Journal of Cognitive Psychology

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Published online: 28 Feb 2014.

To cite this article: Birken Noesen, Mei-Ching Lien & Eric Ruthruff (2014): An electrophysiological study of attention capture by salience: Does rarity enable capture?, Journal of Cognitive Psychology, DOI: 10.1080/20445911.2014.892112

To link to this article: http://dx.doi.org/10.1080/20445911.2014.892112

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An electrophysiological study of attention capture by salience: Does rarity enable capture?

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Several behavioural studies have suggested that rarity is critical for enabling irrelevant, salient objects to capture attention. We tested this hypothesis using the N2pc thought to reflect attentional allocation. A cue display was followed by a target display in which participants identified the letter in a specific colour. Experiment 1 pitted rare, irrelevant abrupt onset cues (appearing on only 20% of trials) against target-relevant colour cues. The relevant colour cue produced large N2pc and cue validity effects even when competing with a rare, salient, simultaneous abrupt onset. Similar results occurred even when abrupt onset frequency was reduced to only 10% of trials (Experiment 2). Experiment 3 examined rare, irrelevant colour singleton cues (20% of trials). Despite being rare and salient, these singleton cues produced no N2pc or cue validity effect indicating little attentional capture. Experiment 4 greatly increased colour cue salience by adding four background boxes, increasing colour contrast and tripling the cue display duration (from 50 to 150 ms). Small cue validity and N2pc effects were obtained, but did not strongly depend on degree of rarity (20% vs. 100%). We argue that rarity by itself is neither necessary nor sufficient to produce attention capture.

Keywords: Attention capture; N2pc; Visual attention.
That is, the salient object in a scene (e.g., an abrupt onset against a static background or a colour singleton against a homogeneously coloured background) is assumed to capture our attention involuntarily even when it has no properties that the observer is looking for at that moment. The contingent capture view, on the other hand, contends that capture is primarily driven by top-down control settings (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Lien, Ruthruff, & Cornett, 2010; Lien, Ruthruff, Goodin, & Remington, 2008). Accordingly, salient stimuli do not capture attention involuntarily if they are truly irrelevant; instead, only objects containing target-defining features have the ability to capture attention.

In most studies supporting the contingent capture view, the irrelevant, salient stimuli were presented relatively often throughout the experiment (e.g., at least 50% of the trials and often 100%; e.g., Bacon & Egeth, 1994; Folk et al., 1992; Lien et al., 2008). This point raises an interesting alternative hypothesis: perhaps salient stimuli normally capture attention strongly, but inhibition is eventually invoked when a salient stimulus repeatedly appears in the visual field (e.g., Becker & Horstmann, 2011; Forster & Lavie, 2011; Gibson & Jiang, 1998; Godijn & Kramer, 2008; Horstmann, 2002; Horstmann & Ansorge, 2006; Neo & Chua, 2006; Yantis & Egeth, 1999). Tests of this hypothesis have reached conflicting conclusions which, as discussed later, might reflect limitations in the use of behavioural measures of capture (but see the oculomotor measure in Godijn & Kramer, 2008). The present study aims to shed additional light on capture by rarity using a more direct, electrophysiological measure of capture.

Before addressing research on attention capture by irrelevant, rare objects, it is important to make an explicit distinction between capture by surprise and capture by rarity. Studies on capture by surprise have primarily focused on the capture effect by the first encounter of an unexpected, surprising object. Studies of rarity, in contrast, manipulate the frequency of a particular salient stimulus, with the capture averaged across the set of trials in which rare objects appeared. The focus of the present research is on the latter issue—capture by rare stimuli—although we will briefly review research on both issues.

CAPTURE BY SURPRISE

Studies on whether surprising objects capture attention in a purely stimulus-driven manner have revealed somewhat conflict findings (e.g., Gibson & Jiang, 1998; Horstmann, 2002, 2005; Horstmann & Becker, 2008). For instance, Gibson and Jiang (1998) used a visual search paradigm in which participants searched for the letter H or U amongst eight letters in a circular array presented for only 86 ms and then masked for 200 ms. These target letters were not distinguishable from other distractor letters based on colour (they were all white) for the first 192 experimental trials. Thus, there was no incentive to search for a specific feature discontinuity (i.e., singleton). The critical manipulation was on Trial 193, where the target letter was an unexpected red colour singleton among white distractors. This unexpected trial was followed by another 192 trials in which the target letters were always colour singletons (i.e., red). Gibson and Jiang measured the target detection accuracy. They reasoned that if attention capture is solely driven by stimulus salience, then the unexpected colour singleton should capture attention on Trial 193 and therefore be detected just as accurately as it was on the subsequent trials (i.e., where participants presumably had learned to search for the colour singleton). In contrast to this prediction, they found that the accuracy for the unexpected trial was lower than the colour-singleton-defined target trials (the last 192 trials). In fact, accuracy on this critical trial was not even better than the accuracy observed from the first 192 trials where the target was not a colour singleton. These findings led Gibson and Jiang to conclude that the unexpected colour singleton did not capture attention.

Nevertheless, it is possible that salient, unexpected objects capture attention initially, but the sudden appearance of this discrepant stimulus also interrupts the current goal-driven behaviour, requiring re-establishment of the task set and thereby delaying responses (see Woods & Patterson, 2001). So the costs and benefits of capture might offset. To demonstrate capture by unexpected objects without contamination from the cost of re-establishing task set, Horstmann (2002) adopted Gibson and Jiang’s (1998) single unexpected trial approach but presented the unexpected colour singleton either 500 ms before or simultaneously with the target display [i.e., the stimulus onset asynchrony (SOA) was 500 ms or
objects. For instance, Yantis and Egeth (1999; 2002) found no improvement in accuracy on the surprise trial in the simultaneous condition. However, an improvement was found when the singleton appeared 500 ms before the target display. In fact, accuracy in this condition was just as high as it was in the subsequent colour-singleton-defined target trials. Horstmann argued that surprising objects capture attention strongly, but the shift of attention takes time. However, one caution regarding this conclusion should be noted. Several authors have suggested that the relatively long SOAs between the cue and the target may have been sufficient for an endogenous shift of attention, even without any capture per se (e.g., Theeuwes, Atchley, & Kramer, 2000; Theeuwes, Godijn, & Pratt, 2004).

CAPTURE BY RARITY

Although examining capture by surprising objects using a single-trial method had some advantages, it also has some limitations, as described earlier. Taking a different approach, other researchers manipulated the frequency of irrelevant, salient objects and examined capture by rarely occurring objects. For instance, Yantis and Egeth (1999; 2002) had participants search for a vertical target among several tilted distractors. One of the distractors was a colour singleton (red among all blue) for 80% of the trials for the “frequent” group and for only 20% of the trials for the “rare” group. All participants were informed that the colour singleton would never be the target; thus, there was no incentive to allocate attention to the salient colour singleton. Instead of measuring accuracy, as in studies of surprise capture, they measured response time (RT). Yantis and Egeth reasoned that if a salient colour singleton captures attention in a purely bottom-up manner, then the presence of an irrelevant colour singleton should impair performance (i.e., slow RT). In addition, this singleton cost should be larger for the rare group than the frequent group. In contrast to these predictions, RT was equivalent between the singleton present and absent trials in both the frequent and the rare groups. These findings led Yantis and Egeth to conclude that rare colour singletons do not have the inherent power to capture spatial attention, supporting Gibson and Jiang’s (1998) conclusion.

Horstmann and Ansorge (2006) examined capture by colour singletons that were even more rare (4%, 8% or 11%) than those in Yantis and Egeth (1999; 20%). In addition to using various SOAs between the onsets of colour singleton and the target (0, 200 and 400 ms), the colour singleton was predictive of the target location (the target singleton block) or a non-target location (the distractor singleton block). Participants were informed regarding the predictability and frequency of the colour singleton. The critical finding was that the degree of singleton rarity (4%, 8% or 11%) had virtually no effect on the benefit or cost of the singleton on target performance.

Whereas the previous studies examined capture by rare colour singletons, Neo and Chua (2006) examined capture by rare abrupt onsets. Attention was prioritised to the target location either by using a 100% valid arrow cue (Experiments 1 and 2) or by presenting the target in a fixed location (Experiment 3), so participants were fully aware of where the target would appear. On some trials, an irrelevant abrupt onset appeared 60 ms or 200 ms before the target (i.e., SOA was 60 or 200 ms) in a non-target location. In Experiment 1, with an abrupt onset on 75% of the trials, onsets had little effect on RT at both SOAs suggesting a failure to capture attention. However, as the frequency of an abrupt onset decreased to only 18.75% in Experiment 2, RT was 30 ms longer in the onset condition than the no-onset condition at the 200-ms SOA. Their findings argue for capture by rare abrupt onsets even when attention has been prioritised to another location (see also Forster & Lavie, 2011).

THE PRESENT STUDY

The studies on capture by rare, salient objects reviewed earlier are inconclusive regarding capture by rare objects. This may be because the use of behavioural measures (e.g., accuracy or overall RT) limits the ability to detect rapid capture of spatial attention. For example, costs and benefits of capture on RT can roughly cancel each other out, as shown in Horstmann’s (2002) study. Shifts can happen too quickly (followed by disengagement) or too slowly to affect RT (e.g., Belopolsky, Schreij, & Theeuwes, 2010). Furthermore, when RT costs do occur, they can reflect not only involuntary capture but also other phenomena such as voluntary attention shifts or filtering costs (e.g., Remington, Folk, & McLean, 2001).

To overcome these limitations, the present study supplemented traditional behavioural measures with electrophysiological measures (e.g., event-related...
potentials, ERPs). ERPs can provide a continuous measure of attentional shifts. Thus, they have the potential to detect a rapid, temporary shift of attention by salient stimuli even when they occur too early or too late to influence overt behaviour (see Handy, Green, Klein, & Mangun, 2001, for an excellent example of uncovering attentional processes using ERP measures). It should be emphasised that we used ERP measures to study capture by rarity, not capture by surprise, due to the limitations of collecting and interpreting ERP measures on a single trial (i.e., low signal-noise ratio).

We used the ERP component called the N2pc (N2-posterior-contralateral) effect to determine whether attention can be captured by irrelevant, salient objects when they appear rarely. The N2pc effect is known to reflect shifts of spatial attention (e.g., Luck & Hillyard, 1994; Woodman & Luck, 2003). This component is an increased negativity over posterior scalp contralateral to an attended stimulus peaking about 170–270 ms after the onset of that stimulus. In other words, the ERP at a given electrode in the right hemisphere becomes more negative when attention is directed to a left-hemifield stimulus (contralateral) than to a right-hemifield stimulus (ipsilateral), and vice versa. The N2pc effect, therefore, can be quantified as the average difference between contralateral and ipsilateral voltages. In contrast to the coarse information provided by behavioural measures, the N2pc effect can provide both temporal (when) and spatial (where) information regarding an attentional shift, and has been widely used as a sensitive and specific index of attention capture in recent years (e.g., Eimer & Kiss, 2008; Hickey et al., 2006; Lien et al., 2008, 2010; Sawaki & Luck, 2010).

We used a cuing paradigm in which the cue display was presented prior to the target display. We chose an SOA of 150 ms (a typical interval used in previous attentional capture studies using the cuing paradigm; e.g., Folk et al., 1992; Lien et al., 2008; but see Experiment 4), so that there was not enough time for an endogenous shift of attention or a saccade. This temporal isolation of the cue and target events also enables us to measure cue validity effects in the behavioural data. Most important, it helps to minimise overlap between cue- and target-elicited N2pc effects and also gives the cue the opportunity to capture attention without simultaneously competing for attention with the target.

Experiment 1 examined capture by a salient abrupt onset when it appeared on only 20% of trials, a frequency similar to that used in previous studies of stimulus rarity (e.g., Neo & Chua, 2006; Yantis & Egeth, 1999). Experiment 2 further reduced the frequency of abrupt onsets to only 10%. Experiments 3 and 4 examined capture by irrelevant colour singleton cues instead of abrupt onsets.

**EXPERIMENT 1**

Experiment 1 examined whether a salient-but-irrelevant abrupt onset has the power to capture spatial attention, producing N2pc and cue validity effects, when it appears rarely. We cannot directly assess attention capture by abrupt onsets using the N2pc effect because the mere presence of the new object in one hemifield would create a lateralisated imbalance in stimulus energy, thereby triggering lateralisated ERPs even if it did not capture spatial attention (see Lien et al., 2008; Sawaki & Luck, 2010 for further discussion regarding eliminating sensory confounds in ERP designs). Because there is no way of knowing whether the measured N2pc effect elicited by the abrupt onset itself was due to sensory or attentional influences, it cannot be meaningfully interpreted. To get around the inability to directly measure the N2pc effect to an abrupt onset, we used the approach of Lien et al. (2008; Experiment 3) and measured the indirect influence of the abrupt onset on capture by a relevant colour cue. In other words, we pitted an abrupt onset against a relevant colour cue; the critical analysis was a comparison of the N2pc effect by the relevant colour cue with and without the simultaneous abrupt onsets.

For the cue display, 80% of the trials contained a relevant colour singleton cue (i.e., a box in the target colour amongst several boxes in a homogenous distractor colour). In the remaining 20% of the trials, an abrupt onset (four dots surrounding one of the distractor colour boxes) appeared simultaneously with the relevant colour singleton cue. The abrupt onset appeared in the same hemifield as the relevant colour singleton cue on 10% of the trials (but never in the same location) and appeared in the different hemifield on the other 10% of the trials (see Figure 1A). To ensure that the relevant cue was a colour singleton in all trials, we coloured the abrupt onset in the same colour as the background distractor boxes. The relevant colour singleton cue did not predict the
target location (25% valid vs. 75% invalid) nor did the abrupt onset. Therefore, participants had no incentive to voluntarily shift attention to the relevant cue or the abrupt onset. It is important to note that two aspects of the design in this experiment were different from Lien et al.’s (2008; Experiment 3) study; in their study, the relevant colour cue was never a colour singleton and the proportion of abrupt onset trials was higher (50% rather than 20%).

The target display always contained two coloured letters and two white letters, all of which were T’s and L’s (see Figure 2 for an example). Participants were asked to search for a letter in a
specific colour (red for half of the participants and green for the other half) and press a key to indicate whether it was a T or an L. Because there were two coloured letters with potential target identities (T or L), the use of a specific top-down attentional setting (e.g., searching for a specific colour) was necessary to perform the task accurately, discouraging the use of a singleton detection mode (e.g., Lien et al., 2008). We compared the capture effects (the N2pc and cue validity effects) for the relevant colour singleton with and without the abrupt onset.

Figure 2. An example event sequence for the relevant colour singleton cue with an abrupt onset condition in Experiment 1. In the real experiment, the boxes in the cue display and letters in the target display were coloured. In this example, participants were instructed to respond to the red letter. In the cue display, the top-left box was red, whereas the other boxes were green. The abrupt onset was green. In the target display, the top-left letter “T” was red, the bottom-left letter “L” was white, the top-right letter “L” was green, and the bottom-right letter “T” was white.
We expected, based on previous studies, that the relevant colour singleton cue would capture attention and thus produce a large N2pc effect and a cue validity effect on RT when it appeared alone. The interesting question was whether the simultaneous, rare abrupt onset would pull attention away from the relevant colour singleton cue, diminishing the relevant cue’s ability to capture attention and thereby reducing or eliminating its N2pc and cue validity effects. According to the salience capture view, attention is first allocated to the most salient stimulus; in the present case, attention would be allocated first to the abrupt onset pulling it away from the relevant colour cue. If so, the abrupt onset should reduce or even eliminate capture by the relevant colour cue (or at least delay its onset).

Although our primary interest was in the cue-elicited N2pc effects, we also examined target-elicited N2pc effects for the sake of completeness. Within a trial, we defined the N2pc effect with respect to the relevant colour singleton cue location. Therefore, when the relevant colour singleton cue and target are in the same hemifield, the cue and target should produce an N2pc effect in the same direction. When they are in different hemifields, however, the polarity of the N2pc effect elicited by the target should be opposite to that of the colour singleton.

Method

Participants. Nineteen undergraduate students from Oregon State University participated in exchange for extra course credit. Three participants’ data were excluded because either their averaged HEOG was larger than ±3µV during the critical time windows (170–270 ms and 350–450 ms after the cue onset) or their EEG artefact rejection was more than 25% of the trials. Therefore, data from 16 participants (12 females and 4 males) were included in the final data analyses. They had a mean age of 23 years (range: 18–32). Eight participants responded to the red letter and eight to the green letter. All reported having normal or corrected-to-normal acuity. They also demonstrated normal colour vision using the Ishihara Test for colour deficiency.

Apparatus and stimuli. Stimuli, displayed on a 19-inch ViewSonic monitor, were viewed from a distance of about 55 cm. Within each trial, three stimulus events were presented in succession (see Figure 2): the fixation display, cue display and target display. The fixation display consisted of five boxes: a centre box surrounded by four peripheral boxes (top-left, bottom-left, top-right and bottom-right). Each peripheral box was equidistant from the centre box (7.66°, centre to centre). Adjacent peripheral boxes were separated by 10.81°, centre to centre. Each box was 2.39° × 2.39° drawn with thin (0.10°) white lines.

For 80% of the trials, the cue display was the same as the fixation display except that one peripheral box contained a relevant colour (i.e., the colour singleton cue), whereas the other boxes all had the identical distractor colour (e.g., for participants assigned to look for the red target, one box would be red and the other boxes would be green). The centre box also contained the background, distractor colour. On the remaining 20% of the trials, the cue display also contained an abrupt onset: four dots arranged in a diamond configuration around one of the background boxes (each dot was 1.04° in diameter and located 0.31° from the edge of the box). To ensure that the relevant cue was a colour singleton, the abrupt onset contained the same colour as the background distractor colour (see Figure 1A). The onset appeared equally often in the same side as the relevant colour singleton cue as in the opposite side (10% of the trials each). As with the relevant colour singleton cue, the abrupt onset did not reliably predict the target location (25% valid vs. 75% invalid).

The target display consisted of the fixation display plus a letter (1.04° width × 1.35° length × 0.31° thickness in Arial font) inside each of the four peripheral boxes. Each hemifield (left vs. right) contained one “T” and one “L”. One letter was red (RGB values: 255, 0, 0; CIE [Yxy]: 21.3, 0.64, 0.33), one was green (RGB values: 0, 153, 0; CIE [Yxy]: 22.8, 0.30, 0.60) and the other two were white (RGB values: 255, 255, 255; CIE [Yxy]: 100, 0.31, 0.33). The two coloured letters were always located in opposite hemifields.

Design and procedure. As shown in Figure 2, each trial started with the presentation of the fixation display for 1,200 ms. Then, as a warning signal, the centre box was turned off for 100 ms and back on for 1,200–1,400 ms (determined randomly with a uniform distribution). The cue display then appeared for 50 ms before being replaced by the fixation display for 100 ms. The target display then appeared for 50 ms. Thus, the interval between the onset of the cue display and the onset of the target
display was 150 ms. The participants’ task was to indicate whether the letter in the target colour was a T or an L. Specifically, participants were to press the leftmost response-box button with their left index finger for the letter “L” and the rightmost button with their right index finger for the letter “T”. Feedback (a tone for an incorrect response or the fixation display for a correct response) was presented for 100 ms. The next trial then began with the 1,200-ms fixation display.

Participants performed one practice block of 30 trials followed by 16 experimental blocks of 80 trials each (a total of 1,280 experimental trials). Eighty per cent of the trials (1,024 trials in total) contained only the relevant colour singleton cue, whereas 20% of the trials (256 trials in total) contained both the relevant colour singleton cue and the irrelevant abrupt onset.

The locations of the relevant colour singleton cue and the target were randomly determined with each location being equally probable. Thus, the location of the relevant colour singleton cue was the same as the location of the target for 25% of the trials (the valid condition) and different for 75% of the trials (the invalid condition). Thus, the cue location did not predict the target location. The same was true for the irrelevant abrupt onset.

Note that we examined the cue validity effect and N2pc effect to the relevant colour singleton cue as a function of whether the abrupt onset was present vs. absent. Although the validity distinction is critical in the behavioural analyses to measure the cue validity effect, it is not critical for measuring the N2pc effect to the relevant colour singleton cue location. The N2pc effect in response to the relevant colour singleton cue can be assessed both for valid and invalid trials. The distinction crucial to the N2pc analyses is whether the relevant colour singleton cue and target are in the same hemifield or different hemifields (50% of trials in which the cue was present for each condition).

EEG recording and analyses. The electroencephalographic (EEG) activity was recorded from F3, F4, C3, C4, T7, T8, P3, P4, P5, P6, PO5, PO6, O1 and O2. These sites and the right mastoid were recorded in relation to a reference electrode at the left mastoid. The ERP waveforms were then re-referenced offline to the average of the left and right mastoids. The horizontal electrooculogram (HEOG) was recorded bipolarly from electrodes at the outer canthi of both eyes, and the vertical electrooculogram (VEOG) was recorded from electrodes above and below the midpoint of the left eye. Electrode impedance was kept below 5 kΩ. EEG, HEOG and VEOG were amplified using Synamps2 (Neuroscan) with a gain of 2,000 and a band-pass of 0.1–50 Hz. The amplified signals were digitised at 500 Hz.

Trials with artefacts were identified in two steps. First, trials with artefacts were rejected automatically using a threshold of ±75µV for a 1,000 ms epoch beginning 200 ms before cue onset and ending 800 ms after cue onset. Each of these candidate artefact trials were then inspected manually. Second, we computed average HEOG waveforms for the left-target and right-target trials, separately, to determine for each participant whether the eyes tended to move. Following Woodman and Luck’s (2003) study, we included in the data analyses only participants whose average HEOG activity was less than ±3µV during the critical time windows (170–270 ms and 350–450 ms after cue onset). Three of the original 19 participants were eliminated because of artefact rejection on more than 25% of the trials. Figure 3 shows the scalp topography of the grand average ERPs for the relevant colour singleton cue trials (80% of the trials).

The critical question in our study is whether the salient abrupt onset would capture attention and reduce or even eliminate the capture by the relevant colour singleton cue. The N2pc data were analysed as a function of whether the abrupt onset was absent (80% of the trials) or present (20% of the trials) and electrode site (P5/P6, O1/O2 and PO5/PO6 electrodes). To quantify the overall magnitude of the N2pc effect, we focused on the time window in which the irrelevant colour singleton cue should produce an N2pc effect (170–270 ms after cue onset). The N2pc effect (i.e., the difference waveform) was measured as the mean amplitude during this time window for the electrode site contralateral to the cue location (e.g., the PO5 electrode when the cue was in the right hemifield) minus the mean amplitude for the electrode site ipsilateral to the cue location (e.g., the PO6 electrode when the cue was in the right hemifield) relative to the mean amplitude during a 200-ms pre-cue baseline period.

Although our experimental logic relies on the cue-elicited N2pc effect, we also reported the target-elicited N2pc effect. In the target-elicited N2pc data analyses, we focused on the time window in which the target should produce an N2pc effect (350–450 ms after cue onset, which
translates to 200–300 ms after target onset). To ensure consistency between the data analyses and presentation of the data (i.e., Figure 4, which plots the N2pc effect with respect to cue location), we analysed the target-elicited N2pc effect with respect to the cue location (rather than the location of the target itself). We submitted the mean amplitude of the difference waveforms (the N2pc effect) during the critical time windows to an analysis of variance (ANOVA), including same/different hemifield as an independent variable.

Results

We excluded trials from the final analyses of behavioural data (RT and proportion of Error [PE]) and ERP data if RT was less than 100 ms or greater than 2,000 ms (0.10% of the trials). Rejection of trials with EEG artefacts led to the further elimination of 7% of trials with no more than 18% rejected for any individual participant. Trials were also excluded from the RT and ERP analyses if the response was incorrect. An alpha level of .05 was used to ascertain statistical significance. Whenever appropriate, p values were
adjusted using the Greenhouse-Geisser epsilon correction for non-sphericity.

**Behavioural data analyses**

Although our experimental logic relies primarily on electrophysiological measures (reported later in this article), we also looked for converging evidence in the behavioural data. Specifically, capture to the relevant colour singleton cue location should result in smaller RT and/or lower PE when the upcoming target appeared in the same location as the relevant colour singleton cue (valid trials) than when it did not (invalid trials). Thus, we assessed the cue validity effect elicited by a relevant colour singleton cue with and without a simultaneous abrupt onset. Therefore, cue validity was defined as the relationship between the location of the relevant colour singleton cue and the target. The behavioural data were analysed as a function of group (red vs. green; a between-subject variable), validity of the relevant colour singleton cue (valid vs. invalid) and cue condition (relevant cue only vs. relevant cue plus abrupt onset cue). Table 1 shows the mean RT and PE for each of these conditions averaged across groups.

For the RT data, a significant cue validity effect of 60 ms was obtained, \( F(1, 14) = 160.92, p < .0001, \eta^2_p = .92 \). RT was 572 ms for invalid trials and 513 ms for valid trials. RT was also 14 ms longer for the relevant plus onset cue (549 ms) than for the relevant cue only (535 ms), \( F(1, 14) = 22.28, p < .001, \eta^2_p = .61 \). The cue validity effect for the relevant colour cue was larger when the abrupt onset was present (70 ms) than when it was absent (49 ms), \( F(1, 14) = 11.97, p < .01, \eta^2_p = .46 \). If anything, the onset actually increased capture by the relevant colour cue, rather than competing with it (we will return to this unexpected finding in the General Discussion section). No effect involving group was significant.

For the PE data, the cue validity effect of .023 was significant, \( F(1, 14) = 11.16, p < .01, \eta^2_p = .44 \).
TABLE 1
Mean response times (RT) in milliseconds and proportion of errors (PE) as a function of cue condition (relevant vs. relevant plus abrupt onset) and cue validity with respect to the relevant cue (valid vs. invalid) in Experiment 1

<table>
<thead>
<tr>
<th>Cue condition</th>
<th>Valid</th>
<th>Invalid</th>
<th>RT (ms)</th>
<th>PE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevant [80%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevant + abrupt onset [20%]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relevant [80%]</td>
<td>.016</td>
<td>.030</td>
<td>.016 (.005)</td>
<td>.030 (.008)</td>
</tr>
<tr>
<td>Relevant + abrupt onset [20%]</td>
<td>.021</td>
<td>.016</td>
<td>.021 (.004)</td>
<td>.037 (.011)</td>
</tr>
</tbody>
</table>

The standard error of the mean is shown in parentheses. The percentage of trials containing each cue condition is shown in brackets.

PE was .019 for valid trials and .042 for invalid trials. Consistent with the RT data, the cue validity effect on PE for the relevant colour cue was larger with the abrupt onset (.030) than without (.016), $F(1, 14) = 10.63$, $p < .01$, $\eta^2_p = .43$. No other effect was significant.

**ERP data analyses**

The N2pc effect (i.e., the average of the difference waveform) was measured from electrode sites relative to the relevant colour singleton cue location. The N2pc effects were analysed as a function of group (red vs. green; a between-subject variable), cue condition (relevant cue only vs. relevant cue plus abrupt onset cue), relevant cue/target spatial relationship (same hemifield vs. different hemifields) and electrode site (P5/P6, O1/O2 vs. PO5/PO6). We analysed the average value of the difference waveform over two different time windows: 170–270 ms after cue onset (to assess the cue-elicited N2pc effect) and 350–450 ms after cue onset (to assess the target-elicited N2pc effect). Each of the subconditions contained 112 trials on average per participant after rejecting trials that were incorrect, fell outside our RT cut-off or showed ocular artefacts. Figure 4 shows the N2pc effect for the P5/P6, O1/O2 and PO5/PO6 electrode sites, as well as the pooled data from these electrode sites, for the relevant cue only condition and the relevant cue plus abrupt onset cue condition, averaged across the two groups.

Cue-elicited N2pc effects. Our primary aim was to determine whether the rare abrupt onset captured attention pulling it away from the relevant colour singleton cue; if so, this would reduce the N2pc effect for the relevant cue. However, the main effect of cue condition was not significant, $F < 1.0$; the N2pc effect was $−0.448 \mu V$ for the relevant cue only and was $−0.382 \mu V$ for the relevant plus abrupt onset cue. The slight numerical decrease in the N2pc effect for the relevant plus abrupt onset cue was not significant and did not replicate in Experiment 2 (see below). Further $t$-tests revealed that both N2pc effects were significantly different from zero, $|t|s(15) ≥ 2.97$, $p’s ≤ .01$. The N2pc effect was larger at the PO5/PO6 and P5/P6 electrode sites ($−0.524 \mu V$ and $−0.493 \mu V$, respectively) than at the O1/O2 electrode site ($−0.228 \mu V$), $F(2, 28) = 10.32$, $p < .001$, $\eta^2_p = .42$. No other effects were significant.

Target-elicited N2pc effects. The target-elicited N2pc data (350–450 ms after cue onset) do not allow a test of our main hypothesis, but are included for the sake of completeness. Also note that because we defined the N2pc effect with respect to the cue location (for consistency with the N2pc figures), the direction of the target-elicited N2pc effect should depend critically on whether the cue and target appeared in the same or different hemifield (see also Lien et al., 2008, 2010).

As predicted from the assumption that the target would capture attention, the target-elicited N2pc effect was negative when the target was in the same hemifield as the relevant cue ($−0.516 \mu V$) but was positive when the target was in the opposite hemifield ($1.480 \mu V$), $F(1, 14) = 36.78$, $p < .001$, $\eta^2_p = .72$. This difference was more

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2 The target-elicited N2pc effect analyses revealed a significant effect of cue/target spatial relationship (same hemifield vs. different hemifields) due to how we defined contralateral and ipsilateral ERPs in calculating the N2pc effect (i.e., with respect to the cue location). We repeated the analysis of target-elicited N2pc effect coded with respect to the target location rather than cue location. Results showed that the main effect of cue/target spatial relationship was significant, $F(1, 14) = 34.34$, $p < .0001$, $\eta^2_p = .71$. A similar result was observed in Experiment 2, $F(1, 20) = 43.64$, $p < .0001$, $\eta^2_p = .69$. The observed pattern—a smaller target-elicited N2pc effect for the same hemifield than different hemifield conditions—was as expected. Given that attention has already been allocated to the relevant colour cue, a target appearing in the same hemifield did not require as much of an attentional shift as a target appearing in the opposite hemifield.
pronounced for the green target group (-0.957 µV vs. 1.946 µV for same vs. different hemifields, respectively) than for the red target group (-0.074 µV vs. 1.013 µV), F(1, 14) = 7.63, p < .05, η² = .35. The overall N2pc effect was more positive for the PO5/PO6 and P5/P6 electrode sites (0.669 µV vs. 0.513 µV, respectively) than for the O1/O2 electrode site (0.264 µV). F(2, 28) = 10.13, p < .001, η² = .42. Finally, the interaction between the electrode site and the relevant cue/target spatial relationship was significant, F(2, 28) = 13.68, p < .001, η² = .49. When the target and the relevant cue were in the same hemifield, the target-elicited N2pc effect was similar across the three electrode sites (-0.506 µV, -0.348 µV and -0.692 µV for the PO5/PO6, O1/O2 and P5/P6 electrode sites, respectively). When they were in different hemifields, the N2pc effect was more positive for the PO5/PO6 and P5/P6 electrode sites (1.844 µV and 1.719 µV, respectively) than for the O1/O2 electrode site (0.876 µV). No other effects were significant.

Discussion

Experiment 1 examined whether a salient, but irrelevant abrupt onset can capture attention when it appears rarely. We adopted a cuing paradigm and pitted the abrupt onset cue against a simultaneous relevant colour cue (see Lien et al., 2008). Although 80% of the trials contained the relevant colour singleton cue only, the remaining 20% of the trials contained both the relevant cue and the abrupt onset cue. If the abrupt onset has a strong pull on attention, it should reduce the ability of a relevant cue to capture attention. Both behavioural and ERP data, however, showed that this was not the case. The cue validity effect on RT for the relevant colour singleton cue was not diminished by the presence of the abrupt onset (70 ms with abrupt onsets and 49 ms without abrupt onsets). If anything, the appearance of an abrupt onset in one location enhanced the capture by the relevant colour singleton cue in a different location. Furthermore, the abrupt onset cue did not produce a cue validity effect; after excluding trials in which the relevant colour cue was valid, mean RT was actually longer for valid trials (602 ms) than invalid trials (567 ms), t(15) = -4.07, p < .001. Most important, the N2pc effect elicited by the relevant colour cue was not eliminated or even significantly reduced by the presence of the abrupt onset suggesting that even a rare onset has little pull on attention. There seems to be a small negative voltage within the time window 70–150 ms after cue onset in the relevant cue plus abrupt onset cue condition. If taken at face value, it would indicate a shift towards the relevant colour cue (not towards the onset). We will come back to this issue in Discussion section of Experiment 2.

EXPERIMENT 2

There were two main purposes of Experiment 2. First, to provide an even more sensitive test of capture by rare abrupt onsets, we further reduced their frequency from 20% of the trials in Experiment 1 to only 10% in Experiment 2. Second, we examined one possible explanation for the absence of capture by abrupt onsets in Experiment 1. The relevant colour singleton cue appeared on 100% of the trials and the abrupt onset appeared along with it on 20% of the trials. It is conceivable that the inhibition of salient events depends not on how often a specific kind of salient distracting event occurs (e.g., abrupt onsets), but how often any salient event occurs (e.g., onsets and/or relevant colour singletons). In other words, the high proportion of trials with the relevant colour singleton cue by itself could have weakened capture by the rare abrupt onset. Experiment 2 therefore reduced the proportion of trials with a relevant colour cue alone from 80% of the trials down to only 10%.

Method

Participants. There were 26 new participants drawn from the same participant pool as in Experiment 1. Again, none of them were in previous experiments. Four participants’ data were excluded because either their averaged HEOG was larger than ±3µV during the critical time windows (170–270 ms and 350–450 ms after the cue onset) or their EEG artefact rejection was more than 25% of the trials. Therefore, data from 22 participants (12 participants responded to the red letter and 10 to the green letter) were included in the final data analyses. All reported having normal or corrected-to-normal acuity. They also demonstrated normal colour vision using the Ishihara Test for colour deficiency.

Apparatus, stimuli, and procedure. The tasks, stimuli and equipment were the same as in
Experiment 1, except for the following change. Both the relevant colour singleton cue condition and the relevant cue plus abrupt onset cue condition each comprised only 10% of the trials. As in Experiment 1, the onset appeared equally often in the same side as the relevant colour singleton cue as in the opposite side (5% of the trials each; see Figure 1B). The remaining 80% of the trials contained no cue.

Results

The data analysis was similar to that of Experiment 1. Application of the RT cut-offs eliminated 0.27% of the trials. Rejection of trials with EEG artefacts led to the further elimination of 3.64% of trials, but no more than 15% for any individual participant.

Behavioural data analyses

The behavioural data were analysed as a function of group (red vs. green; a between-subject variable), cue validity with respect to the relevant colour singleton cue (valid vs. invalid) and cue condition (relevant cue only vs. relevant cue plus abrupt onset cue). Table 2 shows the mean RT and PE for each of these conditions, including the no cue condition, averaged across the two groups.

The RT data closely replicated those of Experiment 1. A significant cue validity effect of 56 ms was obtained, \( F(1, 20) = 67.72, p < .0001, \eta^2_p = .77 \). RT was 595 ms for invalid trials and 539 ms for valid trials. RT was also 22 ms longer for the relevant cue plus abrupt onset cue (578 ms) than for the relevant cue only (556 ms), \( F(1, 20) = 9.77, p < .01, \eta^2_p = .33 \). The cue validity effect for the relevant colour cue was again larger when the abrupt onset was present (66 ms) than when it was absent (46 ms), \( F(1, 20) = 14.59, p < .01, \eta^2_p = .42 \), indicating that the abrupt onset did not pull attention away from the relevant cue (if anything, it did the opposite).

For PE data, the cue validity effect of .025 was significant, \( F(1, 20) = 17.56, p < .001, \eta^2_p = .47 \). PE was .039 for valid trials and was .064 for invalid trials. No other effects were significant.

ERP data analyses

The N2pc effect was measured from electrode sites relative to the relevant colour singleton cue location. The N2pc data were analysed as a function of group (red vs. green), cue condition (relevant cue only vs. relevant cue plus abrupt onset cue), relevant cue/target spatial relationship (same hemifield vs. different hemifields) and electrode site (P5/P6, O1/O2 vs. PO5/PO6). As in Experiment 1, we focused on two time windows: 170–270 ms after singleton cue onset (to assess the target-elicited N2pc effect) and 350–450 ms after singleton cue onset (to assess the target-elicited N2pc effect). Figure 5 shows the N2pc effect for the P5/P6, O1/O2 and PO5/PO6 electrode sites, as well as the pooled data from these electrode sites, for the relevant cue only and the relevant cue plus abrupt onset cue conditions, averaged across the two groups.

Cue-elicited N2pc effects. Our primary aim was to determine whether the rare abrupt onset would capture attention and thereby pull attention away from the relevant colour singleton cue reducing the N2pc effect for the relevant cue. No effects were significant. In particular, the critical main effect of cue condition was not significant, \( F < 1.0; \) the N2pc effect was \(-0.420 \mu V\) for the relevant cue only and was \(-0.490 \mu V\) for the relevant cue plus abrupt onset cue. Thus, the abrupt onset had no apparent pull on spatial attention. Further \( t \)-tests revealed that both N2pc effects were significantly different from zero, \( |t(21)| \geq 4.34, p's \leq .001 \), indicating (as expected) that the relevant cue by itself did capture attention.
**Target-elicited N2pc effects.** The target-elicited N2pc effect analyses (350–450 ms after cue onset) revealed that the target-elicited N2pc effect was negative when the target was in the same hemifield as the relevant cue (−0.437 µV) but was positive when the target was in the opposite hemifield (1.143 µV), \( F(1, 20) = 43.64, p < .001, \eta_p^2 = .69 \). The overall target-elicited N2pc effect was more positive for the relevant cue only condition than for the relevant cue plus onset cues condition. The filled rectangular boxes indicate the time window used to assess the N2pc effect: 170–270 ms after cue onset (for the cue-elicited N2pc effect) and 350–450 ms after cue onset (for the target-elicited N2pc effect). Negative is plotted upwards and time zero represents cue onset.

**Figure 5.** Grand average N2pc difference waveforms, calculated by subtracting activity in electrode sites ipsilateral to the relevant cue location from activity in electrode sites contralateral to the relevant cue location at the P5/P6, O1/O2, and PO5/PO6 electrode sites in Experiment 2. In addition, pooled data were obtained by averaging the N2pc difference waveforms across all three electrode pairs. Data are plotted as a function of whether the cue and the target were in the same hemifield or different hemifields for the relevant cue only condition and the relevant cue plus onset cues condition. The unfilled rectangular boxes indicate the time window used to assess the N2pc effect: 170–270 ms after cue onset (for the cue-elicited N2pc effect) and 350–450 ms after cue onset (for the target-elicited N2pc effect). Negative is plotted upwards and time zero represents cue onset.

**Discussion**

Experiment 2 further reduced the frequency of abrupt onset cues from 20% in Experiment 1 down to only 10%. We also reduced the frequency of relevant cue only trials from 80% in Experiment 1 to only 10% in Experiment 2. Thus, cues were much more rare, further reducing any incentive to actively inhibit them. Replicating the findings of Experiment 1, the N2pc effect elicited by the relevant colour cue was not eliminated or even significantly reduced by the presence of the abrupt onset. Thus, even when the salient abrupt onset appeared on only 10% of trials (even smaller than the 18.75% frequency in Neo & Chua, 2006, which showed capture by abrupt onsets), there was no evidence that it could pull attention away from the relevant cue. The behavioural data were consistent with the N2pc results; the cue validity effect from the relevant colour singleton cue on RT was not diminished by the presence of the abrupt onset (66 ms with abrupt onsets and 46 ms without abrupt onsets). If anything, the appearance of an abrupt onset in one location enhanced the capture by the relevant
colour cue in a different location. As in Experiment 1, the abrupt onset cue did not produce a cue validity effect; after excluding trials in which the relevant colour cue was valid, mean RT was actually 26 ms slower for valid trials (623 ms) than invalid trials (597 ms), \( t(21) = -2.64, p < .05 \).

In both Experiments 1 and 2, there was a small negative voltage within the time window of 70–150 ms after cue onset in the relevant cue plus abrupt onset cue condition (Figures 4 and 5). It is important to note that this component cannot be considered as evidence for capture by salient abrupt onsets, for two reasons. First, the time course was too early to be considered as “attentional” in nature (in previous studies, the N2pc effect never begins at 70 ms). Second, the contralateral versus ipsilateral electrode sites used to calculate the N2pc effect elicited by the relevant colour cue were based on the location of the relevant colour cue not the abrupt onset. Thus, even if the effect were attentional, it would reflect attention to the relevant colour cue and not attention to the abrupt onset. The salient abrupt onset was located in the same hemifield as the relevant colour singleton cue (but in different locations) for half of the trials and was in different hemifields for the other half. Thus, if the salient abrupt onset captured attention, one should expect an overall reduction in the N2pc effect elicited by the relevant colour singleton cue which was not what we observed.

**EXPERIMENT 3**

Experiment 3 examined whether a different type of salient object, namely an irrelevant colour singleton, has the power to capture spatial attention when it appears rarely. The cue display contained a salient-but-irrelevant colour singleton amid several homogeneously coloured background items (e.g., a red box among several green boxes) on 20% of the trials. For the remaining 80% of the trials, the cue display was neutral (all white boxes, unchanged from the fixation display). The colours used for the salient-but-irrelevant colour singleton cue and the background boxes were never used in the target display reducing the incentive to actively inhibit them.

As in Experiments 1 and 2, the target display always contained two coloured letters and two white letters. Each participant looked for only one specific target colour. Thus, the use of a specific top-down attentional setting (e.g., searching for a specific colour) was necessary to perform the task discouraging the use of a singleton-detection mode (e.g., Lien et al., 2008).

**Method**

**Participants.** There were 29 new participants drawn from the same participant pool as in Experiment 1. None participated in the previous experiments. Five participants’ data were excluded because their EEG artefact rejection rate was more than 25% of the trials (see below), and one participant’s EEG data failed to record. The remaining 24 participants (17 females and 7 males) had a mean age of 21 years (range: 18–28). Seven responded to the red letter, six to the green letter, six to the blue letter and the remaining five to the yellow letter. All reported having normal or corrected-to-normal acuity. They also demonstrated normal colour vision using the Ishihara Test for colour deficiency.

**Apparatus, stimuli, and procedure.** The tasks, stimuli and equipment were the same as in Experiment 2, except for the following changes. In addition to the red and green colours used in Experiment 2, we also used blue (RGB values: 0, 51, 255; CIE [Yxy]: 9.59, 0.15, 0.08) and yellow (RGB values: 255, 255, 0; CIE [Yxy]: 92.8, 0.42, 0.51). For 80% of the trials, the cue display was the same as the fixation display. For the remaining 20% of the trials, the four peripheral boxes in the cue display changed colour, leaving one colour singleton and three identical-coloured background boxes (e.g., one blue box and three yellow boxes). The centre box also contained the background colour. The assignment of specific colours (e.g., blue or yellow when the target was red or green) to the irrelevant colour singleton cue and background in the cue display was randomly determined within the blocks (10% of trials for one assignment and 10% for the other) for each participant.

The target display consisted of the fixation display plus a letter (1.04° width × 1.35° length × 0.31° thickness in Arial font) inside each of the four peripheral boxes. Each hemifield (left vs. right) contained one “T” and one “L”. For half of the participants, one letter was red, one was
green and the other two were white. For these participants, the colours blue and yellow were used in the cue display for the irrelevant colour singleton box and the background boxes. For the other half of the participants, the assignment of red/green and blue/yellow was reversed. Thus, target display contained one blue letter, one yellow letter and two white letters. The colours red and green were used in the cue display for the irrelevant colour singleton box and the background boxes.

### Results

The data analysis was similar to that of Experiments 1 and 2. Application of RT cut-offs eliminated 0.25% of trials. Rejection of trials with EEG artefacts led to the further elimination of 8% of trials, with no more than 25% rejected for any individual participant.

#### Behavioural data analyses

The behavioural data were analysed as a function of group (red, green, blue, vs. yellow; a between-subject variable) and cue condition (no cue, valid cue vs. invalid cue; a within-subject variable).

Table 3 shows the mean RT and PE for each of these cue conditions averaged across the four groups.3

- **RT** did not vary across cue conditions, $F(2, 40) = 1.52, p = .23, \eta_p^2 = .07$; mean RT was 555, 548 and 552 ms for no cue, valid cue and invalid cue, respectively. Further t-tests revealed that the cue validity effect (4 ± 9 ms) was not significantly different from zero, $t(23) = 1.05, p = .31$. As in the RT data, the PE data showed no effect of cue condition, $F(2, 40) = 1.03, p = .36, \eta_p^2 = .05$ (PEs = .044, .042 and .051 for no cue, valid cue and invalid cue, respectively). Further t-tests revealed that the cue validity effect on PE (.008 ± .017) was not significant, $t(23) = 1.03, p = .31$. The interaction between group and cue condition was significant on PE, $F(6, 40) = 2.45, p = .04, \eta_p^2 = .27$. For the red target group, PE was lower (.019) for the valid cue than the invalid (.050) and no cue (.048) conditions. However, the pattern was opposite for the blue target group (PEs = .084, .067 and .057 for valid, invalid and no cue, respectively).

For the green and yellow target groups, PE was similar across all three cue conditions. No other effects were significant.

#### ERP data analyses

The N2pc effect (i.e., the average difference waveform) was measured from electrode sites relative to the irrelevant colour singleton cue location. The N2pc effects were analysed as a function of group (red, green, blue vs. yellow; a between-subject variable), cue/target spatial relationship (same hemifield vs. different hemifields), and electrode site (P5/P6, O1/O2 vs. PO5/PO6). As in Experiments 1 and 2, we focused on two time windows: 170–270 ms after cue onset (to assess the cue-elicited N2pc effect) and 350–450 ms after cue onset (to assess the target-elicited N2pc effect). Figure 6 shows the N2pc effect for the P5/P6, O1/O2 and PO5/PO6 electrode sites, as well as the pooled data from these electrode sites, averaged across the groups.

**Cue-elicited N2pc effects.** The cue-elicited N2pc analyses (170–270 ms after cue onset) revealed no significant main effects or interactions, $F’s \leq 1.44, p’s \geq .2503, \eta_p^2 \leq .16$. The N2pc effect was 0.117 µV for the same hemifield and was 0.113 µV for the different hemifield trials. Thus, the irrelevant colour singleton cue failed to produce an overall

### Table 3

<table>
<thead>
<tr>
<th>Irrelevant color singleton [20%]</th>
<th>No cue [80%]</th>
<th>Valid</th>
<th>Invalid</th>
<th>Cue validity effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>555 (19)</td>
<td>548 (18)</td>
<td>552 (17)</td>
<td>4 (4)</td>
</tr>
<tr>
<td>PE</td>
<td>.044 (.007)</td>
<td>.042 (.009)</td>
<td>.051 (.008)</td>
<td>.008 (.008)</td>
</tr>
</tbody>
</table>

The standard error of the mean is shown in parentheses. The percentage of trials containing each cue condition is shown in brackets.

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3 We reported the mean RT and PEs for each cue condition averaged across groups in Table 3 for ease of readability. More detailed data, broken down by target colour and irrelevant cue colour, can be found at [http://people.oregonstate.edu/~lienm/RarityCaptureSupplement.pdf](http://people.oregonstate.edu/~lienm/RarityCaptureSupplement.pdf).
N2pc effect and the effect was not modulated by group or electrode site.

Target-elicited N2pc effects. The target-elicited N2pc analyses (350–450 ms after cue onset) revealed that the target-elicited N2pc effect was negative when the target was in the same hemifield as the singleton cue (−0.975 µV) but was positive when the target was in the opposite hemifield (1.304 µV), $F(1, 20) = 53.74$,
\( p < .0001, \eta_p^2 = .73.4 \) This pattern was more pronounced for the P5/P6 and PO5/PO6 electrode sites than the O1/O2 electrode site, \( F(2, 40) = 9.18, p < .001, \eta_p^2 = .31 \). No other effects were significant.

**Discussion**

Experiment 3 examined whether an irrelevant colour singleton can capture attention when it appears rarely. The cue display contained an irrelevant colour singleton cue on only 20\% of the trials (the other 80\% contained no cue, though the display timing was yoked to that of the cue present trials). The critical finding is that the irrelevant colour singleton cue failed to produce an N2pc effect. The behavioural data are consistent with the N2pc data showing a negligible and non-significant cue validity effect on RT (\( 4 \pm 9 \) ms).

Taken together, both the behavioural and electrophysiological findings are consistent with the claim that irrelevant colour singletons do not elicit attentional capture even when they appear rarely.

**EXPERIMENTS 4A AND 4B**

Relevant colour singleton cues produced large cue validity and N2pc effects in Experiments 1 and 2 consistent with the contingent capture view. When essentially the same stimulus did not have the relevant colour, but was still a colour singleton, it appeared to be completely ignored (Experiment 3). This comparison suggests that relevance dominates salience. Nevertheless, it is reasonable to ask whether the colour singleton could capture attention if it were made much more salient. For example, Theeuwes (2004) found that increasing attention if it were made much more salient. For a comparison suggests that relevance dominates salience. Nevertheless, it is reasonable to ask whether the colour singleton could capture attention if it were made much more salient. For example, Theeuwes (2004) found that increasing attention if it were made much more salient. For example, Theeuwes (2004) found that increasing attention if it were made much more salient. For example, Theeuwes (2004) found that increasing attention if it were made much more salient.

3. This comparison suggests that relevance dominates salience. Nevertheless, it is reasonable to ask whether the colour singleton could capture attention if it were made much more salient. For example, Theeuwes (2004) found that increasing attention if it were made much more salient.

4. We repeated the analyses of target-elicited N2pc effects with respect to target location and found that the main effect of cue/target spatial relationship was small and only marginally significant, \( F(1, 20) = 3.95, p = .061, \eta_p^2 = .16 \). Note that because attention was not captured by the irrelevant colour singleton cue, one would not expect attention allocation to the target (i.e., the target-elicited N2pc effect) to vary as a function of where the cue appeared in relation to the target.

they would be more equiluminant and there would be less luminance change in the cue display to mask the colour change. Also, we used only green and red as colour singletons, against red or green background boxes in the cue display, because they have higher colour contrast. We used blue and yellow colours in the target display.

A final change was that we manipulated singleton frequency (20\% of trials in Experiment 4A vs. 100\% in Experiment 4B), so we could directly assess the impact of rarity, apart from any effect of increased salience. These conditions were run between-subjects, so that there would be no carry-over effect from one condition to the other.

**Method**

**Participants.** There were 20 new participants in Experiment 4A and 21 in Experiment 4B drawn from the same participant pool as in Experiment 1. None participated in the previous experiments. Three participants’ data were excluded because two participant’s EEG artefact rejection rate was more than 80\%. The remaining 19 participants (12 females) in Experiment 4A had a mean age of 21 years (range: 18–28), whereas the remaining 19 participants (11 females) in Experiment 4B had a mean age of 20 years (range: 18–23). Ten responded to the blue letter and the remaining nine to the yellow letter in each experiment. All reported normal or corrected-to-normal acuity. They also demonstrated normal colour vision using the Ishihara Test for colour deficiency.

**Apparatus, stimuli, and procedure.** The tasks, stimuli and equipment were the same as in Experiment 3, except for the following changes. First, we used approximately equiluminant colours: red (RGB values: 255, 0, 0; CIE [Yxy]: 21.26, 0.64, 0.33), green (RGB values of 0, 151, 0; CIE [Yxy]: 22.13, 0.30, 0.60), blue (RGB values of 0, 128, 255; CIE [Yxy]: 22.66, 0.18, 0.16) and yellow (RGB values of 130, 130, 0; CIE [Yxy]: 20.71, 0.42, 0.51). Second, only red and green were used in the cue display and only blue and yellow were used for the target colour (randomly assigned to each participant). The colour singleton cue was either a red colour singleton box amongst several green background boxes, or a green colour singleton box amongst several red background boxes (randomly intermixed within a block).

Third, we added four peripheral boxes arranged
TABLE 4
Mean response times (RT) in milliseconds and proportion of errors (PE) as a function of cue validity (valid vs. invalid) in Experiments 4A and 4B.

<table>
<thead>
<tr>
<th>No cue [80%]</th>
<th>Irrelevant color singleton</th>
<th>Cue validity effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Valid</td>
<td>Invalid</td>
</tr>
<tr>
<td>RT</td>
<td>586 (17)</td>
<td>580 (17)</td>
</tr>
<tr>
<td>PE</td>
<td>.065 (.010)</td>
<td>.067 (.013)</td>
</tr>
<tr>
<td>RT</td>
<td>–</td>
<td>588 (24)</td>
</tr>
<tr>
<td>PE</td>
<td>–</td>
<td>.065 (.011)</td>
</tr>
</tbody>
</table>

The standard error of the mean is shown in parentheses. The percentage of trials is shown in brackets.

Results

The data analysis was similar to that of Experiment 3. Application of RT cutoffs eliminated 0.22% and 0.15% of trials in Experiments 4A and 4B, respectively. Rejection of trials with EEG artefacts led to the further elimination of 5% of trials in both experiments, with no more than 25% rejected for any individual participant.

Behavioural data analyses

The behavioural data were analysed as a function of group (blue vs. yellow; a between-subject variable) and cue condition (no cue, valid cue vs. invalid cue) in Experiment 4A, and a function of a function of group (blue vs. yellow) and cue condition (valid vs. invalid) in Experiment 4B. Table 4 shows the mean RT and PE for each of the cue conditions in each experiment.

Experiment 4A (20% cue presence). For the RT data, the main effect of cue condition was significant, $F(2, 34) = 4.67, p < .05, \eta^2_p = .22$; mean RT was 586 ms, 580 ms and 599 ms for no cue, valid cue and invalid cue, respectively. Further analyses revealed that RT was significantly slower in the invalid cue condition than the valid and no cue conditions, $F's(1, 17) \geq 5.69, p's < .05, \eta^2_p s \geq .25$, but there was no difference between the latter two conditions, $F < 1.0$. Further $t$-tests revealed that the cue validity effect of $19 \pm 16$ ms was significantly different from zero, $t(18) = 2.49, p < .05$. For the PE data, the main effect of group was significant, $F(1, 17) = 5.52, p < .05, \eta^2_p = .25$; the target blue group produced a smaller PE than the target yellow group (.050 vs. .092, respectively). No other effects were significant.

Experiment 4B (100% cue presence). For the RT data, the cue validity effect (8±11 ms) was small and non-significant, $F(1, 17) = 2.72, p = .12, \eta^2_p = .14$; mean RT was 588 and 596 ms for valid and invalid cues, respectively. The cue validity effect was larger for the target blue letter group (19±14 ms) than the target yellow letter group (−5±14 ms), $F(1, 17) = 7.69, p < .05, \eta^2_p = .31$. As in the RT data, the PE data showed no effect of cue validity, $F < 1.0$ (the effect was only −.003 ± .009). No other effects were significant.

ERP data analyses

The N2pc effect was measured from electrode sites relative to the irrelevant colour singleton cue location and analysed as a function of group (blue vs. yellow; a between-subject variable), cue/target spatial relationship (same hemifield vs. different hemifields), and electrode site (P5/P6, O1/O2, vs. PO5/PO6) in each experiment. As in Experiments 1–3, the time window used to assess the cue-elicited effects was reported in the Discussion section of Experiment 4.

We did not conduct an overall ANOVA including experiment (Experiments 4A vs. 4B) as a variable since the level of cue condition was different between these two experiments (only 4A has a no-cue condition). Nevertheless, a between-experiment comparison on cue validity effects was reported in the Discussion section of Experiment 4.
N2pc effect was 170–270 ms after cue onset. However, due to the 100-ms increase in cue duration, the time window used to assess the target-elicited N2pc effect was 450–550 ms after cue onset (i.e., 200–300 ms after target onset). Figure 7 shows the N2pc effect for the P5/P6, O1/O2, and PO5/PO6 electrode sites, as well as the pooled data from these electrode sites, averaged across groups, for each experiment.

**Cue-elicited N2pc effects.** In both Experiments 4A and 4B, the cue-elicited N2pc analyses (170–270 ms after cue onset) revealed no significant main effects or interactions, $F$s $\leq 2.77$, $p$s $\geq .0843$, $\eta_p^2$ $s \leq .14$. There seems to be a trend towards a reverse N2pc effect in Experiment 4A (the overall N2pc effect was 0.242 $\mu$V), $t$(18) = 1.94, $p = .0686$, whereas the overall N2pc effect was only $-0.054$ $\mu$V in Experiment 4B, $|t| < 1.0$. As in Experiment 3, the irrelevant colour singleton cue did not produce N2pc effects during the time window 170–270 ms after cue onset.

Nevertheless, a close inspection of the ERP data revealed an N2pc effect in the early time window (170–210 ms). The overall N2pc effect in the early window was $-0.318$ $\mu$V and $-0.418$ $\mu$V in Experiments 4A and 4B, respectively, $|t|(18) \geq 2.40$, $p$s $< .05$. The between-experiment comparison showed no statistical difference in the magnitude of N2pc effects, $t < 1.0$.

**Target-elicited N2pc effects.** For Experiment 4A (20% cue presence), the target-elicited N2pc analyses (450–550 ms after cue onset) revealed that the target-elicited N2pc effect was negative when the target was in the same hemifield as the singleton cue ($-0.307 \mu$V) but was positive when the target was in the opposite hemifield.
Analyses (450, 100% cue presence). The target-elicited N2pc \( p < .001, \eta_p^2 = .52 \).

This pattern was less pronounced for the target blue group (0.060 \( \mu V \) vs. 0.493 \( \mu V \), respectively) than for the target yellow group (−0.715 \( \mu V \) vs. 0.758 \( \mu V \), respectively), \( F(1, 17) = 5.46, p < .05, \eta_p^2 = .24 \). No other effects were significant.

Similar results were obtained in Experiment 4B (100% cue presence). The target-elicited N2pc analyses (450–550 ms after cue onset) revealed that the target-elicited N2pc effect was negative when the target was in the same hemifield as the singleton cue (−0.872 \( \mu V \)) but was positive when the target was in the opposite hemifield (1.009 \( \mu V \)), \( F(1, 17) = 30.60, p < .0001, \eta_p^2 = .64 \). This pattern was less pronounced for the target blue group (−0.391 \( \mu V \) vs. 0.784 \( \mu V \), respectively) than for the target yellow group (−1.407 \( \mu V \) vs. 1.259 \( \mu V \), respectively), \( F(1, 17) = 4.61, p < .05, \eta_p^2 = .21 \). In addition, the difference between same and different hemifield conditions was more pronounced for the PO5/PO6 electrode sites than the P5/P6 and O1/O2 electrode sites, \( F(2, 34) = 12.06, p < .001, \eta_p^2 = .41 \), which was also more pronounced for the target yellow group than the target blue group, \( F(2, 34) = 8.62, p < .001, \eta_p^2 = .34 \). No other effects were significant.

**Discussion**

Our primary aim in Experiment 4 was to determine whether increase the salience of the irrelevant colour singleton cue would enhance the impact of rarity on attention capture. We therefore made four major changes to the design of Experiment 3 to increase colour singleton salience: (1) we increased the number of background boxes, (2) we increased the cue duration, (3) we used only red and green cues (to achieve higher colour contrast), and (4) we used more equilumant colours so that luminance changes would not mask colour changes. Finally, we presented the irrelevant colour cue for 20% of the trials in Experiment 4A but 100% in Experiment 4B, to determine whether any capture observed is due to rarity or to increased salience.

With the increased salience of the irrelevant colour singleton cue, we found a significant cue validity effect (19 ± 16 ms) on RT in Experiment 4A, with 20% cue presence, and a small but nonsignificant cue validity effect (8 ± 11 ms) in Experiment 4B, with 100% cue presence. Further \( t \)-test on the cue validity effect between Experiments 4A and 4B showed no significant effect of rarity, \( t(36) = 1.23, p = .2260 \). In addition, the cue validity effect in Experiment 4A was not significantly greater than it was in Experiment 3 (4 ± 9 ms), at the same cue frequency, \( t(41) = −1.65, p = .1096 \).

Even though the ERP data showed no significant N2pc effect during the time window 170–270 ms after cue onset, there was an effect during the time window 170–210 ms, which was larger in Experiment 4A than Experiment 3 (−0.318 \( \mu V \) vs. −0.025 \( \mu V \), respectively), \( t(41) = 1.96, p = .0568 \). Nevertheless, the N2pc effects were not significantly different between Experiments 4A and 4B (−0.318 \( \mu V \) and −0.418 \( \mu V \), respectively), \( t < 1.0 \). Thus, although the increased salience appeared to increase capture (albeit relatively weak and short-lived), there was no more capture with rare stimuli than with the frequent stimuli. Taken together, both the behavioural and ERP findings suggest that rarity by itself is not necessary to elicit attentional capture.

**GENERAL DISCUSSION**

Several previous studies have reported cases where rarity increased capture (e.g., Neo & Chua, 2006), whereas others have reported that rare salient objects did not capture attention even when they were irrelevant to the current task set (e.g., Yantis & Egeth, 1999). Some of the confusion may stem from the indirectness of behavioural data (e.g., RT), which opens the door to numerous alternative explanations. For example, people have argued that the RT costs of surprise might cancel out the benefits of capture, or that the shift occurred too early or too late to influence RT. The present study used a more specific and sensitive measure of capture (i.e., the N2pc effect) to determine whether rarity leads to capture by salient stimuli.
We used a cuing paradigm, in which a cue display appeared prior to the target display, to minimise ERP overlap between capture by the rare, salient cue and capture by the target. The cue was always uninformative regarding the target location (25% valid vs. 75% invalid). One important aspect of our design was that the target was always a non-singleton (e.g., the target display might include one red, one green, and two white letters), so that looking for a specific target feature was necessary to perform the task correctly. Capture by rare, salient objects with absolutely no target features would strongly support the claim that capture is driven by salience in a bottom-up manner. It would also implicate an important role of inhibition.

Experiment 1 examined capture by rare abrupt onsets. Specifically, we examined whether an abrupt onset could pull attention away from a cue drawn in the target-relevant colour. The relevant colour singleton cue (containing the target feature) appeared on 100% of the trials and the abrupt onset appeared simultaneously with the relevant colour singleton cue (but in a different location) on only 20% of the trials. As expected, the relevant colour singleton cue produced a significant N2pc effect, indicating that it captured attention. Most important, this N2pc effect was not abolished or even reduced by the simultaneous presence of the abrupt onset. The behavioural data were consistent with the N2pc effect. The cue validity effect produced by the relevant colour singleton cue was 49 ms when it appeared simultaneously with the abrupt onset. Thus, there was no evidence that the abrupt onset, despite being rare, had any ability to pull attention away from a relevant colour cue.

Experiment 2 further reduced the frequency of abrupt onsets from 20% to 10% and also reduced the frequency of the relevant colour cue alone trials from 80% to 10%. Despite the large reduction in the frequency of salient cue events, we still replicated the results of Experiment 1. The N2pc effect elicited by the relevant colour singleton cue was not reduced by the presence of the abrupt onset. The behavioural data converged on the same conclusion—the cue validity effect produced by the relevant colour singleton cue was 46 ms when it was presented alone and was 66 ms when it appeared simultaneously with the abrupt onset.

One interesting and unexpected finding from Experiments 1–2 is that the cue validity effect produced by the relevant colour singleton cue was larger when the abrupt onset was present (70 ms and 66 ms in Experiments 1 and 2, respectively) than when it was absent (49 ms vs. 46 ms). So the abrupt onset showed no ability to pull attention towards itself, but instead appeared to help the relevant cue capture attention (see also Lien, Ruthruff, & Gaspelin, 2014). The mere presence of the abrupt onset somewhere in the display, regardless of its precise location, might boost capture by a relevant stimulus. For instance, the salient abrupt onset might temporarily increase overall alertness, which in turn accelerates attentional shifts towards relevant objects.

Experiment 3 looked for capture by rare colour singletons. An irrelevant colour singleton cue (drawn in a colour that never appeared in the target display) was presented on 20% of the trials. The remaining 80% of the trials contained no cue. Despite being rare, colour singletons produced no N2pc effect. The behavioural data were consistent with this finding. RT was similar for the cue and no-cue conditions and there was no significant difference in RT between valid and invalid cue trials (i.e., no cue validity effect).

Experiment 4 greatly increased the salience of the irrelevant colour singleton cue by increasing the duration of the cue display from 50 ms to 150 ms and the number of background boxes from 4 to 8. Only red and green were used in colour singleton display, because they have higher colour contrast, and only blue and yellow as the target colour. We also used more equiluminant colours so that the luminance changes would be less likely to mask colour changes. The irrelevant colour singleton cue appeared 20% of the trials in Experiment 4A and 100% of the trials in Experiment 4B. With greatly increased salience, we found a small capture effect in the behavioural data (cue validity effects were 19 ± 16 ms vs. 8 ± 11 ms in Experiments 4A and 4B, respectively, albeit nonsignificant in the latter). Nevertheless, the overall cue validity effect produced by the irrelevant colour singleton cue (averaged across Experiments 4A and 4B) was only 29% of the overall cue validity effect produced by the relevant colour singleton cue (averaged across Experiments 1 and 2). The cue-elicited N2pc data are also consistent with behavioural data, showing signs of short-lived, early capture (during the time window 170–210 ms after cue onset). Most important, the between-experiment comparison on the N2pc effect revealed no more capture with rare stimuli than with those salient, frequent stimuli. Together, the present findings (both N2pc effects and cue...
validity effects) suggest that capture by salient objects does not strongly depend on rarity.

Thus, rarity appears to be neither necessary nor sufficient to produce capture by salient objects. Some previous studies have revealed evidence for capture by irrelevant, salient objects even when they were presented very frequently (e.g., Jonides & Yantis, 1988; Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1984; to a small extent, the present Experiment 4B; but see also Lien et al., 2008). Moreover, rarity does not always lead to capture. Our salient events were rare in Experiments 1 and 3 (only 20% of trials), yet no capture by salient objects was observed (see also Horstmann & Ansorge, 2006; Yantis & Egeth, 1999). The absence of capture was also evident even when we further reduced the frequency from 20% to only 10% in Experiment 2. Furthermore, colour singletons produced no more capture when they were rare than when they were frequent (Experiments 4A vs. 4B). In sum, although rarity might play a role in some situations, it does not appear to generally be a critical determinant of capture.

Decrease in capture across trials?

In the present study, the salient-but-irrelevant object (the abrupt onset and the irrelevant colour singleton) appeared on only 10% to 20% of the trials (with the exception of Experiment 4B). Capture by these salient objects was assessed based on trial-averaged data rather than a single, critical trial, as in some previous studies of surprise capture (e.g., Gibson & Jiang, 1998; Godijn & Kramer, 2008; Horstmann, 2002; Horstmann & Becker, 2008). It is therefore conceivable that salient stimuli did capture attention the first few times it was presented, but then inhibition was eventually applied (even though inhibition would not be needed on the 80–90% of trials with no cue). Thus, averaging data across those trials may have resulting in an underestimation of initial capture by rare, salient objects. For instance, Godijn and Kramer (2008) examined oculomotor capture by surprising onsets on a trial-by-trial basis. Saccadic movement towards the abrupt onset occurred for 28% of the participants for the first occurrence of the onset, but for only 5% of the participants on subsequent presentations. As converging evidence of capture by surprising onsets, saccadic latencies to targets simultaneously presented somewhere else were longer for the first occurrence of the onset than for the subsequent occurrences. Godijn and Kramer concluded that the novelty of the onset modulates oculomotor capture. Although their findings seem compelling, there are other possible explanations for the reduction in oculomotor capture over time observed by Godijn and Kramer. For instance, participants might have developed a sharper representation of the target stimulus, allowing it to be fixated more rapidly and with less error (i.e., fewer shifts to distracting stimuli).

Although it is not feasible to measure the N2pc for individual trials, it is possible to examine session halves. The capture by surprise hypothesis predicts that the strength of the capture effect by the rare object would be greatest for the first few encounters and then decrease over time. To critically evaluate this possibility, we examined the cue validity effect for the first half of the rare cue trials (i.e., the irrelevant abrupt onset trials) versus the second half of those cue trials on the pooled data from Experiments 1 and 2. The data analyses on the cue validity effect produced by the relevant colour cue, with the variables of cue condition (with vs. without abrupt onsets) and session (first half vs. second half), revealed no significant validity by session interaction, \( F < 1.0 \). The non-significant trend went in the opposite direction (67 ± 12 ms cue validity effect with abrupt onsets and 51 ± 9 ms without abrupt onsets for the first half of the trials; 68 ± 13 ms and 44 ± 11 ms, respectively, for the second half). Consistent with the behavioural data, the cue-elicited N2pc effect analyses revealed no significant interaction between cue condition and session, \( F < 1.0 \). The N2pc effects by the relevant colour cue with and without abrupt onsets were −0.315 µV and −0.352 µV, respectively, for the first half, and were −0.545 µV and −0.471 µV for the second half.

A similar analysis was conducted for the pooled data from Experiments 3 and 4A (both 20% cue presence), examining irrelevant colour singletons rather than abrupt onsets. The data analysis on the cue validity effect with the variable of session (first half vs. second half) revealed no sign of a decreasing cue validity effect from the first half of the session to the second half, \( t < 1.0 \) (the effect was 11 ± 5 ms for the first half and was 9 ± 6 ms for the second half). Consistent with the behavioural data, the cue-elicited N2pc effect analyses for the time window 170–270 ms after cue onset also revealed no effect of session half, \( t < 1.0 \) (the N2pc effect was actually reversed: 0.208 µV and

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0.139 µV for the first and second half of the trials, respectively). Even with the analysis focusing on the time window 170–210 ms after cue onset in Experiment 4A, there was still no session effect, $t < 1.0$; in fact, the N2pc effect was numerically larger for the second half session ($-0.374 \mu V$) than the first half ($-0.205 \mu V$). In summary, we found no evidence for the claim that rare abrupt onsets or rare irrelevant colour singletons captured attention early in the session but not late in the session.

**Relations to other studies**

The critical finding of the present electrophysiological study is that rarity does not appear to generally be a critical determinant of capture. Töllner, Müller, and Zehetleitner (2012) recently examined capture with different probabilities of irrelevant colour singleton distractors and how capture was modulated by inter-trial priming. They used a visual search paradigm, in which participants looked for a line tilted ±15° among 8, 12, or 18 background vertical lines. All lines contained a gap at the top or bottom and participants had to determine the gap location of the target line. All lines, including the tilted target line, were presented in the same colour. However, an additional irrelevant colour singleton distractor appeared on 25% or 50% of the trials. They measured Posterior-Contralateral-Negativity (PCN; similar to the N2pc effect). They found that the irrelevant colour singleton distractor failed to elicit a PCN, suggesting that it did not capture attention. Nevertheless, the *target-elicited* PCN was modulated by the probability of the irrelevant colour singleton distractor and the inter-trial relationship. Specifically, the target-elicited PCN was delayed for the low probability condition and when there was no distractor presented on the preceding trial. As discussed earlier, the sudden appearance of the discrepant stimulus might interrupt the current goal-driven behaviour, requiring reestablishment of the top-down task set and thereby delaying target processing (see Woods & Patterson, 2001).

Even though we found that abrupt onsets did not pull attention away from a relevant cue in Experiments 1–2, the finding leaves open the logical possibility that the abrupt onset somehow managed to capture attention to itself whereas having no impact on capture by the relevant cue. It also remains possible that other types of salient stimuli might be able to capture attention only when rare or surprising or capture by salient object occurs in the absence of a strong top-down task set for specific target features. For instance, Becker and Horstmann (2011) found that a surprising, unexpected motion singleton (i.e., a rotating square) captured attention despite top-down control settings for a specific shape, using a design similar to Gibson and Jiang’s (1998) single critical trial manipulation. An array of Landolt C’s within squares was presented at either set size 4 or 8, one of which had a gap in the horizontal orientation. Participants determined whether this gap faced left or right. On the critical trial, the target location was always validly cued by a simultaneously presented rotating square. Unlike Gibson and Jiang (1998), who found no evidence of capture by a surprising colour singleton, Becker and Horstmann (2011) found evidence of capture by the rotating square. Specifically, there was no set size effect on gap detection RT for the critical trial, indicating that visual attention was allocated first to the location of the novel motion singleton. This capture occurred only when the motion was an unexpected feature that participants had never encountered before.

Unlike colour singletons and abrupt onsets, motion may have the inherit power to capture our attention involuntarily (see also Abrams & Christ, 2003; Al-Aidroos, Guo, & Pratt, 2010; Pratt, Radulescu, Guo, & Abrams, 2010). From an evolutionary perspective, attention capture by moving objects is essential for survival. For instance, these moving objects might alert us to dangers within the environment or possible sources of food. Thus, the capture by rare, novel moving objects may be a special case that reflects an involuntary bottom-up attention capture. This possibility deserves further investigation.

Another possibility is that capture by salient stimuli depends on the nature of the task being performed. For instance, Hickey et al. (2006) have provided evidence for capture by irrelevant colour singletons when participants looked for a shape singleton (e.g., a diamond among circles). On 2/3 of the trials, one of the background, non-singleton shape object contained a unique colour (the irrelevant colour singleton; e.g., red among all green). They found that the irrelevant colour singleton delayed responses for the target shape singleton. The target-elicited N2pc effect was smaller with the presence of the irrelevant colour singleton than the absence of the irrelevant colour singleton. These findings are generally consistent with the salience capture view. However, it has been argued...
that participants might have adopted a strategy of looking for any singleton object (known as singleton-detection mode; e.g., Bacon & Egeth, 1994).

CONCLUSIONS

Using both behavioural and electrophysiological measures, the present study investigated whether rarity is the critical ingredient for enabling capture by salient but irrelevant objects. Despite being salient and rare (appearing on 20% or even 10% of trials), abrupt onsets failed to capture attention away from a cue drawn in the target colour. Similarly, irrelevant colour singletons (appearing on 20% of trials) failed to produce the usual signs of attentional capture—cue validity effects and N2pc effects. Even when we made the colour singleton much more salient (Experiment 4), rarity had no impact on capture. These findings support the claim that attention capture depends strongly on top-down control settings, not rarity. Rarity in the range examined here (10% and 20%) is neither necessary nor sufficient for attention capture.

Original manuscript received July 2012
Revised manuscript received December 2013
Revised manuscript accepted January 2014
First published online February 2014

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