Research Report

Object Onset and Parvocellular Guidance of Attentional Allocation

Geoff G. Cole, Robert W. Kentridge, and Charles A. Heywood

University of Durham, Stockton-on-Tees, United Kingdom

ABSTRACT—***The parvocellular visual pathway in the primate brain is known to be involved with the processing of color. However, a subject of debate is whether an abrupt change in color, conveyed via this pathway, is capable of automatically attracting attention. It has been shown that the appearance of new objects defined solely by color is indeed capable of modulating attention. However, given evidence suggesting that the visual system is particularly sensitive to new onsets, it is unclear to what extent such results reflect effects of color change per se, rather than effects of object onset. We assessed attentional capture by color change that occurred as a result of either new objects appearing or already-present "old" objects changing color. Results showed that although new object onsets accrued attention, changing the color of old objects did not. We conclude that abrupt color change per se is not sufficient to capture attention.***

The ability of an organism to orient rapidly to a potentially threatening event has clear implications for survival. Hence, one of the goals of the mammalian visual system is to swiftly and automatically alert the observer to unexpected visual events. Identifying the stimulus properties that elicit such a response will help to clarify the mechanisms of attentional capture. The persuasive nature of people's color experience might suggest color as one such candidate. Furthermore, color differences readily enable people to segment visual scenes into objects and their backgrounds (Mollon, 1989) and could therefore also serve to signal the appearance of new objects. A pivotal study reported by Snowden (2002) showed that abrupt changes in color are indeed capable of automatically attracting attention. However, it remains unclear whether color change per se or the onset of color that defined new objects was the effective stimulus in that study. Our aim in the present study was to determine whether either type of stimulus event, or both in combination, is effective in marshaling attentional resources.

Early studies implicated luminance change as the stimulus property most likely to modulate the rapid deployment of attention (Yantis & Jonides, 1984). This makes heuristic sense; a new object appearing in the visual field is likely to be accompanied by a luminance change. The importance of luminance detection is supported by many of the physiological properties of the magnocellular (M) visual pathway, which is known to convey luminance information. Cells in the M pathway sum the outputs of middle- and long-wavelength cones, have short response latencies, are sensitive to high temporal but low spatial frequencies, and signal motion. This pathway originates in the retina and projects, via the lateral geniculate nucleus, to cortical visual areas, including parietal areas implicated in spatially selective attention. The role that color plays in attracting attention is more controversial. In comparison with the cells in the M channel, the cells in the color-opponent parvocellular (P) channel appear less well suited to a role in attentional capture. In particular, cells in the P channel respond sluggishly and are insensitive to high temporal frequencies. Such properties are not likely to be characteristic of a system involved in the rapid deployment of attention.

Indeed, researchers have found little empirical evidence that color has any attentional guidance properties (Folk & Annett, 1994; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1990; but see Turatto & Galfano, 2001). However, Snowden (2002) showed that abrupt changes in color, conveyed solely by signals in the P channel, are indeed capable of automatically attracting attention. Snowden's study was based on the classic precuing paradigm of Posner and his colleagues (e.g., Posner, Snyder, & Davidson, 1980). In this paradigm, observers are presented with an attention-capturing cue immediately prior

Address correspondence to Geoff G. Cole, Cognitive Neuroscience Research Unit, Wolfson Research Institute, Queen's Campus, University of Durham, Thornby, Stockton-on-Tees, United Kingdom, TS17 6BH; e-mail: g.g.cole@durham.ac.uk.

to the onset of a target. The cue might be, for instance, the onset of an object (Steinman, Steinman, & Lehmkuhle, 1995) or the brightening of a box (Posner & Cohen, 1984). The important manipulation is the spatial relationship between the cue and target. Reaction time (RT) is faster when the target occurs in close proximity to the cue (i.e., the cue is valid) than when the target is displaced from the cue location (i.e., the cue is invalid). The conventional explanation for the effect is that the cue attracts attention to its location; the processing of a target subsequently presented at that location is then facilitated.

In the experiment of Snowden (2002), the cue was the onset of four boxes that appeared briefly in either the left or the right half of the display. Shortly afterward, one of two differently oriented line segments appeared in one of the two locations. The task was to indicate as quickly as possible which of the two targets was presented. RTs were reduced when the target appeared on the same side as the preceding (color) cue. In other words, the cue automatically attracted observers' attention, resulting in the facilitation of target processing after valid cues. In order to ensure that participants were responding on the basis of chromatic information conveyed by the P channel, rather than unintended luminance differences or unsigned chromatic contour transmitted by the color-blind M channel, Snowden used the method of random luminance masking (Barbur, Harlow, & Plant, 1994; see Fig. 1). The introduction of rapid luminance fluctuations in the elements of the display rendered the M channel ineffective in detecting the introduction of color change. Snowden's clever use of this type of stimulus suggested a role for the P channel in attentional allocation.

Although such stimuli ensured isolation of the color-processing P channel, the design did not dissociate the effects of abrupt changes in color from the effects of object onset. Snowden (2002) unequivocally showed that a P-channel transient could capture attention, but this capture could have been due either to the P-channel transient per se or to the fact that, in Snowden's design, the color change created new objects. This reasoning is based on a wealth of studies suggesting that the visual system is particularly sensitive to the onset of new objects, compared with many other types of stimulus events. For instance, targets that are associated with an object onset accrue an RT advantage compared with targets associated with movement (Franconeri & Simons, 2003[1]; Hillstrom & Yantis, 1994). Additionally, we (Cole, Kentridge, Gellatly, & Heywood, 2003; Cole, Kentridge, & Heywood, 2004) have shown that the onset of an object is less susceptible to change blindness (Simons, 2000) than are many other types of change, including color change of objects.

Our aim in this experiment, therefore, was to assess whether transient signals in the P channel inevitably attract attention, or

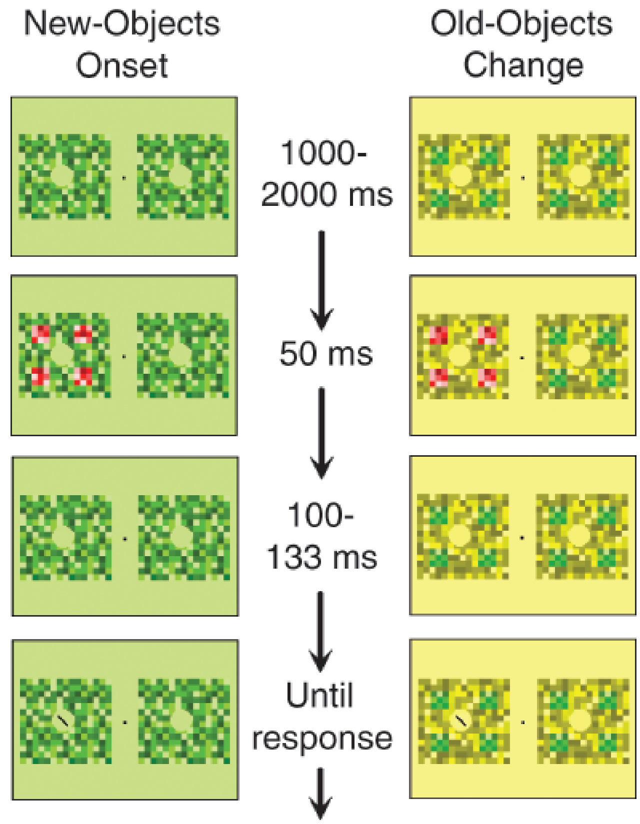

Fig. 1. Examples of stimuli and illustration of the display sequence used by Snowden (2002) and in the present study. In the old-objects condition, used only in the present study (sequence shown on the right), four green objects were present on each side of the display for between 1,000 and 2,000 ms in Frame 1. The objects on one side of the display then changed to red in the second frame for 50 ms before returning to green in Frame 3. The target was presented between 100 and 133 ms later, and this fourth frame remained until the participant responded. The procedure was identical for the new-objects trial (sequence shown on the left), used both by Snowden and in the present study, except that no old objects were presented and the noise patches were different in color. The two examples shown are for a valid-cue trial using large cues. Note that the figure is not to scale.

whether they do so only if they also constitute the appearance of a new object. We adopted Snowden's (2002) basic method with a modification that allowed a given P-channel transient to occur either as an abrupt color change to an existing color-defined object or as a new colored object. A crucial aspect of the design was that the P-channel transient was identical in the two cases. We expected that if a signal conveyed via the P pathway can indeed attract attention, the capture effect would occur in both conditions. If, by contrast, Snowden's capture effect occurred as a result of the color change giving rise to the appearance of a new object, capture would occur only in the new-objects condition.

METHOD

On each trial, the stimulus consisted of two square patches of random luminance noise, one presented on each side of fixation. Each patch measured approximately 8.4° in both height and

[1]Although Hillstrom and Yantis (1994) found no attentional capture for motion, Franconeri and Simons (2003) found a larger capture effect for onset compared with motion, as measured by set-size search slopes.

width and contained 441 (21×21) smaller squares, all of which measured 0.4° along each side. Every 40 ms, each of the small squares changed randomly in luminance to one of 60 possible values between 21.6 and 26.4 cd/m^2 (average = 24 cd/m^2), thereby providing random luminance masking for color changes in the display. These patches were presented against a uniform 24-cd/m^2 background. A uniform, unchanging 24-cd/m^2 disc measuring 1.15° in diameter was superimposed at the center of each noise patch. The two discs, in which targets could be presented, were positioned such that their centers were located 5.5° from the black fixation point.

Cues were presented by changing the color of some of the squares within one of the mask patches. In order to assess any effect of cue size, we used two different sizes of cues. In the small-cue condition, the color change took place in four of the small squares, one in each quadrant of one of the two larger squares. The four cues were located one at each corner of an imaginary square measuring 4.4° along each side. In the large-cue condition, nine squares (3×3) at each corner of the imaginary square changed color. The target, presented at the center of one of the unchanging central discs, was a sloping black line 0.08° wide and 0.5° long; it tilted either +45° or −45° from the meridian.

In the new-objects condition, the background, the mask patches, and their central discs were all colored green. In the old-objects condition, the background, mask patches, and central discs were all colored yellow; however, within the mask patches, the squares that corresponded to both left and right cue locations were colored green. Changing some of the green squares to red generated cues (i.e., onsets) in the new-objects condition; changing green squares (old objects) to red, against a yellow background, generated color-change cues, but not new objects, in the old-objects condition. Put simply, either red new objects appeared on a green luminance-noise background or green old objects changed to red on a yellow luminance-noise background. All of the squares making up the cues varied in luminance in exactly the same fashion as the rest of the squares of the mask patches. A critical aspect of this design is that the color changes that created cues were identical in the two conditions; all that differed was the background. The colors were selected such that the red and the green had equal magnitude and opposite-sign cone contrasts (±12.5% root mean square calculated using Smith-Pokorny cone fundamentals) to the midpoint yellow along the isoluminant axis. The midpoint yellow had CIE (Commission Internationale de l'Eclairage) x, y coordinates of 0.42, 0.45.

The display sequence for trials in both conditions is shown in Figure 1. At the beginning of a trial in the old-objects condition, four objects were present on each side of the display. After 1,000 to 2,000 ms, the cue was presented for 50 ms. Following an interval of 100 to 133 ms, the target appeared, remaining until the participant responded. A response initiated the next trial. The time course of a new-objects trial was identical with the sole exception that no old objects were present in the sequence. Participants were shown demonstration trials before completing 64 practice trials and then 128 experimental trials in each of four blocks. Each block comprised trials of either the new-objects or the old-objects condition, with either small cues or large cues, for a total of 512 trials divided equally among all conditions. Valid-cue and invalid-cue trials were presented in random order within each block.

The experiment and stimuli were generated via a Cambridge VSG 2/5 linked to a gamma-corrected Sony monitor. Participants were asked to decide as quickly as possible which of the two targets occurred on each trial and to respond by pressing one of two buttons on a button box. They were asked to maintain accuracy and also informed that the cue did not predict the location of the target. Participants were seated approximately 57 cm from the display. There were 10 participants.

RESULTS

All incorrect responses were omitted from the analysis. Additionally, all responses more than 2 standard deviations above and below the mean for a given participant were excluded. These exclusions resulted in the removal of approximately 8% of responses. Mean RTs from all 10 observers are shown in the top panel of Figure 2. All participants' mean RTs were entered into a 2 (cue validity: valid vs. invalid) × 2 (type of color change: new objects vs. old objects) analysis of variance.[2] As Figure 2 suggests, a main effect was observed for cue validity, $F(1, 9) = 15.4$, $p < .01$, $\eta^2 = .63$. Although the main effect of type of color change was not significant, $F(1, 9) = 2.1$, $p < .2$, $\eta^2 = .18$, the interaction was, $F(1, 9) = 5.3$, $p < .05$, $\eta^2 = .37$. Post hoc analysis revealed that the main effect of validity was due to the fact that valid cues were associated with faster RTs in the new-objects condition, as the difference in RTs for the two validity conditions of the old-objects condition was not significant, $F(1, 9) < 1$.

A similar pattern of results emerged when error rates were considered (see Fig. 2, lower panel). Means showed an effect of cue validity in the new-objects condition, but not in the old-objects condition.

In summary, although the onset of colored objects induced a cuing effect, changing the color of old objects did not. The only slightly puzzling aspect of the data is that valid cues in the new-objects condition did not produce the fastest RTs, as one might have predicted. The combination of valid cues and new objects did, however, produce the greatest accuracy.

[2]Initially, we included cue size as a factor but found it had no main effect and no interaction with any of the other factors. Therefore, in order to increase power, we collapsed across the large- and small-cue conditions.

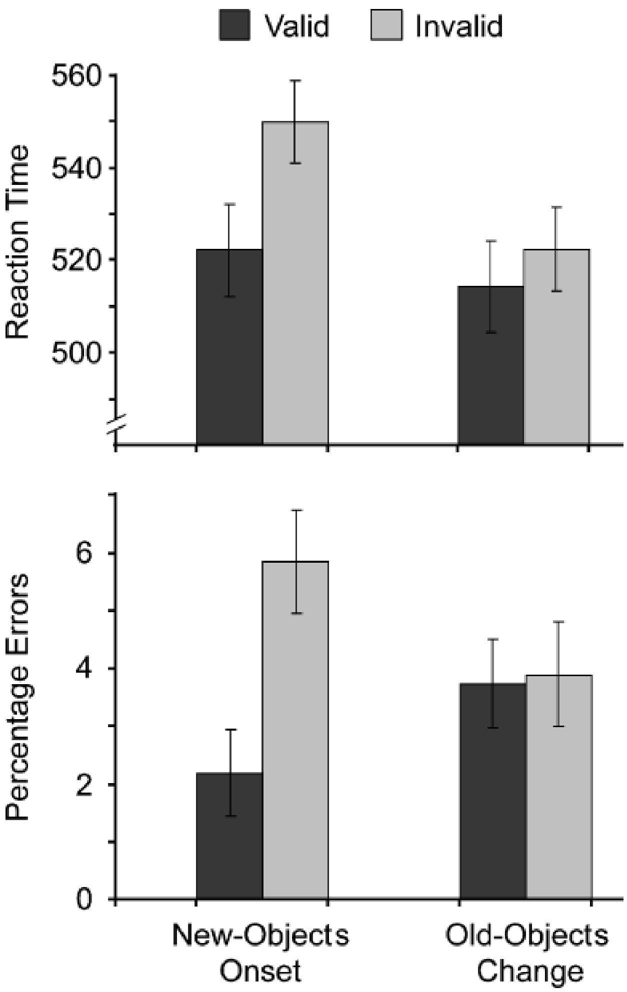

Fig. 2. Reaction times (top panel) and error rates (bottom panel) for both color-change conditions for valid- and invalid-cue trials. Standard error bars are also shown.

DISCUSSION

The aim of our experiment was to investigate whether a P-channel color signal alone could attract attentional resources. We assessed the effectiveness with which an abrupt color change captured attention when the change constituted either the onset of new objects or a change in the color of old objects. Our results show that an abrupt color change needed to constitute the appearance of new objects in order to be effective as an attentional cue. When such a transient merely changed the color of existing objects, this cuing effect was abolished. In other words, a P-channel transient per se does not necessarily attract attention, but a new object defined purely by a P-channel modulation can capture attention. Hence, the P-channel signal that Snowden (2002) identified as being an effective attentional cue was effective because it defined a new object. Our data are consistent with other work showing that changing the properties of an object is less effective in attracting attention than presenting a new object (Cole et al., 2004; Gellatly, Cole, & Blurton, 1999; Yantis & Jonides, 1984).

Although the present data show that an abrupt color change per se does not have the capacity to capture attention, it is clear from previous work that changing certain properties of an old object can indeed capture attention. For instance, the cue presented in Posner's precuing paradigm was an object changing luminance (e.g., Posner et al., 1980; see the introduction). Indeed, attentional capture by a changing old object is perhaps inevitable if the change is salient enough. One remaining and related issue concerns the definition of a new object. It is not clear which aspect of the stimuli in the new-objects condition alerted the visual system to the appearance of new objects. It may have been, for instance, the detection of chromatic contour (Kentridge, Cole, & Heywood, 2004; see also Sumner, Adamjee, & Mollon, 2002). We are currently pursuing the issue of which attributes of a stimulus define a new object.

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