8 cdm^{-2} (Lovegrove and Pepper, 1994).

The present study was designed as an extension of the study by Michimata *et al.* (1999). Five different colours [a pinkish-red, (hereafter 'pink'), a bluish-green (hereafter 'cyan'), a violet, a yellowish-green (hereafter 'mustard') and neutral—Illuminant C] were selected that were tailored to the cone-opponent processing that occurs in the early visual system, i.e. cardinal colour directions (Krauskopf *et al.*, 1982). These cone-opponent axes are sometimes called colour-opponent, although that term is also used, somewhat confusingly, to refer to colour-opponency defined by unique hues—red vs green, blue vs yellow—here, the colours selected were chosen to reflect activity in cone-

opponent pathways, not colour-opponent mechanisms defined by unique hues, see Figure 1.

INSERT FIGURE 1 HERE

The retina contains three types of cone photoreceptors, broadly sensitive to long (L), middle (M) or short (S) wavelengths (see Dartnall *et al.*, 1983, for mean absorbance spectra for each cone type: the L, M and S cones respond to a range of wavelengths and have peaks at $558.4 \pm 5.2 \text{ nm}$, $530.8 \pm 3.5 \text{ nm}$ and $419.0 \pm 3.6 \text{ nm}$, respectively). These cone types underlie all aspects of visual perception (other than purely scotopic), so it is not unreasonable to suggest that adapting to a particular coloured background could affect the identification of local or global shapes. The violet, neutral and mustard background colours selected in the present study lay on a tritan line in any chromaticity diagram (a line of constant L- and M-cone activity, the activity of the S-cones only varies): these colours lie on a vertical line in the MacLeod-Boynton (1979) diagram, Figure 1. The pink, neutral and cyan backgrounds lay on a line of constant S-cone activity (the activity of the L- and M-cones only varies): these colours lie on a horizontal line in the MacLeod Boynton (1979) diagram, Figure 1. These cone-opponent, or cardinal, colours have not been used before in a global precedence study.

Previously, it was considered that the magnocellular pathway received inputs from the L- and M-cones only, however, it has now been demonstrated that, at least in the macaque, all cone types may contribute to this pathway (see Chatterjee and Callaway, 2002 for a review), however, this is still debated (Sun *et al.*, 2006a,b; Solomon and Lennie, 2007; Tailby *et al.*, 2008; Jayakumar *et al.*, 2013). The choice of colours in the present study does not, therefore, allow a test of the role that background colour may have on the magnocellular pathway and subsequent effects on global precedence. The choice does, however, allow an assessment of the role background colours, selected for the classically defined cone-opponent pathways, or cardinal colour directions, have on global precedence. Cells in the L-M pathway (pink-cyan) receive antagonistic input from the L- and M-cones. Cells in the S-(L+M) pathway (violet-mustard) receive inputs from the S-cones opposed by a combination of signals from the L- and M-cones (Hurvich and Jameson, 1957; De Valois *et al.*, 1966; Krauskopf *et al.*, 1982; Derrington *et al.*, 1984; Lennie and D'Zmura, 1988; Abramov and Gordon, 1994; Dacey and Packer, 2003).

Although these pathways are recognized as classic, or cardinal, in psychophysical, psychophysiological and electrophysiological research, the neural circuitry underlying their characteristic cone-opponent properties still remains somewhat elusive. This is

particularly so for the S-cone signals, which are primarily processed in the koniocellular pathway, but it is not entirely clear what other contributions they may make to the parvocellular or other pathways (Solomon and Lennie, 2007; Tailby *et al.*, 2008; Lee *et al.*, 2012; Dacey *et al.*, 2014). Nevertheless, these cardinal colour directions are well documented as perceptually important for a range of tasks, regardless of the underlying neuronal circuitry or the existence of additional, or higher-order, colour mechanisms (for a review, see Eskew, 2009).

As the present study compares the effects of coloured backgrounds on global precedence, participants also completed a test of colour discrimination, the Farnsworth-Munsell 100-hue test (FM100, Farnsworth, 1943; 1957a,b). This is a standard test of colour vision, with published norms for different age groups (e.g. Verriest *et al.*, 1982; Knoblauch *et al.*, 1987; Kinnear and Sahraie, 2002). Overall error rates give an indication of a person's general ability to discriminate between colours, whereas subsets of the colours in the test show discriminability of either tritan (S-cone isolating) or L- and M-cone isolating colours (tritan: caps 1-12, 34-54, 76-85; L-M: caps 13-33, 55-75; Smith *et al.*, 1985; Kinnear and Sahraie, 2002). In the present study, associations were investigated between local and global shape perception on the cone-opponent coloured backgrounds and colour discrimination overall, and for the tritan and L- and M-cone subsets of the FM100 hue test.

Participants also completed the non-verbal components of the WAIS (Wechsler Adult Intelligence Scale, Wechsler, 1981) and the Standard progressive matrices plus (SPM+) version of Raven's progressive matrices (Raven, 2008) to determine whether non-verbal intelligence, as measured by these tests, correlated with performance on the local and global shape tasks and on the FM100. Vidal *et al.* (2004) have suggested that general intelligence may modulate global precedence, as they reported that their poor readers showed a large effect of letter congruence (they made more errors for incongruent global-local letter combinations than for congruent) and both error rates were substantially larger than those from the normal readers and their dyslexic students. The poor readers also differed significantly from their normal readers and dyslexic students on a test of general intelligence (Yuste, 1995). Cranwell *et al.* (2015) have reported that performance on the FM100 test is significantly associated with nonverbal IQ, using non-verbal tasks taken from the WASI (Wechsler Abbreviated Scale of Intelligence, Wechsler, 1999).

Based on this previous research (Navon, 1977, 1981a,b), it was expected that accuracy would be greater and reaction time would be faster for congruent trials (global shape

and local shape elements the same) than incongruent (global shape and local shape elements differ) whether the task was to identify the global or local shapes. It was also expected that accuracy would be greater and reaction times would be faster for the global shape tasks than for the local, regardless of element congruency. No specific predictions were made regarding performance on the shape tasks on each coloured background, as the background colours used in this study have not been used before. Given that previous studies have used saturated red and green backgrounds, however, it was considered possible that any performance differences would involve the pink and cyan backgrounds, compared to the neutral (colours that are discriminable only by the L and M cones, Figure 1). Finally, it was expected that performance on the FM100 would correlate with performance on the measures of non-verbal IQ. No specific predictions were made regarding associations between performance on the local and global shape tasks and performance on the FM100, or non-verbal IQ measures, as they have not been assessed before.

2. Methods

2.1 Participants: Thirty-four participants completed the local and global shape tasks and the FM100 test, average age 29 (± 8.3) years, range 19 – 56 years. Seventeen of these completed a second session where they undertook the non-verbal components of the WAIS and the Raven's SPM+, average age 33 (± 8.5) years, range 22 – 56 years. All had visual acuity of at least 6/9 monocularly, and 6/6 binocularly (tested with a Lighthouse near visual acuity chart). None had a colour vision abnormality according to the FM100 test. Total error scores (TES) on the FM100 test ranged from 8 to 108, median 60 (average ± 1 std. error: 54 ± 5), partial error scores (PES) on each sub-set of caps ranged from 4 to 60 (L-M: 25 ± 3 , median 26; tritan: 29 ± 3 , median 32). Participants with higher TES did not show a bias for either axis (the participant with a TES of 108, for example, had PES of 60 (L-M) and 48 (tritan), indicating overall poor colour discrimination rather than a traditional colour anomaly involving the L, M or S-cones).

Participants were either given a small honorarium for their time and expenses or were undergraduate students who received course credits. All were naïve to the purpose of the study. Informed written consent was obtained in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). The study received ethical approval from the Department's ethics committee.

2.2 Apparatus

2.2.1 The experiment was created and run using MATLAB on an Apple MacAir, OSX (10.5.8), connected to a LaCie 22 inch Diamondtron CRT monitor with a spatial and

temporal resolution of 1280x960 pixels and 100Hz, respectively. Calibration of the monitor was performed with a Minolta Chroma meter CS-100, using an iterative routine that adjusts the colours displayed on screen until the required luminances and chromaticities are recorded (Shepherd, 1997a).

2.2.2 Farnsworth Munsell 100-Hue test The FM100 test was completed under a daylight source (MacBeth, Sol-Source), as recommended. The FM100 test consists of four wooden trays containing 85 coloured caps that, together, span a colour circle ranging from green to yellow, through to orange, pink, purple/violet and blue hues. Each wooden case contains two non-removable colour caps that serve as anchors to facilitate placing the remaining caps in the correct order. The other caps in each tray are tipped out and shuffled, and the task is to replace them in each tray so that the colours form a smooth sequence between the two anchors. The four trays were presented to different participants in a random order. No time limit was imposed, but each tray took approximately two or three minutes to complete.

2.2.3 Non-verbal IQ The non-verbal components of the WAIS were administered following its standard procedure (Wechsler, 1981). The tests included block design (arranging red and white coloured blocks to form pre-specified patterns); picture completion (identifying what is missing in a line drawing of common objects such as a door, boat or violin); picture arrangement (ordering sets of three to six cartoons on cards in a sequence to tell a sensible story); object assembly (a set of jigsaw puzzles) and the digit symbol coding task (digits and symbols are paired in a template, such as 1 with ^, 2 with ||, 3 with X, etc, and the task is to copy the correct symbol underneath a string of digits presented in rows on a sheet of paper). All tasks except picture completion have a time limit and are to be completed as fast as possible.

The SPM+ version of the Raven's progressive matrices was administered following its standard procedure (Raven, 2008). It comprises 60 multiple choice test pages, each displaying nine items: eight line drawings and a blank box in a 3x3 array. Each set of eight line drawings share a common theme, and the complexity of each drawing increases across the rows and down the columns, but together they create a unified series. The task is to choose, from a set of six possible exemplars at the bottom of the test page, which is the correct one to complete the series. The SPM+ version of the progressive matrices was selected to present sufficient difficulty to the adult participants tested here. Pilot trials indicated that the standard, coloured, and advanced, versions of the progressive matrices resulted in ceiling effects with little variation in scores.

2.3 Local and global displays: Following Michimata *et al.* (1999), participants were presented briefly with one of four shapes on different trials: a global square made up of small square (congruent) or diamond (incongruent) local elements, or a global diamond made up of small diamond (congruent) or square (incongruent) local elements. Each display was masked shortly after display offset to ensure that afterimages of a previous stimulus could not interfere with the perception and response to a subsequent one (see Figures 2 and 3 for representations of the stimuli, the mask, and the sequence and timing of events on each trial). The displays were viewed at a distance of 60 cm. Distance between the participant and the screen was measured before beginning and they were asked to maintain that viewing distance. No chin-rest was used, however, to minimise discomfort. An experimenter was present to one side of the participant to monitor performance and each participant's head position.

INSERT FIGURES 2 & 3 HERE

Each local element measured 3 x 3 mm ($0^{\circ} 17'$ visual angle) and had a luminance of 2 cdm^{-2} . The global square had a width of 18 mm ($1^{\circ} 43'$ visual angle); the global diamond, 25 mm ($2^{\circ} 23'$ visual angle). The distance between each local element was identical in each display (4.5 mm, $0^{\circ} 25'$ visual angle). The circular mask was larger, diameter 80 mm ($7^{\circ} 37'$ visual angle), and consisted of a black circle with randomly sized and positioned holes coloured the same as the background.

Each display was presented on five coloured backgrounds [tritan/S-cone: (i) violet, (ii) mustard; L(-M)-cone: (iii) pink, (iv) cyan; and (v) neutral (Illuminant C), see Figure 1]. Each background had a luminance of 20 cdm^{-2} . The pink and cyan were the most saturated available on the monitor at 20 cdm^{-2} and which also lay on a horizontal line in the MacLeod-Boynton (1979) r,b chromaticity diagram (MB). Both were selected to be an equal, but opposite, distance from the neutral in the MB diagram. The violet was also the most saturated that could be displayed at 20 cdm^{-2} that lay on a tritan line running through the neutral in the MB diagram (a vertical line); the mustard was selected to be equal distance from the neutral in the MB diagram when the b axis is logarithmically transformed (\log_{10}). These colours were selected so that they would appear equally saturated for the pink and cyan, and violet and mustard, colours (see the vector model for colour contrast reported in Shepherd, 1997b; 1999; Shepherd and Wyatt, 2008 for further details). The black elements of the mask had a luminance of 2 cdm^{-2} , the holes in the mask had the same luminance and chromaticity as the coloured backgrounds. The CRT monitor was the only source of light in an otherwise dark room. Rod intrusion cannot be ruled out with these screen luminances, however, Shepherd (1994) and

Shepherd and Wyatt (2008) have previously used similar screen colours with luminances ranging from 58 cdm^{-2} to 2.5 cdm^{-2} and found, in a colour matching task, rod intrusion to become apparent only below 4.5 to 7.0 cd m^{-2} . This is returned to in the Discussion.

Participants were all right handed and used their first and second fingers of their right hand to press either 'G' or 'V' on the keyboard to indicate whether the shape was a diamond or a square, respectively. These response keys were selected to map responses to the tasks: it was explained that 'G' is above 'V' on a keyboard, and that diamonds point up. The keys were clearly marked and had a tactile bump added to each so that they could be easily located in the dark.

2.4 Procedure: Acuity and the FM100 tests were presented first, followed by the experimental trials. Block order (local or global task, background colour) was counterbalanced. Initially, the four types of stimuli (global square or diamond, local squares or diamonds, congruent or incongruent with the global shape) were presented together in one display, similar to that portrayed in Figure 2, and the tasks were described. It was explained that, for the global task, they should focus on the overall shape of the pattern, and, for the local task, to focus on the individual elements. There was a central fixation point (width 0.1°), and participants were asked to respond to each display as quickly and accurately as possible after being presented with the mask.

There were 40 practice trials using the neutral background (20 for the local task and 20 for the global). The experimental trials began with two minutes of adaptation to the relevant background colour, followed by 640 experimental trials, divided into 10 blocks. Adaptation was maintained during the experiment as the background colour remained on screen throughout each block of trials. The number of trials was selected based on pilot work, to give sufficient trials and not unduly tire the participants. For each main task (global or local), there were 64 trials per coloured background. The first four trials of each block were discarded as practice to allow the participant to adjust to each new shape task. The remaining 60 trials were evenly split between (i) diamond and square shapes and (ii) congruent and incongruent global and local shapes. Thus, there were 15 trials per shape task on each coloured background presented in pseudo random order (the random ordering had to be constrained to ensure 15 trials per shape task). Either after a break, or at a separate session, participants completed the Raven's SPM+ and non-verbal components of the WAIS. The acuity, FM100 and experimental tests were completed within one hour, the non-verbal IQ tests together took approximately 90 minutes.

3. Results

The analyses were conducted using SPSS version 23 or Microsoft Excel (version 15.33). The accuracy and reaction time data for the local and global shape tasks were not normally distributed, nor could be successfully transformed to fit a normal distribution (square root, log10 and arcsine transformations attempted: Kolmogorov-Smirnov tests). Therefore, non-parametric comparisons were performed. The accuracy data were negatively skewed: the reaction time data were positively skewed.

3.1. *Accuracy for the global vs local tasks:* For all tasks (local and global, congruent and incongruent), accuracy was very good: performance was, on average, over 93% correct. As can be seen from Figure 4, accuracy for the tasks on each coloured background was fairly comparable, apart from those trials where the task was to identify global shapes with incongruent local elements on pink and cyan backgrounds (Figure 4A). This difference, however, was not statistically significant (global incongruent trials on five coloured backgrounds, Friedman test, $\chi^2(4) = 1.4, p=0.8$). The other comparisons (global congruent trials, local incongruent and local congruent trials, each on five coloured backgrounds) also showed no significant differences, as can be seen in Figures 4A and 4B (three separate Friedman tests, $p>0.2$).

INSERT FIGURE 4 HERE

Disregarding colour, the overall proportion correct for the global tasks was significantly greater than for the local tasks, replicating previous research (Figure 5A, Wilcoxon signed-ranks tests, $p=0.0025$, one-tailed). This held for congruent, but not incongruent, displays (Figure 5B, two further Wilcoxon signed-ranks tests, congruent displays, $p=0.018$, Bonferroni corrected; incongruent displays, $p=0.15$, NS).

INSERT FIGURE 5 HERE

3.2. *Reaction time for the global vs local tasks (correct responses only):* Reaction times over 1000ms were removed. For all tasks (local and global, congruent or incongruent), reaction times were comparable, yet somewhat shorter reaction times can be seen, overall, for the global shape task (Figure 6A) than for the local (Figure 6B, see also Figure 7A), as expected. This difference was statistically significant when performance was averaged across background colour (global vs local reaction time, Wilcoxon signed-ranks test, $p=0.003$). This held for both congruent and incongruent displays (Figure 7B: four Wilcoxon signed-ranks tests, smallest $p=0.001$, largest $p=0.04$, Bonferroni

corrected). As expected, the fastest times occurred for the congruent, global tasks and the longest for the local, incongruent.

There were no differences for reaction times on each of the coloured backgrounds, whether for the global or local tasks. This was confirmed by four separate Friedman tests (global congruent task on five coloured backgrounds, and similarly for the global incongruent, local congruent and local incongruent tasks, $p > 0.17$).

INSERT FIGURE 6 HERE

Differences in reaction times were calculated for the global and local tasks (incongruent minus congruent). These difference scores were normally distributed (Kolmogorov-Smirnov tests, $p > 0.15$). A paired sample t-test revealed that the difference in reaction times between incongruent and congruent trials for the local task was significantly larger than the difference in reaction times between incongruent and congruent trials for the global task [$t(33) = -2.7$, $p = 0.01$, two tailed, Bonferroni corrected].

INSERT FIGURE 7 HERE

3.3. *Farnsworth-Munsell 100-hue test (FM100)*: Total error scores (TES) correlated significantly with the overall proportion correct for every shape task condition (five coloured backgrounds, local and global tasks, congruent and incongruent, for an overview see Figure 8, which shows correlations (Spearman's rho) for ranked TES and ranked performance on local and global tasks collapsed across coloured backgrounds: patterns for each individual coloured background were similar. Those with higher FM100 total error scores (poorer colour discrimination) performed less accurately on each of the local and global tasks on each coloured background. For individual conditions, the highest correlation was -0.80 , $p < 0.001$, the lowest, -0.54 , $p = 0.001$. Reaction time also correlated significantly with overall performance on the local and global tasks: those with higher FM100 scores also had slower reaction times on the local and global tasks for all but the local mustard and global pink conditions. For individual conditions: the lowest correlation was -0.25 ($p = 0.15$, NS, local mustard), the highest was -0.52 ($p = 0.002$, local pink).

INSERT FIGURE 8 HERE

It might be expected that there would be a correlation between performance on the L-M subset of the FM100 test, and performance on the shape tasks on pink and cyan

backgrounds. Equally, it might be expected that there would be a correlation between performance on the tritan subset of the FM100 test, and performance on the shape tasks on violet and mustard backgrounds (see Introduction). In fact, there were significant correlations between accuracy for all tasks on each coloured background and both subsets of the FM100 test (largest $r_s = -0.80$, smallest $r_s = -0.39$, all $p < 0.02$).

We tested whether overall accuracy for the local and global tasks on each background correlated more highly with performance on the L-M or tritan subsets of the FM100 test. This was indeed the case for the local and global tasks on the pink background, the local task on the cyan background, and the local task on the neutral background (see Table 1). Performance for the local tasks on pink, cyan and neutral backgrounds correlated more highly with performance on the L-M subset of the FM100 test, than with the tritan subset. Thus, it appears that performance on a shape discrimination task on certain coloured backgrounds (pink, cyan, neutral) is more highly associated with the ability to discriminate similar colours on the FM100 test (the L-M subset), even though background colour is irrelevant to the shape tasks.

INSERT TABLE 1 HERE

There were no significant differences in the correlations between performance on the L-M and tritan subsets of the FM100 task and reaction times, for any of the coloured backgrounds or shape tasks (smallest $r_s = -0.23$, largest $r_s = -0.45$, $p > 0.05$).

3.4. *WAIS and SPM+ non-verbal IQ measures*: The data for both the WAIS and SPM+ tests were normally distributed (Kolmogorov-Smirnov test, $p = 0.2$). As expected, performance on these tests correlated significantly ($r = 0.64$, $p = 0.004$): those with higher scores on one measure of non-verbal IQ had higher scores on the other.

3.5. *Non-verbal IQ measures and FM100 test*: Performance on the non-verbal components of the WAIS and on the SPM+ correlated with performance on the FM100 colour discrimination test, TES ($r = -0.72$ and -0.70 , respectively, $p = 0.001$ for each): those with higher non-verbal IQ scores had lower FM100 error scores (better colour discrimination). This confirms an earlier report using the WASI in typically developing and atypically developing (autism spectrum) children (Cranwell *et al.*, 2015), although here the correlations are much higher for the present healthy adult group, and the WAIS (used in the present study) includes more tests than the WASI.

3.6. *Non-verbal IQ measures and the global/local tasks:* The WAIS non-verbal IQ measure, *but not the SPM+*, correlated significantly with the overall proportion correct for both shape tasks (Figure 9): those with higher WAIS scores were more accurate at both global and local tasks (global: $r_s = 0.63$, $p=0.007$; local $r_s = 0.48$, $p=0.05$). Of the individual WAIS test components, performance on block design and object assembly correlated most highly with both the FM100 TES and accuracy for the global and local shape tasks. Scores on the SPM+, however, did not correlate significantly with the overall proportion correct for either the global or local shape tasks (global: $r_s = 0.36$, $p=0.16$, local: $r_s = 0.18$, $p=0.5$) Reaction times did not correlate significantly with scores on either of the non-verbal IQ measures.

INSERT FIGURE 9 HERE

4. Discussion

The present study investigated links between background colours, colour discrimination, non-verbal IQ and the phenomenon of global precedence. Global and local shape tasks were performed on five different coloured backgrounds. First, regardless of the background colours, we replicated overall expected trends. There was a global advantage (higher *accuracy* and faster *reaction times* for the global than for the local shape tasks), as has been previously reported (Navon, 1977; Michimata *et al.*, 1999, see Figures 5 and 7). There was, however, no complete replication of the asymmetric interference in *reaction times* previously reported: overall, participants were slower to identify the local shapes when they differed from the global (incongruent trials) compared to when the local and global shapes were the same (congruent trials). This is as has been previously reported. Our participants were also slower, however, to identify the global shapes when they differed from the local components (incongruent trials) than when the global and local shapes were the same (congruent trials). This is not as has been previously reported. The relative size of the reaction time difference was, nevertheless, greater for the local congruent and incongruent trials than for the global congruent and incongruent trials (Figure 7), which provides some support for asymmetric interference in reaction times for local and global tasks, if not a complete replication.

Second, the lack of differences for *reaction times* on different coloured backgrounds (Figure 6) is not consistent with the results of Michimata *et al.* (1999) who reported reaction time differences for local and global, congruent and incongruent, tasks on red, compared to green, backgrounds. In Figure 4, *accuracy* for global, incongruent trials, was lowest on the pink background, but accuracy was also low on the cyan background,

compared to the other coloured backgrounds, and these differences were not statistically significant. Thus, there is no compelling evidence from the present study that the background colour affected either accuracy or reaction times on the local and global shape tasks.

The background colours that were chosen for the present study were selected to differentially activate the cone opponent pathways early in the visual system (cardinal colour directions). Care was taken to ensure that the colours selected for the experiment were equally saturated (after Shepherd, 1997b; 1999; Shepherd and Wyatt; 2008) and of equal measured luminance. The saturation was limited only by the colour gamut available on a CRT monitor at a reasonable luminance (20 cdm^{-2}), which was five times that used by Michimata *et al.* (1999). The lack of significant differences in accuracy or reaction times, when performance on each of the five coloured backgrounds was compared, is considered unlikely to be due to having less salient colour backgrounds. Nevertheless, a direct comparison of the different colours (red, green vs pink, cyan) at equivalent luminance would clarify this issue.

Future research could, for example, look at the effects of background colour using colour-opponent (unique) hues, as well as the cone-opponent colours used here. The colours used in previous studies (Michimata *et al.*, 1999; Lovegrove and Pepper, 1994, Vidal *et al.* 2004) did not consider either of these types of colour stimuli. Hierarchical shape perception may reflect processing at higher levels of visual processing than occurs in cone-opponent pathways, so a comparison of cone-opponent versus colour-opponent (defined by unique hues), or using colours defined by identified higher-order colour mechanisms, could be useful. It would be an improvement on earlier work that has just specified that they used red, green, or blue.

Unique red has been estimated to be perceived at around 605 nm (range 596-700), and unique green at 505 nm (range 490-555, Kuehni, 2004; Mollon and Jordon, 1997), see Figure 1. As mentioned in the Introduction, it appears Michimata *et al.* (1999) used just the red and green phosphors on their CRT (see the corners of the triangle labelled 'R' and 'G' in Figure 1 for a representation of their phosphor chromaticities). Thus, the red and green used by Michimata *et al.* (1999) are closer to a unique red and a unique green than those used in the present study. Given the range of individual differences reported for unique hues (Kuehni, 2004; Mollon and Jordon, 1997), a preliminary next step could be to compare performance on the cone-opponent, cardinal, background colours used here with background colours created by activating only the red or green phosphors, all at the same luminance and with the same participants. If there were differences

between the two sets of colours, in a single experiment, it may warrant determining unique hues for each participant individually and running a follow up study, to clarify how important the particular red and green colours used are to have any effect on local and global shape perception.

Another further study could explore the effects of luminance: the displays used by Michimata *et al.* (1999) and Vidal *et al.* (2004) were very much dimmer (4.0 and 5.4 cdm^{-2} , respectively) than those used in the present study (20 cdm^{-2} , see methods). Any effects of rod intrusion would be greater for the displays used in these earlier studies than for the displays used in the present study. The rods are virtually insensitive to the long wavelengths emitted by the red phosphor of a CRT, but could respond to the wavelengths emitted by the green phosphor. As mentioned in the methods, Shepherd (1994) and Shepherd and Wyatt (2008) used similar screen colours to those used in the present study with luminances ranging from 58 cdm^{-2} to 2.5 cdm^{-2} and found, in a colour matching task, rod intrusion to become apparent only below 4.5 to 7 cd m^{-2} (effects differed slightly for different colours and different individuals). Rod intrusion could, therefore, affect performance for low luminance green backgrounds. Performance differences on red backgrounds, compared to green, reported in the earlier studies could have nothing to do with red light suppressing activity in post-receptoral cone-driven pathways, but could involve, instead, a lack of activation of the rods on the red background, compared to the green. If rod intrusion is apparent, the question of rod intrusion and global precedence would be an interesting line of further research. Future studies could compare global precedence using coloured backgrounds at high and low luminances. Including tritan coloured backgrounds at high and low luminances could be particularly informative to assess the effects of rod intrusion on performance (see Shepherd and Wyatt, 2008).

The significant correlations between overall performance on the hierarchical shape tasks and the FM100 TES, tritan PES and L-M PES were not anticipated, since the colour of the background was not relevant to be able to perform the shape tasks. The significant differences in the *size* of the correlations between accuracy on some of the shape tasks on pink, cyan and neutral backgrounds and performance on the L-M subset of the FM100 test, compared to performance on the tritan subset, were also not anticipated (Table 1). These differences could be explored further using more difficult local and global shape tasks: for the displays and tasks used here (selected to be the same as used by Michimata *et al.*, 1999), average performance was greater than 93% correct. To make the task more difficult, for example, the location of the hierarchical shapes could be spatially moved around, to introduce some spatial uncertainty. Briefer displays and a

shorter delay to mask them, or using more complex displays, may also bring accuracy rates down and reveal subtle effects of particular background colours.

Returning to the other tests performed, the two tests of NVIQ correlated significantly, and both correlated with performance on the FM100, consistent with the results reported by Cranwell *et al.* (2015). They concluded that performance on the FM100 test is mediated not only by a person's ability to discriminate colour, but by some components of NVIQ, such as the ability to attend to local and global aspects of the tests and their part-whole relationships, perceptual organisation and good visuomotor skills. Cranwell *et al.* (2015) employed the WASI, which is an abbreviated and modified form of the WAIS. Instead of the five non-verbal tests of the WAIS (block design; picture completion; picture arrangement; object assembly and the digit symbol coding task, see methods); the WASI includes just two: block design and matrix reasoning (similar to the SPM+ test used here, but shorter as it contains only 30 items). Cranwell *et al.* (2015) combined scores on block design and matrix reasoning to create a composite measure of NVIQ, which they used to correlate with performance on the FM100 test, they did not perform separate analyses for each component. One other study that has correlated a battery of tests of general ability (19 items from the Johnson O'Connor Research Foundation) reported low correlations between each item and FM100 TES (Acton and Schroeder, 2001). They concluded the ability to discriminate colours was distinct from the measure of general intelligence they extracted, *g*. Their battery does not include tests similar to those in the WAIS, WASI, or SPM+.

In the present study, performance on block design and object assembly from the WAIS correlated most highly with both the FM100 TES and accuracy for the global and local shape tasks. The SPM+ scores, however, only correlated with the FM100 TES. Both tests require attention to complexity at local and global levels. As Cranwell *et al.* (2015) have noted, the FM100 similarly requires attention to local elements while ignoring others (when participants compare and select adjacent coloured caps) and requires switching attention to the global array of the set of caps in each tray (to assess whether the colour scale they have created progresses smoothly from one end to the other). These similarities in task demands can account for the significant correlations between performance on the WAIS, SPM+ and FM100 tests. The lack of significant correlations between performance on the SPM+ and the local and global shape tasks, however, suggests that there are differentiable elements of NVIQ, and performance on visual tasks, that are worth exploring further.

The WAIS and SPM+ measure somewhat different aspects of NVIQ: block design and object assembly (WAIS) require participants to assess and organise, manually, increasingly complex global patterns, based on local shapes. The tests require attention to local and global elements and manual dexterity. Participants have to sort, order, rotate, and position objects that are placed on the desk in front of them, within a time limit. The SPM+, on the other hand, involves reasoning and extrapolation in sets of line drawings that become increasingly complex. The SPM+ does also require attention to local and global detail as the exemplars increase in complexity across the rows and down the columns of each test sheet, but the manipulations required to do the task are in the mind rather than in the mind and hand. The assessment of NVIQ is seldom assessed in conjunction with studies of many aspects of visual perception. The present study indicates that perhaps different components of NVIQ should be.

To conclude, there is still further research to be performed on the links between global precedence, shape and colour perception and NVIQ. Future studies could compare cone-opponent to colour (unique hue) opponent mechanisms, or higher order defined colour mechanisms. The role of luminance and rod intrusion could also be examined. Future research could also explore individual components of tests that assess NVIQ and performance on particular tasks using a consistent set of NVIQ measures.

Acknowledgements: this research was funded by Birkbeck, University of London.

References

- Abramov, I. & Gordon J. (1994). Color appearance: on seeing red, or yellow, or green, or blue. *Annual Review of Psychology*, 45, 451-485.
- Acton, G.S. & Schroeder, D.H. (2001). Sensory discrimination as related to general intelligence. *Intelligence*, 29, 263-271.
- Amirkhiabani, G. & Lovegrove, W.J. (1997). Perceptual organization and the global-local relationship. *Psychologia*, 40, 1-41.
- Blanca, M., Lopez-Montiel, D. & Lopez-Montiel, G. (2006). Factors influence the global dominance with hierarchical stimuli. *Anales de Psicología*, 22, 273-289.
- Breitmeyer, B. G. & Williams, M. C. (1990). Effects of isoluminant-background color on metacontrast and stroboscopic motion: Interactions between sustained (P) and transient (M) channels. *Vision Research*, 30, 1069-1075.
- Breitmeyer, B. G. & Breier, J. I. (1994). Effects of background color on reaction time to stimuli varying in size and contrast: Inferences about human M channels. *Vision Research*, 34, 1039-1045.
- Chapman, C., Hoag, R. & Giaschi, D. (2004). The effect of disrupting the human magnocellular pathway on human global motion perception. *Vision Research*, 44, 2551-2557.
- Chatterjee, S. & Callaway, E. M. (2002). S cone contribution to the magnocellular visual pathway in macaque monkey. *Neuron*, 35, 1135-1146.
- Cranwell, M.B., Pearce, B., Loveridge, C. & Hurlbert, A.C. (2015). Performance on the Farnsworth-Munsell 100-hue test is significantly related to nonverbal IQ. *Investigative Ophthalmology and Visual Science*, 22, 3171-3178.
- Dacey, D.M. & Packer, O.S. (2003). Colour coding in the primate retina: diverse cell types and cone-specific circuitry. *Current Opinion in Neurobiology*, 13, 421-427.
- Dacey, D.M., Crook, J.D., Packer, O.S. (2014). Distinct synaptic mechanisms create parallel S-ON and S-OFF color opponent mechanisms in the primate retina. *Visual Neuroscience*, 31, Special Issue: SI 139-151.
- Dartnall, H.J.A., Bowmaker, J.K. & Mollon, J.D. (1983). Human visual pigments: Microspectrophotometric results from the eyes of seven persons. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 220, 115-130.
- De Cesari, A. & Loftus, G.R. (2011). Global and local vision in natural scene identification. *Psychonomic Bulletin & Review*, 18, 840-847.
- De Monasterio, F.M. (1978). Properties of concentrically organized X and Y ganglion cells in macaque retina. *Journal of Neurophysiology*, 41, 1394-1417.
- De Valois, R.L., Abramov, I. & Jacobs, G.H. (1966). Analysis of response patterns of LGN cells. *Journal of the Optical Society of America*, 56, 966-977.
- Derrington, A.M., Krauskopf, J. & Lennie, P. (1984). Chromatic mechanisms in lateral geniculate nucleus of macaque. *Journal of Physiology*, 357, 241-265.

- Dreher, B., Fukada, Y. & Rodieck, R.W. (1976). Identification, classification and anatomical segregation of cells with X-like and Y-like properties in the lateral geniculate nucleus of old-world primates. *Journal of Physiology*, 258, 433-452.
- Eskew, R.T. (2009). Higher order color mechanisms: A critical review. *Vision Research*, 49, 2686-2704.
- Farnsworth, D. (1943). The Farnsworth-Munsell 100-Hue and Dichotomous Tests for Color Vision. *Journal of the Optical Society of America*, 33, 568-574.
- Farnsworth, D. (1957a). *The Farnsworth-Munsell 100-Hue test for the examination of color discrimination. Revised*. Maryland: Munsell Color Company, Inc.
- Farnsworth, D. (1957b). *The Farnsworth-Munsell 100-Hue test for the examination of color discrimination: Manual*. Baltimore: MacBeth.
- Hurvich, L.M. & Jameson, D. (1957). An opponent-process theory of color vision. *Psychological Review*, 64, 384-404.
- Jayakumar, J., Dreher, B. & Vidyasagar, T.R. (2013). Tracking blue cone signals to the primate brain. *Clinical and Experimental Optometry*, 96, 259-266.
- Kimchi, R. (1992). Primacy of wholistic processing and global local paradigm – critical review. *Psychological Bulletin*, 112, 1-24.
- Kinnear, P.R. & Sahraie, A. (2002). New Farnsworth-Munsell 100 hue test norms of normal observers for each year of age 5-22 and for age decades 30-70. *British Journal of Ophthalmology*, 66, 1408-1411.
- Knoblauch, K., Saunders, F., Kusada, M., Hynes, R., Podgor, M., Higgins, K.E. & de Monasterio, F.M. (1987). Age and illuminance effects in the Farnsworth-Munsell 100-hue test. *Applied Optics*, 26, 1441-1448.
- Krauskopf, J., Williams, D.R. & Heeley, D.W. (1982). Cardinal directions of colour space. *Vision Research*, 22, 1123-1131.
- Kuehni, R.G. (2004). Variability in unique hue selection: a surprising phenomenon. *Color Research and Application*, 29, 158-162.
- Lamb, M.R. & Yund, E.W. (1993). The role of spatial frequency in the processing of hierarchically organized stimuli. *Perception and Psychophysics*, 54, 773-784.
- Lamb, M.R. & Yund, E.W. (1996). Spatial frequency and attention: effects of level-, target-, and location repetition on the processing of local and global forms. *Perception and Psychophysics*, 58, 363-373.
- LaGasse, L. L. (1993). Effects of good form and spatial frequency on global precedence. *Perception and Psychophysics*, 53, 89-105.
- Lee, B.B., Shapley, R.M., Hawken, M.J. & Sun, H. (2012). Spatial distributions of cone inputs to cells of the parvocellular pathway investigated with cone-isolating gratings. *Journal of the Optical Society of America A – Optics Image Science and Vision*, 29, A223-A232.
- Lennie, P. & D'Zmura, M. (1988). Mechanisms of color vision. *Critical Review of Neurobiology*, 3, 333-400.

Lee, I.A. & Preacher, K.J. (2013, September). Calculation for the test of the difference between two dependent correlations with one variable in common (Computer software). Available from <http://quantpsy.org> (accessed June, 2017).

Livingstone, M.S. & Hubel, D.H. (1984). Anatomy and physiology of a color system in the primate visual cortex. *Journal of Neuroscience*, 4, 309-356.

Livingstone, M.S. & Hubel, D.H. (1988). Segregation of form, color, movement and depth: anatomy, physiology and perception. *Science*, 240, 740-749.

Lovegrove, W. & Pepper, K. (1994). The influence of low-level processing in the global precedence effect. In S. Ballesteros (Ed.). *Cognitive approaches to human perception*. Hillsdale, NJ: Erlbaum. pp. 71-90.

MacLeod, D. I. & Boynton, R. M. (1979). Chromaticity diagram showing cone excitation by stimuli of equal luminance. *Journal of the Optical Society of America*, 69, 1183-6.

Michimata, C., Okubo, M. & Mugishima, Y. (1999). Effects of background color on the global and local processing of hierarchically organized stimuli. *Journal of Cognitive Neuroscience*, 11, 1-8.

Mollon, J.D. & Jordan, G. (1997). On the nature of unique hues. In: Dickinson, C., Murray, I. & Carden, D. (Eds). *John Dalton's colour vision legacy*. London: Taylor and Francis, pp. 381-392.

Navon, D. (1977). Forest before trees: The precedence of global characters in visual perception. *Cognitive Psychology*, 9, 353-383.

Navon, D. (1981a). The forest revisited: More on global precedence. *Psychological Research*, 43, 1-32.

Navon, D. (1981b). Do attention and decision follow decision? Comment on Miller. *Journal of Experimental Psychology: Human Perception and Performance*, 7, 1175-1182.

Poirel, N., Pineau, A. & Mellett, E. (2008). What does the nature of the stimuli tell us about the global precedent effect? *Acta Psychologica*, 127, 1-11.

Raven, J.C. (2008). *Raven's Educational UK Standard Progressive Matrices – plus version*. Pearson Education Limited: London.
<http://www.pearsonclinical.co.uk/Psychology>

Shepherd, A.J. (1994). *Psychophysical studies of contrast colours*. Ph.D. thesis, Cambridge, U.K.

Shepherd, A.J. (1997a). Calibrating screens for continuous colour displays. *Spatial Vision* 11, 57-74.

Shepherd, A.J. (1997b). A vector model of colour contrast in a cone excitation colour space. *Perception* 26, 455-470.

Shepherd, A.J. (1999). Remodelling colour contrast: implications for visual processing and colour representation. *Vision Research* 39, 1329-1345.

Shepherd, A.J. & Wyatt, G. (2008). Changes in induced hues at low luminance and following dark adaptation suggest rod-cone interactions may differ for luminance increments and decrements. *Visual Neuroscience*, 25, 387-394.

- Skottun, B.C. (2004). On the use of red stimuli to isolate magnocellular responses in psychophysical experiments: a perspective. *Visual Neuroscience*, 21, 63-68.
- Smith, V.C., Pokorny, J. & Pass, A.C. (1985). Color-axis determination on the Farnsworth-Munsell 100-Hue test. *American Journal of Ophthalmology*, 100, 176-182.
- Solomon, S.G. & Lennie, P. (2007). The machinery of colour vision. *Nature Neuroscience Reviews*, 8, 276-286.
- Steiger, J. H. (1980). Tests for comparing elements of a correlation matrix. *Psychological Bulletin*, 87, 245-251.
- Stromeyer, C.F., Cole, G.R. & Kronauer, R.E. (1987). Chromatic suppression of cone inputs to the luminance flicker mechanism. *Vision Research*, 27, 1113-1137.
- Sun, H., Smithson, H. E., Zaidi, Q. & Lee, B. B. (2006a). Specificity of cone inputs to macaque retinal ganglion cells. *Journal of Neurophysiology*, 95, 837-849.
- Sun, H., Smithson, H.E., Zaidi, Q. & Lee, B.B. (2006b). Do magnocellular and parvocellular ganglion cells avoid short-wavelength cone input? *Visual Neuroscience*, 23: 441-446.
- Tailby, C., Szmajda, B.A., Buzás, P., Lee, B.B. & Martin, P.R. (2008). Transmission of blue (S) cone signals through the primate lateral geniculate nucleus. *Journal of Physiology*, 586, 5947-5967.
- Verriest, G., Van Laetham, J. & Uvijis, A. (1982). A new assessment of the normal ranges of the Farnsworth-Munsell 100-Hue test scores. *American Journal of Ophthalmology*, 93: 635-642.
- Vidal, J., Luna, D. & Elosúa, M.R. (2004). Influencias del color de fondo sobre el procesamiento de patrones visuales jerárquicos en sujetos disléxicos, malos lectores y normolectores [Background color influences on processing visual hierarchical patterns in dyslexics, poor readers and normal readers. *Acción Psicológica*, 3, 101-109.
- Vidal-López, J. & Romera-Vivancos, J.A. (2009). Is manipulation of color effective in study of the global precedence effect? *Perceptual and Motor Skills*, 108: 631-635.
- Weschler, D. (1981). *Wechsler Adult Intelligence Scale--Revised*. San Antonio, Psychological Corporation. Available from the CPS Testing Library, Center for Psychological Studies at Nova Southeastern University.
- Weschler, D. (1999). *Wechsler Abbreviated Scale of Intelligence*. San Antonio: Psychological Corporation.
- Wiesel, T.N. & Hubel, D.H. (1966). Spatial and chromatic interactions in the lateral geniculate body of the rhesus monkey. *Journal of Neurophysiology*, 29: 1115-1156.
- Yuste, C. (1995). *Inteligencia general y factorial*. Madrid: TEA Ediciones.

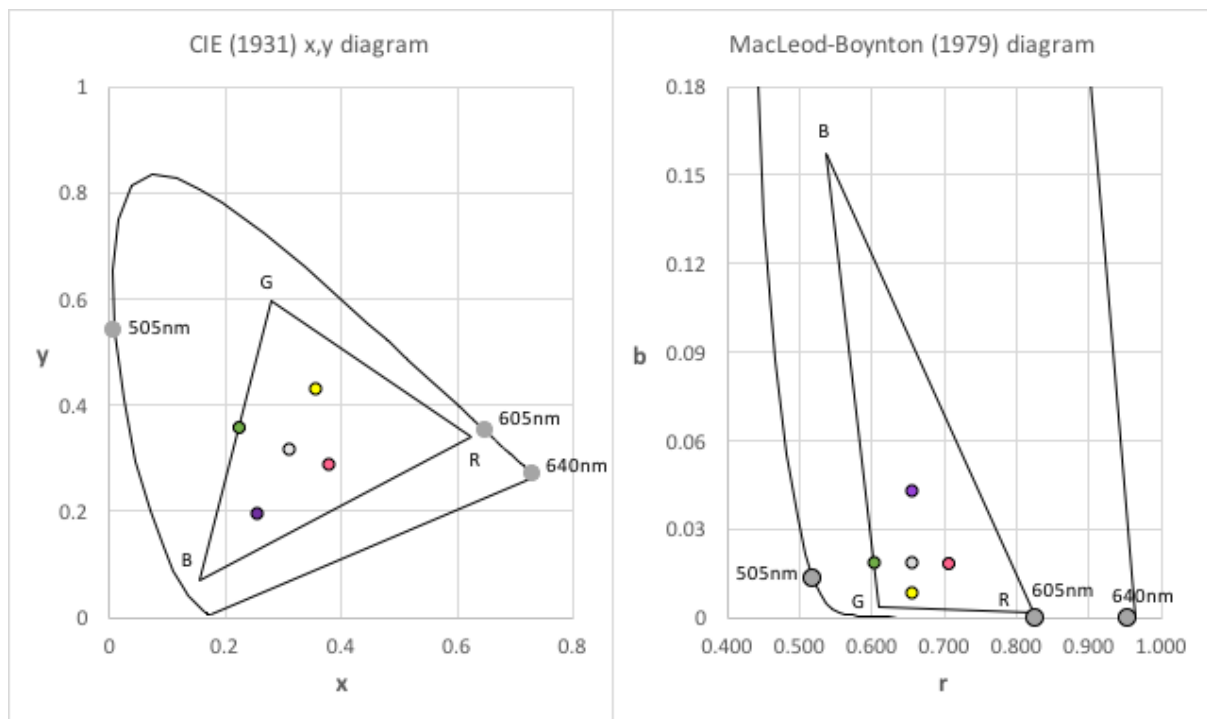


Figure 1. The chromaticities of the coloured backgrounds used in the present study, plotted in the CIE (1931) x,y chromaticity diagram and the MacLeod-Boynton (1979) r,b diagram (see the cross-shaped set of circular symbols). Also plotted are the chromaticities of the red (R), green (G) and blue (B) phosphors of the LaCie Diamondtron CRT monitor to show the range of colours available, and on the spectrum locus (outermost solid line) are added the chromaticities for light of 505, 605 and 640 nm, for comparison with earlier studies. CIE (1931) x,y chromaticity co-ordinates for the five background colours were: violet (0.257, 0.195), mustard (0.357, 0.428), pink (0.379, 0.287), cyan (0.228, 0.355), neutral (0.310, 0.316). These translate to MacLeod-Boynton (1979) r,b co-ordinates as (0.656, 0.042), (0.656, 0.007), (0.709, 0.018), (0.605, 0.018), (0.656, 0.018), respectively. See text for further details.

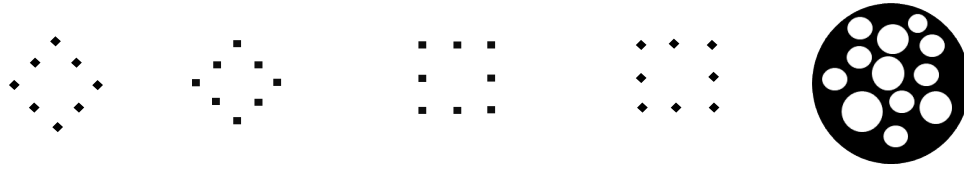


Figure 2. The stimuli used in the experiment. From left to right: the global diamond composed of local diamond elements (congruent); the global diamond composed of local square elements (incongruent); the global square composed of local square elements (congruent); the global square composed of local diamond elements (incongruent); the display used to mask the briefly presented displays. There was a brief interval (100 ms) between the offset of each shape stimulus and the mask, when the screen was blank. This combination provided an effective mask for each shape stimulus. See Figure 3 for the complete sequence and timing of events. Note the stimuli are not drawn to scale: see text for their actual sizes.

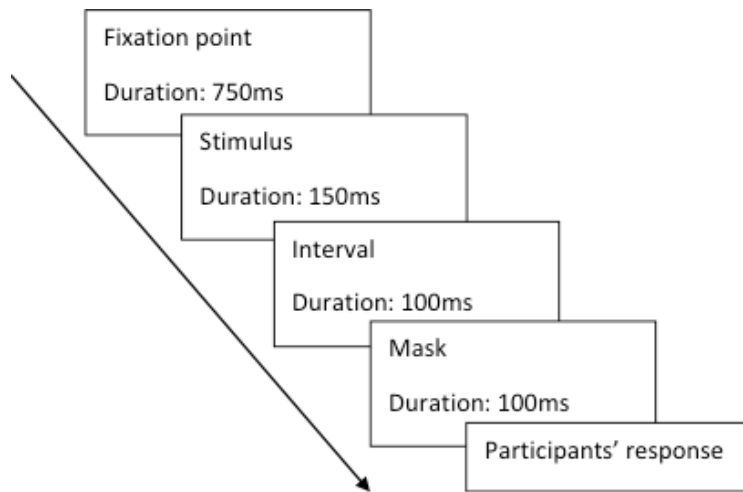


Figure 3. The sequence of events on each trial. Between the stimulus and the mask, and after the mask, the screen displayed the background colour until a response was made.

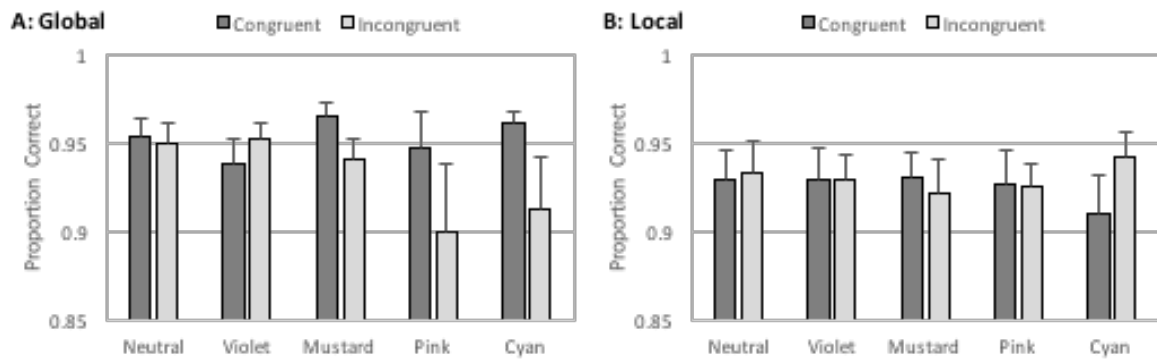


Figure 4. Proportion of correct responses for each coloured background and each condition. A: Proportion correct for the global shape task, congruent and incongruent global and local elements. B: Proportion correct for the local shape task, congruent and incongruent global and local elements. Error bars denote ± 1 standard error.

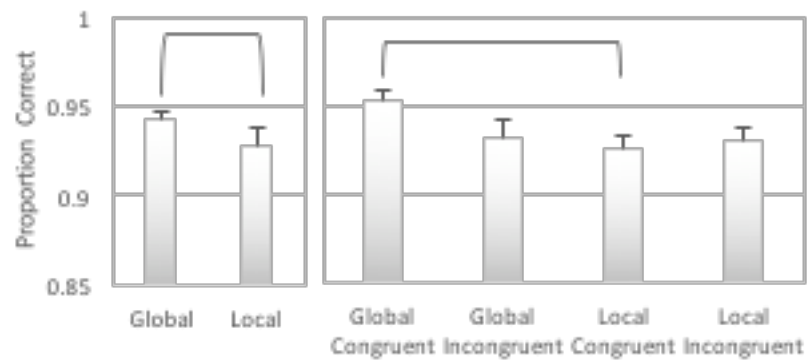


Figure 5. Accuracy data for the global and local tasks (left hand side) and with a breakdown for congruent and incongruent displays (right hand side). Significant differences are denoted by the grey brackets above the bars. Error bars denote ± 1 standard error.

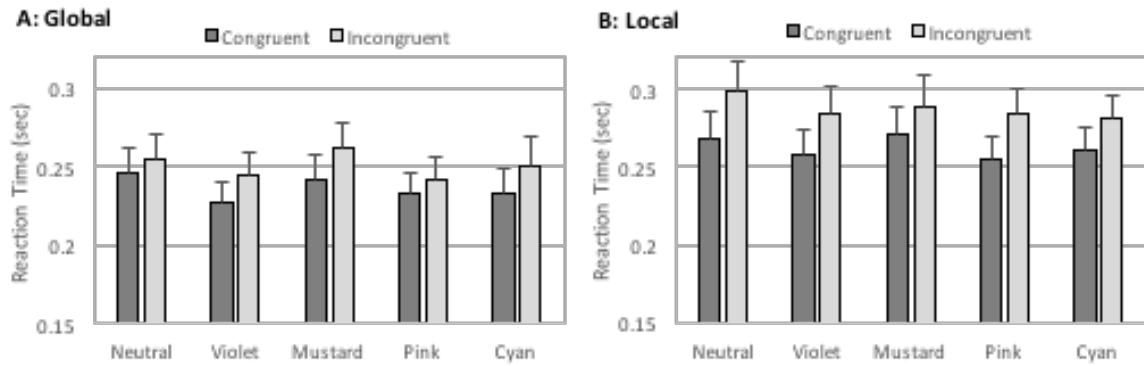


Figure 6. Reaction times (correct responses only) for each coloured background and each condition. A: Reaction times for the global shape task, congruent and incongruent global and local elements. B: Reaction times for the local shape task, congruent and incongruent global and local elements. Error bars denote ± 1 standard error.

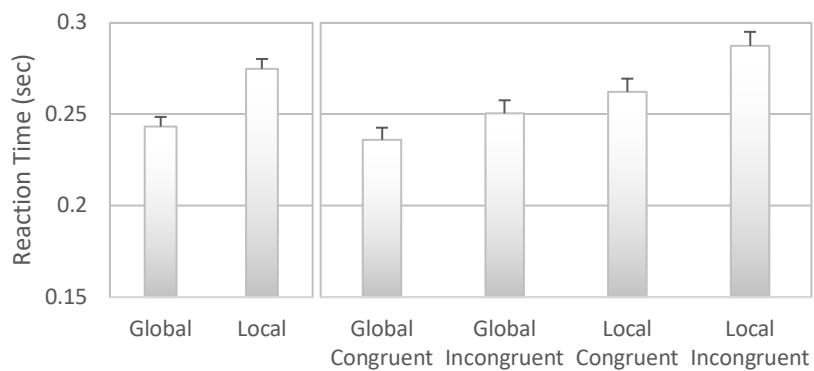


Figure 7. Reaction times for the global and local tasks (left hand side) and with a breakdown for congruent and incongruent displays (right hand side). Significant differences are denoted by the grey brackets above the bars. Error bars denote ± 1 standard error.

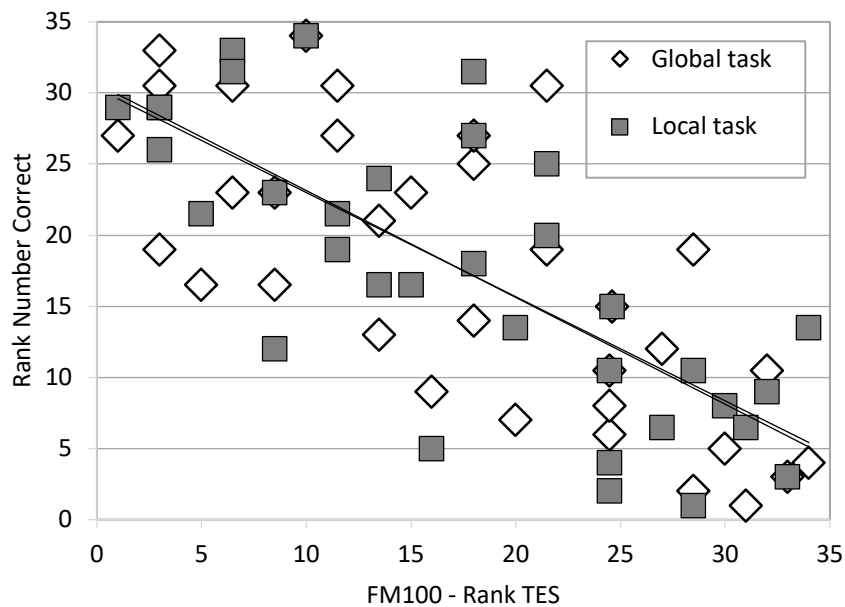


Figure 8. Correlations (Spearman's rho) between local and global task performance (rank number correct) and Farnsworth-Munsell total error scores (TES). The trend-lines for global and local tasks are similar (global $R^2=0.54$, local $R^2=0.56$).

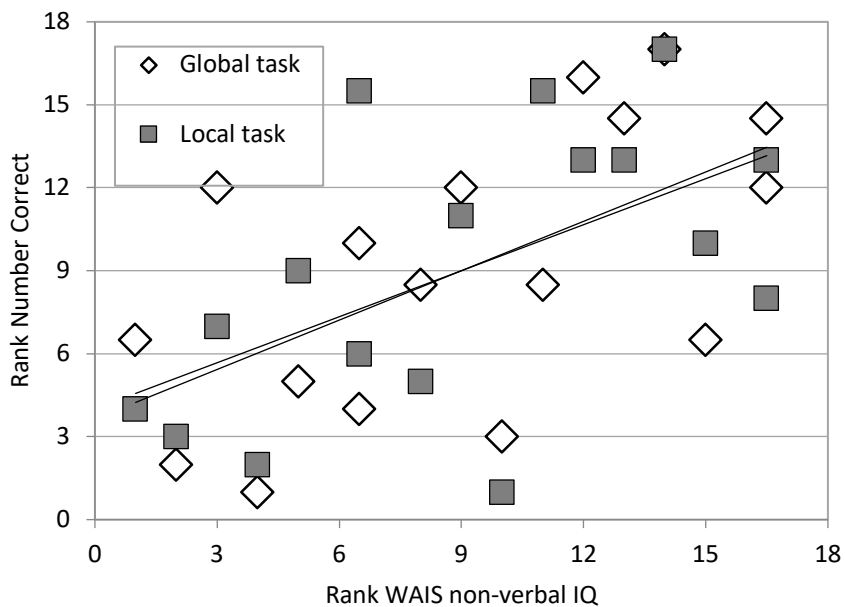


Figure 9: Correlations (Spearman's rho) between local and global task performance (rank number correct) and performance on the WAIS measure of non-verbal IQ. The trend-lines for global and local tasks are similar (global $R^2=0.36$, local $R^2=0.31$).

	L-M FM100 subset	Tritan FM100 subset	
Pink background			
Global task	$r_s = -0.69$	$r_s = -0.50$	$p = 0.047$
Local task	$r_s = -0.80$	$r_s = -0.63$	$p = 0.032$
Cyan background			
Local task	$r_s = -0.65$	$r_s = -0.39$	$p = 0.016$
Neutral background			
Local task	$r_s = -0.66$	$r_s = -0.44$	$p = 0.027$

Table 1: The correlations between performance on the L-M and tritan subsets of the FM task and overall accuracy on the pink, cyan and neutral coloured backgrounds, averaged across shapes (square or diamond) and congruency (congruent or incongruent). Significant differences in strength between each pair of correlations are shown, using techniques presented in Steiger (1980) and Lee and Preacher (2013).