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

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ABSTRACT

This study explored associations between performance on a global precedence task, display background colour, 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, 1981b) refined his proposal, suggesting that global shapes are processed rapidly and the smaller, detailed, components slightly more slowly, not necessarily sequentially. Navon (1977, 1981a, 1981b) concluded that whilst participants can pay attention to the global level of a stimulus without attending to its local

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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 2000 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 Amirkhiani & Lovegrove, 1997; Blanco, Lopez-Montiel, & Lopez-Montiel, 2006; De Cesaris & Loftus, 2011; Kimchi, 1992; Poiré, Pineau, & Mellett, 2008). 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, Okubo, and Mugishima (1999) and Vidal, Luna, and Elosúa (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-Lopez & 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 frequency above or below that cut-off point, respectively. Lamb and Yund (1993, 1996) 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 & 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-wave-length light (peaks between 640 and 660 nm) in primates at the levels of the retina (De Monasterio, 1978), the LGN (Dreher, Fukada, & Rodieck, 1976; Wiesel & Hubel, 1966), and the striate cortex (Livingstone & 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-wave-length backgrounds, such as a reduction in sensitivity to luminance flicker on intense red, compared to green, backgrounds (Stromeyer, Cole, & Kronauer, 1987), decreased metacontrast masking on red, compared to white or green backgrounds (Breitmeyer & Williams, 1990), increased reaction times to detect briefly flashed luminance increments on red, compared to green or blue, backgrounds (Breitmeyer & Breier, 1994) or increased motion coherence thresholds on red backgrounds (Chapman, Honig, & Giaschi, 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 in 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
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