



Colour-specific differences in attentional deployment for equiluminant pop-out colours: Evidence from lateralised potentials



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ABSTRACT

We investigated how target colour affected behavioural and electrophysiological results in a visual search task. Perceptual and attentional mechanisms were tracked using the N2pc component of the event-related potential and other lateralised components. Four colours (red, green, blue, or yellow) were calibrated for each participant for luminance through heterochromatic flicker photometry and equated to the luminance of grey distracters. Each visual display contained 10 circles, 1 colored and 9 grey, each of which contained an oriented line segment. The task required deploying attention to the colored circle, which was either in the left or right visual hemifield. Three lateralised ERP components relative to the side of the lateral coloured circle were examined: a posterior contralateral positivity (Ppc) prior to N2pc, the N2pc, reflecting the deployment of visual spatial attention, and a temporal and contralateral positivity (Ptc) following N2pc. Red or blue stimuli, as compared to green or yellow, had an earlier N2pc. Both the Ppc and Ptc had higher amplitudes to red stimuli, suggesting particular selectivity for red. The results suggest that attention may be deployed to red and blue more quickly than to other colours and suggests special caution when designing ERP experiments involving stimuli in different colours, even when all colours are equiluminant.

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1. Introduction

Colour is an effective cue for attentional selection and as such is often used in experiments probing attentional mechanisms (Bacon and Egeth, 1994; Clark, 1969; Jolicœur et al., 2008; Posner, 1980; Von Wright, 1972; Woodman and Luck, 2003). Attentional selection enables us to concentrate our limited attentional resources on a subset of the visual information reaching the visual cortex. Selection is required to avoid the loss of relevant information at later stages of processing because higher-level visual areas can only process and/or store a finite number of relevant objects (Cowan, 2000; Dell'Acqua et al., 2012). Visual spatial attention mechanisms are believed to process visual items serially (whether individually or in small groups) at some point in the visual processing stream in order to be identified in more detail and to control further processing (Sperling, 1960; Treisman and Gelade, 1980).

1.1. Colors and visual spatial attention

Usually, colours are used as a discriminative tool for segregating visual targets from distracters. This section provides a brief overview

of the results of a few key studies in which chromaticity was shown to have an experimental effect in attentional tasks. Additional discussion can be found in a number of more detailed studies (for which we suggest key studies e.g. Carter, 1982; Treisman and Gelade, 1980; Wolfe, 1994).

Two recent papers evaluate the contributions of colour to visual spatial attention (see also Ansorge and Becker, 2013; Lennert et al., 2011, for additional evidence). The first study addresses the contribution of colour to motion processing in automatic target selection (Tchernikov and Fallah, 2010). The authors measured smooth pursuit eye movements that occur spontaneously immediately following a saccade to a circular region containing dots moving coherently either left or right. The dots were red, green, blue, or yellow (with luminance equated across colours). In two experiments, pursuit movements were initiated earlier for red dots. In Experiment 1, this was evaluated with one colour at a time. The participant's task was to move their eyes in the general direction of the colored stimulus after the disappearance of a white fixation cross. In Experiment 2, different colours were put in opposition and red tended to win over other colours (if two sets of dots moved in the region in different directions, the spontaneous pursuit movements were in the same direction as the moving red dots). Overall, a hierarchy of colours was found, from red (strongest), to green, to yellow, to blue (weakest).

A second paper also evaluated reaction times (RTs) to targets of different desaturated colours (Lindsey et al., 2010). In this study,

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desaturated colour targets (pink, green, blue, and orange) were placed in a visual display among white and saturated distracters. Participants had to indicate the presence or absence of a target on every trial. To minimise the magnitude of difference in colour appearance, the authors chose desaturated targets (30 cd/m²) that laid at the midpoint of a line segment between saturated distracter (12 cd/m²), and white distracter (60 cd/m²) in Cie L*ab colour space. Those colours were furthermore tested through two auxiliary experiments, the first involving direct heterochromatic matching, and the second based on Maximum Likelihood Difference Scaling. The authors found faster RTs for desaturated red than desaturated orange and green, and slower RTs for desaturated blue (red < orange < green < blue).

What can be retained from these studies is that there seems to be an attentional bias for some colours over others, favouring their selection by attention and hastening our response when they are target. So far, mostly RTs have been reported, but RTs effects are often coupled to observable electrophysiological effects (Brisson et al., 2007; Mazza et al., 2009a). Here we used event-related potentials (ERPs) as a way to monitor, millisecond-to-millisecond, the deployment of attention to colored targets. Our goal was to determine if, like visual search or spontaneous capture of smooth pursuit eye movements, the mechanisms that guide and engage attention reflected by the N2pc component of the ERP would show systematic variations as a function of stimulus colour. We chose colours (red, green, blue, yellow) that are frequently used in visual search task (with and without electrophysiology) involving colour. Our main interest was in the lateralised electrophysiological components known for their link to visual attention, namely the N2pc. However, we were also interested in two other lateralised components, one just before the N2pc, the Ppc (positivity posterior contralateral), and the other just after the N2pc, the Ptc (positivity temporal contralateral).

1.2. The N2pc

The N2pc is a lateralised ERP component that can be calculated by subtracting the electrical potentials measured at electrodes sites ipsilateral to a lateral attended object from the electrical potentials measured at electrode sites contralateral to that object. The N2pc is observed over the posterior scalp, with peak amplitude typically observed at or near electrodes PO7/PO8. As the name suggests, the latency of the N2pc is in the N2 time range, which is 180–280 ms following the onset of an attended stimulus (Brisson and Jolicoeur, 2007; Luck and Hillyard, 1994; Robitaille and Jolicoeur, 2006). Luck and Hillyard (1994) argued that the N2pc reflects spatial filtering of distracters, whereas Eimer (1996) and, more recently, Mazza et al. (2009a, 2009b) argued that the N2pc reflects target enhancement.

It is no surprise that, much like in behavioural attentional studies, colour is often used in ERP experiments involving the N2pc (Eimer, 1996; Hickey et al., 2009). Studies usually report conditions in which the target and distracter are equiluminant to equate bottom-up effective intensity. Then, after making sure that an equal number of participants/trials are performed with each colour, different colour trials are averaged together. Typically, the direct effect of colours on the N2pc is not discussed, with possible differences assumed to have been equated across conditions. This approach is technically sound when there are no colour-specific interactions, but has downplayed what appear to be quite substantial effects that are interesting in their own right. When experimenters do study the effect of colours on the N2pc, it is often with search questions unrelated to chromaticity (e.g., effect of language on detection/disparity between target and distracter). This results in a near absence of reports of N2pc latency or amplitude effects between colours (Liu et al., 2009; Regier and Kay, 2009).

One pertinent paper regarding our research question evaluated the role of physical disparity between target and distracter items (Zhao et al., 2011). In their study, the authors modulated the physical difference (through colour in one condition) between target and distracters

while observing the effect on the N2pc. They compared conditions in which the disparity from the distracter was high (distracter light blue, target dark blue) and a condition in which it was low (distracter medium blue, target dark blue), by manipulating the RGB values of the colours while maintaining them equiluminant. Participants were asked to find the stimulus (a cross) that differed in colour and to decide whether the top or the lower segment of the vertical bar of the target was longer. A main effect of colour disparity was found, with the mean amplitude of the N2pc in the high colour disparity condition being larger (more negative) than the low-disparity condition. A marginal effect of latency was also found, with the N2pc related to low disparity being later than the high-disparity N2pc. Both ERP results dovetailed with the behavioural data in which the high disparity condition had faster RTs than the low disparity condition.

1.3. The Ppc

Rarely discussed, the posterior contralateral positivity (Ppc) is a lateralised component earlier than the N2pc, roughly from 150 to 200 ms post stimulus. In a study by Corriveau et al. (2012), neither the mean amplitude of the Ppc nor its latency depended on the lateral item status as target or distracter. This early-lateralised response appeared to reflect an attention driven spatial “attend-to-me” signal that arises in the waveforms of an unbalanced visual display containing a salient stimulus only on one side.

1.4. The Ptc

The Ptc is a positive component that can be observed over the contralateral hemisphere of the attended item. The Ptc was observed between 290 and 340 ms post stimulus in previous experiments. The label “temporal” follows the suggestion of Hilimire et al. (2009). Hilimire et al. (2009) suggested the Ptc might reflect local attentional competition resulting from the spatial proximity between a target and a salient distracter. The amplitude of the component generally becomes larger (more positive) as the physical separation between the target and a salient distracter decreases (Hilimire et al., 2009). This modulation of Ptc amplitude could reflect distracter inhibition after initial attentional deployment (the N2pc), in order to isolate a target once it has been identified (Hilimire et al., 2011). Their component did not vary with target-distracter saliency difference (manipulated through colour saturation of the target or the salient distracter) (Hilimire et al., 2010).

From previous ERP and behavioural experiments, we expected to see a difference in the N2pc amplitude and latency for colours that allow a better attentional deployment, possibly resulting in a colour hierarchy (Tchernikov and Fallah, 2010; Zhao et al., 2011). More precisely, we anticipated a shorter N2pc latency to red targets, based on the Tchernikov and Fallah (2010) results. However, Lindsey et al. (2010) only found an advantage for desaturated reds, and so the typical red stimuli used in most attention selection experiments may not be subject to the special effect for desaturated red. Predictions for other colours are even more difficult to make, given paucity of results and inconsistent results across studies.

Very few experiments explored the role or even the existence of the Ppc and Ptc. Previous experiments dealing with the Ppc component indicate that it reflects the representation of an unbalanced visual display (Corriveau et al., 2012). Since colour attentional bias should create an unbalanced display, we would expect for the present experiment a more positive Ppc for colours with a stronger attentional response, namely the red target compared to other targets. The Ptc reportedly representing inhibitory processing of close distracters could amplify in amplitude for colours with increased salience like red, since more inhibition should be required for more salient targets (Hilimire et al., 2010).

In most of our recent work we equated the luminance of colours using a specialised instrument (Minolta CS100 chromameter). We wondered, however, if individual differences luminance responses could

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