



Attentional capture by masked colour singletons

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ABSTRACT

We tested under which conditions a colour singleton of which an observer is unaware captures attention. To prevent visual awareness of the colour singleton, we used backward masking. We find that a masked colour singleton cue captures attention if it matches the observer's goal to search for target colours but not if it is task-irrelevant. This is also reflected in event-related potentials to the visible target: the masked goal-matching cue elicits an attentional potential (N2pc) in a target search task. By contrast, a non-matching but equally strong masked colour singleton cue failed to elicit a capture effect and an N2pc. Results are discussed with regard to currently pertaining conceptions of attentional capture by colour singletons.

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1. Introduction

Colour is a powerful feature for discriminating relevant from irrelevant visual objects (e.g., Hansen & Gegenfurtner, 2009). Each specific colour, however, conveys different information to an organism, conditional on what the organism actually aims to do. Accordingly, during visual search for relevant objects humans frequently exert top-down control over which colours to attend to and which to ignore (cf. Duncan & Humphreys, 1989; Green & Anderson, 1956; Wolfe, 1994; Wolfe & Horowitz, 2004).

In line with this general notion, a number of psychological experiments suggested that objects capture attention to the degree that they match a set of searched-for relevant colours. In a typical experiment, participants search for a predefined colour target and they do not know where exactly this target will be shown (Folk & Remington, 1998; Gibson & Kelsey, 1998). Two sorts of peripheral cues can then be used to indicate a target position in advance of the target. (1) Cues with a colour similar to that of the searched-for targets. These are the matching cues because their colour matches the search templates which are specified for the targets. (2) Cues with a colour dissimilar to the targets. These are the non-matching cues because their colours do not match the search templates. The cues are presented prior to the target, either at the position of the target (valid condition) or at another position than the target (invalid condition). If a cue captures attention, it will facilitate discrimina-

tion and detection of a target at the cued position relative to a target away from the cue (Posner, 1980).

In line with the concept of goal-directed attentional capture, Folk and Remington (1998) found that if cue and target positions were uncorrelated and cues therefore did not reliably inform about the target's position, (1) goal-matching colour cues captured attention, whereas (2) non-matching colour cues did not (for a review, see Burnham, 2007). Goal-matching cues created a validity effect, with faster responses to validly than to invalidly cued targets while non-matching cues did not. The results were found although both top-down matching and non-matching colour cues were equally "salient": both of these cues were so-called colour singletons. This means that all cues had an individuating colour by which they stood out against a background consisting of homogeneously coloured alternative stimuli.

Yet, even a non-informative and task-irrelevant colour singleton can capture attention in a stimulus-driven way (cf. Burnham & Neely, 2008). This has advantages, too. An irrelevant colour that attracts or captures attention has the power to overcome the pertaining goal settings. Thus, stimulus-driven attentional capture allows switching to a more adaptive behaviour (cf. Horstmann, 2002, 2005). Think of fishes like sticklebacks, or birds like ruffs. These species have different colours during mating and non-mating phases. As a consequence of stimulus-driven capture by irrelevant colour singletons, an animals' mating gown could interrupt mating-unrelated behaviour in an on-looking con-specific so that the onlooker could switch to more adaptive courting behaviour on instance of seeing the unanticipated mating gown colour. Such advantages of attending to task-irrelevant colours are one reason

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why local feature contrast (as realised in colour singletons) has been regarded to capture attention in a stimulus-driven manner (cf. Bergen & Julesz, 1983; Itti & Koch, 2001; Parkhurst, Law, & Niebur, 2002).

The exact way in which stimulus-driven capture interacts with top-down contingent capture by non-informative colour singletons is not yet fully understood. Two general principles have been advocated to explain the interaction (cf. Reynolds, Chelazzi, & Desimone, 1999; Serences et al., 2005). First, top-down control could be achieved by top-down contingent capture (Folk, Remington, & Johnston, 1992). This means that an observer can set up a template to search for a particular colour (or in general a particular feature) in advance of visual stimulation (Ansorge & Horstmann, 2007; Duncan & Humphreys, 1989). Thus, attention could be biased toward relevant template-matching features right from stimulus onset (e.g., Bichot, Rossi, & Desimone, 2005).

Secondly, top-down control over attention to colour singletons could be occurring after an initial phase of stimulus-driven attention (cf. Kim & Cave, 1999; Ogawa & Komatsu, 2004; Wolfe, 1994). With respect to colour, this means that attention would be initially driven by a local colour difference in an image (cf. Itti & Koch, 2001) or by local colour salience (cf. Donk & van Zoest, 2008; Theeuwes, 1992, 1994). Only after initial capture took place, participants might be able to selectively ignore the irrelevant stimuli (Belopolsky, Schreij, & Theeuwes, 2010; Theeuwes, Atchley, & Kramer, 2000).

Note that according to this view, colour contrast or colour salience is defined in merely objective or algorithmic terms only: it is determined by a measured local “colour difference” between stimulus and surround or between one singleton stimulus and several non-singleton stimuli. This algorithmic definition is typical of modelling approaches. For example, a colour difference could be measured as the standard deviation within a circumscribed region of the image (cf. Frey, Honey, & König, 2008).

However, colour salience could be used in a more refined sense as referring to the subjective representation of such a colour difference. Under this perspective, a local colour difference is a favourable if not even a crucial prerequisite of stimulus-driven capture. Yet, a mere local colour difference would not be sufficient for stimulus-driven capture. In addition to a high colour difference, participants would need to be aware of this colour difference for its stimulus-driven capture.

In the present study, we tested the influence of awareness on stimulus-driven and top-down contingent attentional capture by non-informative colour singletons. We used singleton colour cues with a top-down matching or a non-matching colour. We prevented our participants' awareness of the singleton colour cue to large extents by backward masking of the cue (cf. Breitmeyer, Ro, & Singhal, 2004; Schmidt, 2002). Our expectations were as follows. First, if a colour singleton captures attention independently of awareness as implied by computational theories of feature-driven attention (cf. Parkhurst et al., 2002), we should find attentional capture by invisible colour singleton cues. Importantly, there is evidence that a colour singleton remaining outside of the awareness of an observer can capture attention if task relevant (Kristjánsson, Vuilleumier, Malhotra, Husain, & Driver, 2005; Scharlau & Ansorge, 2003; Woodman & Luck, 2003).

Secondly, however, whether or not stimulus-driven capture by colour singletons depends on awareness has not been tested so far. For instance, in Kristjánsson et al.'s (2005) study, participants searched for singletons. Therefore, the invisible colour singletons in that study could have captured attention in a top-down contingent fashion or in a stimulus-driven way. If attentional capture by colour singletons outside awareness is stimulus-driven there should be evidence for attentional capture for both goal-matching and non-matching colour singleton cues in the present experiment.

In addition to a behavioural validity effect of the cues, we recorded N2pc elicited by the masked cues. The N2pc is a stronger negative event-related potential (ERP) component at posterior scalp sites contra- than ipsilateral of an attended stimulus (cf. Luck & Hillyard, 1994). Of importance in the present context: the N2pc provides a window into the time course of the attentional effect. It is, thus, a more exhaustive measure of attention than the behavioural cueing effect. Specifically, the N2pc allows us to find evidence to tell the two forms of top-down control apart that we introduced above. If a rapid suppression of a non-matching singleton colour cue takes effect only after initial stimulus-driven capture by such a singleton cue (cf. Theeuwes et al., 2000), the N2pc might show evidence of this initial capture even where no behavioural cueing effect is seen in the RTs (cf. Ansorge & Heumann, 2006). Stimulus-driven capture reflected in the N2pc would then quickly fade and as a result no cueing effect would be found in the RTs to the targets.

2. Experiment 1

One of the tasks of our participants was to search for a visible colour-defined target and to report its shape. Search for a particular colour was enforced by presenting only one visible colour target and several visible differently coloured distractors per trial. Thus, the visible targets were non-singletons and our participants were forced to search for a colour to find this target. Singleton search was not an option for finding the target. As a consequence, any capture effect of the non-matching and non-predictive colour singleton cue under these conditions must be stimulus-driven.

The participants' awareness of the cues was diminished by backward masking of the cues (Breitmeyer, 1984; Breitmeyer & Ogmen, 2006; Klotz & Wolff, 1995). In addition to the target search task to assess the cueing effect we used cue detection as a second task for verifying the participants' low awareness of the masked cues. The two tasks of searching for the visible target and detecting the masked singleton colour cue were integrated into one block: we asked our participants to withhold their response if they saw a matching colour singleton cue preceding the target display and to only respond to (the shape of) the searched for visible colour target if they did not see a matching singleton colour cue before the target. In this way, we can eliminate all trials from the target search task in which the participants correctly reported the presence of the goal-matching singleton colour cue (cf. Bridgeman, Kirch, & Sperling, 1981; Ivanoff & Klein, 2003).

Based on the number of trials in which participants did not respond, we were also able to assess the cue's visibility in general. Because trials in which participants did not respond indicated that the participants believed that they had seen the matching cue, non-response trials where actually a matching cue was shown were taken as “hits”, while non-response trials where a non-matching cue was shown were taken as “false alarms (FAs)” in the sense of signal detection theory (SDT; cf. Green & Swets, 1966). The probabilities of hits and FAs were then compared to one another in form of SDT's effect-size measure d' (Green & Swets, 1966; Macmillan & Creelman, 2005). This measure becomes zero for chance performance and can become infinitely large with an ever increasing number of correct responses. The measure d' is recommended to assess residual stimulus visibility because of its high sensitivity (cf. Klotz & Neumann, 1999; Reingold & Merikle, 1988).

Note that under the present conditions, the target search task requires that the participants maintained a particular colour-search mode. In addition, the participants' successful performance of finding a visible colour target in each trial also reinforces this search mode and thus motivates the participants to maintain their goal setting of searching for the target's and the matching cue's

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