Rapid top-down control over template-guided attention shifts to multiple objects

Anna Grubert[1], Johannes Fahrenfort[2], Christian N. L. Olivers[2], and Martin Eimer[1]

[1]Department of Psychological Sciences, Birkbeck, University of London
[2]Department of Experimental and Applied Psychology, VU University

Correspondence concerning this article should be addressed to Martin Eimer, Department of Psychological Sciences, Birkbeck, University of London, Malet Street, London WC1E 7HX, UK. E-mail: m.eimer@bbk.ac.uk

Abstract

Previous research has shown that when observers search for targets defined by a particular colour, attention can be directed rapidly and independently to two target objects that appear in close temporal proximity. We investigated how such rapid attention shifts are modulated by task instructions to selectively attend versus ignore one of these objects. Two search displays that both contained a colour-defined target and a distractor in a different colour were presented in rapid succession, with a stimulus onset asynchrony (SOA) of 100 ms. In different blocks, participants were instructed to attend and respond to target-colour objects in the first display and to ignore these objects in the second display, or vice versa. N2pc components were measured to track the allocation of spatial attention to target-colour objects in these two displays. When participants responded to the second display, irrelevant target-colour objects in the first display still triggered N2pc components, demonstrating task-set contingent attentional capture while a feature-specific target template is active. Critically, when participants responded to the first display instead, no N2pc was elicited by target-colour items in the second display, indicating that they no longer rapidly captured attention. However, these items still elicited a longer-latency contralateral negativity (SPCN component), suggesting that attention was oriented towards template-matching objects in working memory. This dissociation between N2pc and SPCN components shows that rapid attentional capture and subsequent attentional selection processes within working memory can be independent. We suggest that early attentional orienting mechanisms can be inhibited when task-set matching objects are no longer task-relevant, and that this type of inhibitory control is a rapid but transient process.

Keywords: visual attention, top-down control, visual search, event-related brain potentials, attentional capture

1. Introduction

In visual search tasks, observers try to find a specific target object that appears among task-irrelevant distractor objects. Although the location of target objects is not known, search can be guided by knowledge about the features of these objects. Representations of the visual properties of looked-for objects are assumed to be activated prior to the start of a particular search process, and these representations have been described as attentional task set or attentional templates (Duncan & Humphreys, 1989; Folk, Remington, & Johnston, 1992; Wolfe & Horowitz, 2004; Olivers, Peters, Houtkamp, & Roelfsema, 2011). Once a particular attentional control set is activated, stimuli with features that match this set will attract attention, while stimuli with non-matching features do not. As a result, attention can be deployed preferentially to candidate target objects that possess one or more template-matching features (e.g., Wolfe, 2007; see also Eimer, 2014, 2015a, for a more detailed discussion of the cognitive and neural basis of template-guided visual search).

Although attentional templates are critical for the guidance of attention during visual search, activating a particular feature-specific target template can also result in attentional capture by task-irrelevant distractor objects, provided that these objects possess a template-matching feature. This has been shown in spatial cueing experiments that demonstrated task-set contingent involuntary attentional capture effects (Folk et al., 1992; Folk, Remington, & Wright, 1994; Folk & Remington, 1998). When search arrays are preceded by spatially uninformative and task-irrelevant cue arrays that have to be ignored, cue stimuli that match current target attributes trigger spatial cueing effects (i.e., faster RTs to targets at cued versus uncued locations), indicating that these cues are able to attract attention in a task-set contingent fashion. This was also confirmed by event-related potential (ERP) studies that have measured the N2pc component as an electrophysiological marker of spatially selective attentional processing. The N2pc is an enhanced negativity that is elicited at posterior electrodes contralateral to the visual field of a target object in multi-stimulus visual displays. This component typically emerges 180-200 ms after stimulus onset, is generated in extrastriate areas of the ventral visual processing stream (Hopf et al., 2000), and reflects the attentional selection of candidate target objects among distractors in visual search (e.g., Luck & Hillyard, 1994; Eimer, 1996; Woodman & Luck, 1999). In experiments where target displays were preceded by uninformative cue displays, template-matching cue objects were found to trigger reliable N2pc components, demonstrating that they captured attention in spite of the fact that they were known to be task-irrelevant (e.g., Eimer & Kiss, 2008; Lien et al., 2008). Task-set contingent automatic attentional capture effects have also been found when target-matching cue stimuli were not physically salient (Lamy, Leber, & Egeth, 2004; Eimer et al., 2009), demonstrating that these effects do not depend on bottom-up salience signals, but are the result of a match with a currently active attentional target template.

The phenomenon of task-set contingent attentional capture by task-irrelevant cues presented prior to the target shows that before an attentional goal (i.e., the selection of the target) has been achieved, template-matching nontarget objects cannot be excluded from attentional processing. That is, observers apparently cannot selectively attend to only the second of two potentially relevant events presented in rapid sequence, while ignoring the first. What is not yet known is how fast observers can abandon a particular search goal once the target has been found. Specifically, can observers selectively attend to the first of two potentially relevant events, while ignoring the second? If attentional templates can be switched off rapidly, template-matching distractor objects that follow the target should no longer be able to capture attention. If this was the case, it would demonstrate effective and rapid control over attentional templates. The goal of the present study was to investigate this type of attentional control.

We used procedures that were similar to those employed in a recent study from our lab (Eimer & Grubert, 2014) that investigated the time course of allocating attention to two target objects that were presented sequentially and in rapid succession by measuring N2pc components to these objects. The procedures used in this earlier study and the main N2pc results are illustrated in Figure 1. On each trial, two search arrays that contained a colour-defined target and a distractor on different sides were presented in rapid succession, and the stimulus onset asynchrony (SOA) between the two arrays was manipulated. In blocks where the targets in the first and second display appeared on opposite sides (see Figure 1A), an N2pc was first triggered contralateral to the first target, before a second N2pc with opposite polarity emerged contralateral to the second target. The point in time when the second opposite-polarity N2pc started to emerge closely matched the SOA between the two displays. When this SOA was 100 ms (as shown in Figure 1B), the N2pc to the second target emerged about 100 ms after the onset of the N2pc to the first target. With shorter SOAs (10 or 20 ms) the N2pc reversal elicited by the second target started within 20 or 30 ms after selection of the first target. The fact that these polarity reversals were tightly time-locked to the onset of the second target strongly suggests that the presentation of a new target object on the opposite side can affect the current distribution of spatial attention very rapidly, and elicit rapid attention shifts towards the location of this new target object. In another condition of the same study, the target in one display appeared on the vertical meridian and the target in the other display on the horizontal meridian (Figure 1C). Because the N2pc is a contralateral component, it is not elicited by targets on the vertical meridian, and therefore only reflects the attentional selection of the other (horizontal) target object (see also Hickey, McDonald, & Theeuwes, 2006; Hickey, Di Lollo, & McDonald, 2009; Eimer, Kiss, & Nicholas, 2011). When the SOA between the two displays was 100 ms, the N2pc to horizontal targets in the first display (H1) preceded the N2pc to horizontal targets in the second display (H2) by almost exactly 100 ms (Figure 1D). When this SOA was reduced to 20 or 10 ms, the onset latency difference between the N2pc components to H1 and H2 targets mirrored this objective time interval perfectly, and both N2pc components overlapped in time.

These earlier N2pc results demonstrate that different target objects can be selected concurrently, with each selection process following its own independent time course (see also Grubert & Eimer, 2015, for similar observations in tasks where two successively presented targets were defined by two different colours, and Jenkins, Grubert, & Eimer, in press, for evidence that rapid concurrent attentional selection processes can also be activated when target objects are defined by their shape or alphanumerical category). They suggest that multiple template-guided attentional allocation processes can be activated in parallel, in line with parallel models of visual attention (e.g., Desimone & Duncan, 1995; Bundesen, Habekost, & Kyllingsbaek, 2005), but not with strictly serial models of attentional object selection in visual search (e.g., Treisman, 1988; Wolfe, 1994, 2007; but see Woodman & Luck, 1999, 2003, and Grubert & Eimer, 2016, for N2pc evidence that selection processes can operate serially in different task contexts). However, the question remains whether and to what degree such rapid parallel selection processes are subject to top-down attentional control. Because the features of the target objects were known in advance, the allocation of attention to these objects may operate in a largely automatic fashion, contingent on the relevant task settings that were established at the start of the experiment by instructing participants to detect specific target colours (e.g., Folk et al., 1992).

We tested this hypothesis in the present study with a stimulus setup that was identical to our previous experiment (Eimer & Grubert, 2014), but where participants were now instructed to find and respond to only one of the two target-colour items that were presented on each trial, and to ignore the other target-colour item. In Experiment 1, two displays that each contained one target-colour item and a distractor item in a different nontarget colour were separated by a 100 ms SOA. In some blocks, stimulus pairs were presented to the left and right of fixation (bilateral presentation condition), and the two target-colour items appeared either on the same side or on opposite sides in the two successive displays (as shown in Figure 1A). In other blocks, one stimulus pair on the vertical meridian and another pair on the horizontal meridian were presented successively (horizontal/vertical presentation condition; Figure 1C). The order in which display types (same side versus opposite side or horizontal versus vertical stimulus pair) varied randomly across trials. Participants' task was to attend and respond only to the target-colour item in one of the two successively presented displays, and to ignore the target-colour item in the other display. In some blocks, participants had to identify the target-colour item in the first display (digit versus letter) and to ignore the target-colour item in the second display (first display task-relevant: D1 blocks). In other blocks, the target-colour item in the second display had to be identified and the first display had to be ignored (second display task-relevant: D2 blocks).

N2pc components to horizontal target-colour objects in the first and second display were measured separately in D1 and D2 blocks, in order to find out whether the ability of these objects to attract attention was affected by instructions to selectively attend to only one of these objects. If template-guided attentional target selection processes are generally insensitive to such task instructions, N2pc results in Experiment 1 should be essentially identical to the results from our previous experiment (Eimer & Grubert, 2014) shown in Figure 1, where template-matching objects in both displays were task-relevant. In D2 blocks where participants had to find the target object in the second display, target-colour objects in the first display appeared before this search goal had been achieved. If template-matching but task-irrelevant objects cannot be prevented from capturing attention under these circumstances (as shown by the spatial cueing studies of task-set contingent attentional capture described above), both target-colour objects should attract attention in D2 blocks, and both should therefore elicit N2pc components (as in Eimer & Grubert, 2014; see Figure 1B and D). When the two target-colour items are presented successively on opposite display sides, an N2pc should initially be elicited by the first target and then reverse polarity, reflecting the subsequent allocation of attention to the target in the second display. In the horizontal/vertical presentation condition, horizontal targets in the first and second display should trigger N2pc components that emerge within approximately 100 ms of each other, matching the objective SOA between the two displays.

In D1 blocks where participants had to find targets in the first display, the task-irrelevant target-colour object in the second display always appeared after the target object had been encountered. Our starting hypothesis was that if attentional templates are de-activated rapidly after a search goal has been achieved (cf. Olivers & Eimer, 2011), these irrelevant target-colour objects may no longer be able to attract attention in these blocks. If this was the case, these objects should not elicit N2pc components. In D1 blocks where the two target-colour items appear on opposite sides, N2pc components should be elicited exclusively contralateral to the target in the first display, and no additional reverse-polarity N2pc to target-colour items in the second display should be observed. In the horizontal/vertical presentation condition, an N2pc should be triggered by horizontal target objects in the first display, but not on trials where a horizontal target-colour item was presented in the second display. Given that the SOA between the two displays was only 100 ms, such a pattern of N2pc results would suggest that attentional task sets can be switched off extremely rapidly. The alternative possibility is that target-colour objects in both displays elicit N2pc components of similar size in D1 blocks (similar to the pattern of N2pc components found when both objects are task-relevant; Eimer & Grubert, 2014). Such a result would show that feature-specific search templates cannot be deactivated immediately after a target object has been found. To foreshadow, our results suggested a more complex scenario, in which the template remains active, but spatial orienting is delayed.

2. Experiment 1

2.1. Methods

2.1.1. Participants.

Fifteen paid participants were tested. Three of them were excluded from analyses because of excessive eye movement activity resulting in a loss of more than 60% of all trials. The remaining twelve participants were 25 to 37 years old (mean age 28.8 years). Five were female; two were left-handed. All participants had normal or corrected-to-normal vision, including colour vision (tested with the Ishihara colour vision test; Ishihara, 1972).

2.1.2. Stimuli and procedure.

Participants were tested in a dimly illuminated soundproof and electrically shielded cabin. Stimuli appeared on a 22-inch Samsung wide SyncMaster 2233 LCD monitor with a resolution of 1280x1024 pixels and a 100 Hz refresh rate at a viewing distance of approximately 100 cm. Manual responses were registered with two purpose-built response keys, vertically aligned and centred in front of the observers. Stimulus presentation, timing, and response recording were controlled by a LG Pentium PC running under Windows XP, using the Cogent 2000 toolbox (www.vislab.ucl.ac.uk/Cogent/) for MATAB (Mathworks, Inc.).

On each trial, two search displays were presented in rapid succession (Figures 1A and C). The two displays were presented for 20 ms each and were separated by a 100 ms SOA. Each display contained one item in the target colour (i.e., the red items in Figures 1A and C), and a second item in a nontarget colour, presented against a black background. The four possible stimulus colours were red (CIE colour coordinates .616/.338), green (.261/.558), blue (.183/.178), and yellow (.399/.476). All colours were equiluminant (~11.8 cd/m^2). Each of the four colours served as the target colour for three participants. The nontarget colour in each display was randomly chosen from the three remaining colours, with the constraint that it was never identical in the two displays of the same trial. The two displays on each trial contained four different alphanumerical stimuli that were selected randomly from a set of uppercase letters (B, H, S, or T) and digits (1, 2, 3, or 4). Each stimulus subtended 0.9° x 0.9° of visual angle and was presented at an eccentricity of 2.4° from central fixation. A central grey (.324/.348) fixation cross was present throughout each block.

There were two blocked stimulus presentation conditions. In *bilateral* blocks, all search displays contained one stimulus on the left side and one on the right side of fixation (Figure 1A). To avoid masking interference between the two successive displays presented on each trial, one stimulus pair always appeared in the upper visual field and the other one in the lower visual field, with presentation sequence (upper→lower; lower→upper) randomized across trials. The two successive target-colour stimuli were equally likely to appear on the same side or on opposite sides on any given trial. In *horizontal/vertical* blocks, one stimulus pair was presented on the horizontal meridian, and the other one on the vertical meridian (Figure 1C), with presentation sequence (horizontal→vertical, vertical →horizontal) randomised across trials.

Participants' task was to report the identity (digit or letter) of one of the two target-colour items, and to ignore the target-colour item in the other display. Which of the two displays was task-relevant was varied across blocks. In *D1 blocks*, the target-colour item in the first display had to be reported, and the target-colour item in the second display had to be ignored. In *D2 blocks*, the second display was task-relevant, and the target-colour item in the preceding display could be ignored. To report the presence of a digit or letter target in the relevant display, participants pressed the top or bottom response key, respectively. The key-hand mapping (left or right hand on top or bottom key) was counterbalanced across participants and remained constant for each participant.

The experiment included 24 blocks, with six successive blocks for each combination of presentation condition (bilateral versus horizontal/vertical) and relevant display (D1 versus D2). Each block contained 64 trials, resulting in 1536 experimental trials in total. In the bilateral presentation condition, target-colour items appeared on the same or on opposite sides on 32 trials per block, and each trial was equally likely to start with a target-colour item in the left or right visual field. In the horizontal/vertical presentation condition, there were 32 trials per block where the horizontally arranged display preceded the vertical display, and 32 trials where this order was reversed. Target-colour items were equally likely to appear at the top or bottom position of the vertical display, and at the left or right position of the horizontal display. Six participants completed twelve D1 blocks where the first display was task-relevant followed by twelve D2 blocks, and this order was reversed for the other six participants. In both groups, three participants completed six blocks with bilateral stimulus displays prior to six blocks with horizontal/vertical displays, and this order was reversed for the other three participants.

2.1.3. EEG recording and data analysis.

EEG was DC-recorded from 23 scalp sites at standard positions of the extended 10/20 electrode placement system, sampled at 500 Hz and digitally low-pass filtered at 40 Hz. No additional off-line filters were applied. Impedances were kept below 5 kΩ. All electrodes were referenced to the left earlobe during recording, and were re-referenced offline to the average of both earlobes. Trials with artifacts (eye movements exceeding ±30 µV in the HEOG channels; blinks exceeding ±60 µV at Fpz; muscular movements exceeding ±80 µV in all other channels), with incorrect, anticipatory (faster than 200 ms), very slow (slower than 1500 ms), or missing responses were excluded from EEG analyses. After trial rejection, 89.6% and 93.7% of all trials remained in the analysis of bilateral D1 and D2 blocks (overall ranging between 82.8% and 98.2% between participants), and 89.1% and 92.9% of all trials remained in the analysis of horizontal/vertical D1 and D2 blocks, respectively (ranging from 79.2% to 96.9% between participants). For the analyses of N2pc components, EEG on these remaining trials was segmented into 600 ms epochs, from -100 ms to 500 ms relative to the onset of the first display. All ERPs were corrected relative to a 100 ms pre-stimulus baseline. For the bilateral presentation condition, ERPs were computed only for trials where the two colour-target items were presented on opposite sides, separately for each combination of relevant display (D1 or D2), and side of first target-colour object (left or right). For the horizontal/vertical presentation condition, ERPs were computed separately for each combination of relevant display (D1 or D2), display sequence (horizontal display first or second: H1 or H2), and side of the horizontal target-colour object (left or right). N2pc components to target-colour items in the first and second display were quantified on the basis of ERP mean amplitudes measured at lateral posterior electrode sites PO7 and PO8 within two 80 ms time windows that were separated by 100 ms, reflecting the SOA between the two displays (190-270 ms and 290-370 ms post-stimulus relative to the onset of the first display). N2pc onset latencies were calculated separately on the basis of jack-knifed difference waves (Miller, Patterson, & Ulrich, 1998; Ulrich & Miller, 2001). Difference waves obtained by subtracting ipsilateral from contralateral ERPs, were averaged for twelve subsamples, excluding one different participant from each average. Onset latencies were defined as the point in time when the voltage of the negative going deflection of the difference waveform of each subsample exceeded 50% of its peak value. The statistical values of the *t*-tests on jack-knifed data were corrected according to the formula described by Miller et al. (1998; denoted as t_c). All t-tests were two-tailed and Bonferroni corrected where necessary. Effect sizes are reported in terms of partial eta squared for *F*-tests and *t*-tests on jackknifed means (labelled $\eta_p{}^2{}_c$; see Grubert & Eimer, 2016, for more details on this procedure) and Cohen's *d* (Cohen, 1988), with a confidence interval of 95%, for all other *t*-tests. Longer-latency lateralised ERP components beyond the N2pc were assessed on the basis of EEG epochs that were computed within a longer time window (from 100 ms prior to 700 ms after D1 onset, relative to a 100 ms pre-stimulus baseline).

2.2. Results

2.2.1. Behavioural results

Trials with anticipatory (< 200 ms) and slow (> 1500 ms) reaction times (RTs) were excluded from analysis (less than 1% of all trials). Figure 2 (top panel) shows mean RTs and error rates in the bilateral and horizontal/vertical presentation conditions, separately for blocks in which the first or second display was task-relevant.

Bilateral presentation. RTs were analysed with a repeated-measures ANOVA with the factors relevant display (D1 versus D2) and target colour sequence (same-side trials versus opposite-sides trials). RTs were faster in D2 blocks where the second display was task-relevant relative to D1 blocks (549 versus 594 ms), *F*(1,11) = 7.5, *p* = .019, $\eta_p{}^2$ = .41. There was no RT difference between same-side and opposite-side trials (569 versus 575 ms), *F*(1,11) = 1.5, *p* = .243. An interaction between relevant display and target colour sequence, *F*(1,11) = 5.8, *p* = .035, $\eta_p{}^2$ = .34, was due to the fact that the RT advantage for D2 over D1 blocks was more pronounced for same-side than different-side trials (53 versus 36 ms). Error rates were generally low (5.0 and 3.9% in D1 and D2 blocks, respectively), and did not differ reliably between conditions, all *F*(1,11) < 1.4, all *p* > .277.

To determine whether the category of the target-colour stimulus (letter or digit) in the currently task-irrelevant display affected responses to target letters versus digits in the other relevant display, additional analyses compared performance on congruent trials where the two target-colour items were both letters or digits and incongruent trials where one of them was a letter and the other a digit (Figure 2, bottom panels). RTs were faster on congruent as compared to incongruent trials, and this was the case both in D1 blocks where the first display was task-relevant (581 versus 607 ms), $t(11) = 4.3$, $p = .001$, $d = .29$, and in D2 blocks (524 versus 575 ms), $t(11) = 5.0$, $p < .001$, $d = .85$. These RT congruency effects were larger in D2 as compared to D1 blocks (50 versus 25 ms), $t(11) = 2.9$, $p = .015$, $d = .88$. There were no reliable congruency effects on error rates, all $t(11) < 2.2$, all $p > .055$.

Horizontal/vertical presentation. RTs were analysed with the factors relevant display (D1 versus D2) and display sequence (horizontal → vertical versus vertical → horizontal). Responses were faster in D2 blocks relative to D1 blocks (568 versus 649 ms), $F(1,11) = 8.9$, $p = .012$, $\eta_p^2 = .45$. There was no main effect of display sequence and no interaction between relevant display and display sequence, both $F(1,11) < 3.1$, both $p > .113$. The same pattern was found for accuracy, with higher error rates in D1 as compared to D2 blocks (7.0% versus 3.9%), $F(1,11) = 10.8$, $p = .007$, $\eta_p^2 = .49$, and no significant effects involving the factor display sequence, both $F(1,11) < 3.5$, both $p > .093$. As in the bilateral presentation condition, RTs were faster on congruent relative to incongruent trials, both in D1 blocks where the first display was task-relevant (620 versus 681 ms), $t(11) = 3.3$, $p = .007$, $d = .45$, and in D2 blocks (537 versus 600 ms), $t(11) = 4.9$, $p < .001$, $d = .85$ (Figure 2, bottom panels). The size of these RT congruency effects did not differ between D1 and D2 blocks (61 versus 63 ms), $t(11) < 1$. There were also congruency effects on error rates (3.8 versus 10.2% and 2.4 versus 5.3% on congruent and incongruent trials in D1 and D2 blocks, respectively), both $t(11) > 3.5$, $p < .005$, $d > .99$, which were more pronounced in D1 relative to D2 blocks (6.4 versus 2.9%), $t(11) = 3.8$, $p = .003$, $d = .85$.

2.2.2. ERP results

Bilateral presentation – Opposite Side Trials. Figure 3 (top panels) shows grand-average event-related potentials (ERPs) elicited at electrode sites PO7 and PO8 contra- and ipsilateral to the target-colour stimulus in the first display on trials where the target-colour items in the two displays appeared on opposite sides. ERPs are shown separately for D1 blocks where the first display was task-relevant and the second display had to be ignored (left panel) and for D2 blocks where target-colour items in the second display were response-relevant (right panel). Target-colour items in the first display triggered N2pc components both in D1 and in D2 blocks. When the second target-colour item was relevant (D2 blocks), ERP waveforms reversed polarity (arrow in Figure 3), reflecting the emergence of an N2pc contralateral to the side of the target item in the second display. Importantly, no such polarity reversal was elicited in D1 blocks where the target-colour item in the second display could be ignored. This pattern of N2pc results is illustrated in N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs, separately in D1 and D2 blocks (Figure 3, bottom panel). The N2pc to the target-colour item in the first display emerged 190 ms after display onset, and its size was very similar in D1 and D2 blocks. When the second display was task-relevant (D2 blocks), the N2pc reversed polarity around 290 ms after the onset of the first display (i.e., 190 ms after the second array was presented). No such N2pc polarity reversal was apparent in D1 blocks where the target-colour item in the second display could be ignored.

These informal observations were confirmed by repeated measures ANOVAs of N2pc mean amplitudes for the factors relevant display (D1 versus D2) and laterality (electrode contralateral versus ipsilateral to the target-colour item in the first display). In the time window corresponding to the N2pc to the first display (190-270 ms post-stimulus), a main effect of laterality, $F(1,11) = 38.3$, $p < .001$, $\eta_p^2 = .78$, confirmed that reliable N2pc components were elicited by target-colour items in the first display. Importantly, there was no interaction between laterality and relevant display, $F(1,11) = 1.1$, $p = .315$, demonstrating that N2pc components to target-colour items in the first display were equally large regardless of whether these targets were task-relevant or had to be ignored. Follow-up *t*-tests conducted separately for D1 and D2 blocks confirmed the presence of reliable N2pc components to target-colour items in the first display both in D1 blocks (-1.4 µV), $t(11) = 5.2$, $p < .001$, $d = .35$, and in D2 blocks (-1.2 µV), $t(11) = 6.8$, $p < .001$, $d = .27$. Onset latencies of the N2pc components to target-colour items in the first display did not differ between D1 and D2 blocks (198 versus 193 ms), $t_c(11) = 1.3$, $p = .224$.[1]

---

[1] As can be seen in Figure 3, both contralateral and ipsilateral ERPs in the N2pc time range were generally more positive (i.e., downward-going) when the second display was

In the time window corresponding to the N2pc to target-colour items in the second display (290-370 ms after the onset of the first display), there was no overall main effect of laterality, $F(1,11) < 1$, but a significant interaction between laterality and relevant display, $F(1,11) = 39.2$, $p < .001$, $\eta_p^2 = .78$, reflecting the fact that ERP waveforms switched polarity when the target in the second display was task-relevant, but not in blocks where the second target had to be ignored. This was confirmed by follow-up analyses conducted separately for D1 and D2 blocks. In D2 blocks, there was a reliable N2pc contralateral to the visual field of the second target (1.2 µV), $t(11) = 3.0$, $p = .013$, $d = .25$. The onset of this opposite-polarity N2pc component in D2 blocks was delayed by approximately 120 ms relative to the onset of the N2pc in response to the first display (315 versus 193 ms), $t_c(11) = 14.9$, $p < .001$, $\eta_{p\,c}^2 = .95$. In D1 blocks, there was no such N2pc polarity reversal. Here, the enhanced negativity contralateral to the first target remained present during the 290-370 ms post-stimulus interval in D1 blocks (-0.6 µV), although this effect only approached significance, $t(11) = 2.0$, $p = .067$.

Horizontal/vertical presentation. Figure 4 shows grand-average ERPs triggered at electrodes PO7 and PO8 contra- and ipsilateral to horizontal target-colour items on trials where this item appeared in the first display (H1 trials, left panels) and trials where it appeared in the second display (H2, right panels). ERPs are shown separately for D1 blocks where the first display was task-relevant (top panel) and for D2 blocks (middle panel). Difference waveforms obtained by subtracting ipsilateral from contralateral ERPs in D1 and D2 blocks are presented in Figure 4 (bottom panel), separately for H1 and H2 trials. When the horizontal target-colour item was presented in the first display (H1 trials), an N2pc was elicited both when this item was response-relevant (D1 blocks) and when it had to be ignored (D2 blocks). In contrast, horizontal target-colour items in the second display appeared to elicit an N2pc only when they were relevant (D2 blocks), but not in D1 blocks.

These observations were verified by means of two repeated measures ANOVAs conducted separately on N2pc mean amplitudes obtained in response to horizontal target-colour items in the first display (190-270 ms post-stimulus) and in the second display (290-

---

relevant (Figure 3, top right panel) than when the first display was relevant (top left panel), and this was reflected by a main effect of relevant display, $F(1,11) = 12.0$, $p = .005$, $\eta_p^2 = .52$.

370 ms after the onset of the first display). Both analyses included the factors relevant display (D1 versus D2) and laterality (electrode contralateral versus ipsilateral to the horizontal target-colour item). For target-colour items in the first display, a main effect of laterality, $F(1,11) = 41.1$, $p < .001$, $\eta_p^2 = .79$, confirmed the presence of reliable N2pc components. An interaction between laterality and relevant display, $F(1,11) = 5.3$, $p = .042$, $\eta_p^2 = .32$, was due to the fact that N2pc amplitudes were larger in D1 blocks where target-colour items were task-relevant relative to D2 blocks (see Figure 4, bottom left panel). However, follow-up analyses conducted separately for D1 and D2 blocks confirmed that N2pc components were reliably elicited by horizontal target-colour items in the first display not only in D1 blocks (-1.7 µV), $t(11) = 7.0$, $p < .001$, $d = .30$, but also in D2 blocks where they were task-irrelevant (-1.3 µV), $t(11) = 5.2$, $p < .001$, $d = .23$. N2pc onset latencies were also virtually identical in D1 and D2 blocks (203 versus 202 ms), $t_c(11) < 1$.

For trials where horizontal target-colour items appeared in the second display, a main effect of laterality, $F(1,11) = 10.9$, $p = .007$, $\eta_p^2 = .50$, was accompanied by a significant interaction between laterality and relevant display, $F(1,11) = 18.1$, $p = .001$, $\eta_p^2 = .62$. Follow-up *t*-tests confirmed that in D2 blocks, task-relevant horizontal target-colour items in the second display elicited a reliable N2pc (-1.3 µV), $t(11) = 4.5$, $p = .001$, $d = .28$. In contrast, no significant N2pc was triggered by these items in D1 blocks where they had to be ignored (-0.3 µV), $t(11) = 1.3$, $p = .212$ (see Figure 4, bottom right panel). Additional analyses directly compared N2pc components triggered in D2 blocks by horizontal target-colour items in the first or second display. There was no amplitude difference between these N2pc components, $t(11) < 1$. Their respective onset latencies were 202 ms and 310 ms, $t_c(11) = 9.1$, $p < .001$, $\eta_p{}^2{}_c = .88$, which closely matched the objective 100 ms onset asynchrony between the two successive displays.

While target-colour items in the second display did not trigger reliable N2pc components in D2 blocks, they still elicited a considerable sustained posterior contralateral negativity (SPCN component; e.g., Mazza et al., 2007; Jolicoeur, Brisson, & Robitaille, 2008) that started at around 300-350 ms after the onset of the second display and remained present for at least another 300 ms. This is illustrated in Figure 5 (top panel), which shows contralateral-ipsilateral difference waveforms for trials from horizontal/vertical blocks where a task-relevant or -irrelevant horizontal target-matching item appeared in the second display, for a 700 ms time window after the onset of the first display. To confirm the presence of SPCN components, we conducted an additional analysis of ERPs elicited by target-colour items in the second display at lateral posterior electrodes PO7/8 in D1 and D2 blocks. These ERPs were computed on the basis of epochs that were extended by 200 ms relative to the epochs used for the N2pc analyses (from 100 ms prior to 700 ms after onset of the first display, as shown in Figure 5). A repeated measures ANOVA on SPCN amplitudes (measured during a 400-700 ms time-window relative to the onset of the first display, which corresponds to the 300-600 ms interval after the onset of the second display) obtained a main effect of laterality (electrode contralateral versus ipsilateral to the horizontal target-colour item in the second display), $F(1,11) = 53.5$, $p < .001$, $\eta_p^2 < .83$, reflecting the presence of reliable SPCN components to these items. The interaction between laterality and relevant display (D1 versus D2) approached significance, $F(1,11) = 4.7$, $p = .054$, $\eta_p^2 < .30$, indicating that target-colour items in the second display tended to elicit larger SPCN components in D2 blocks. However, and critically, follow-up analyses conducted separately for D1 and D2 blocks showed that SPCN components were reliably elicited by target-colour items not only when they were relevant (D2 blocks; -1.6 µV; $t(11) = 5.9$, $p < .001$, $d < .42$) but also in D1 blocks where they had to be ignored (-1.0 µV; $t(11) = 5.9$, $p < .001$, $d < .34$).

2.3. Discussion of Experiment 1

The results of Experiment 1 confirmed that while a search template for a particular target colour is active, template-matching nontarget objects will attract attention. In D2 blocks where participants were instructed to respond to target items in the second display and to ignore target-colour objects in the first display, target-colour objects in the first display elicited solid N2pc components. In line with previous behavioural and N2pc studies investigating task-set contingent attentional capture effects (e.g., Folk et al., 1992; Eimer & Kiss, 2008), this result demonstrates that these objects attracted attention even though they were not response-relevant. When the two target-colour items appeared on opposite sides in the first and second display in D2 blocks (bilateral presentation condition), the N2pc was initially triggered contralateral to the first of these items, and then changed polarity, reflecting the emergence of an N2pc to the second target-colour item (Figure 3). In D2 blocks where one display contained a horizontal stimulus pair and the other a vertical pair (horizontal/vertical presentation condition) task-irrelevant horizontal items in the first display also triggered N2pc components (Figure 4). The observation that N2pc amplitudes to target-colour objects in the first display were smaller in D2 blocks where they had to be ignored than in D1 blocks suggests that task instructions had some modulatory effect on the ability of these objects to attract attention. However, and critically, the fact that N2pc components were elicited by both task-irrelevant first and response-relevant second horizontal target-colour items in D2 blocks clearly shows that while a target template for an upcoming selection episode is active, template-matching items that have to be ignored cannot be prevented from attracting attention.

At first sight, the N2pc results found for D1 blocks appear to suggest that such templates are switched off extremely rapidly once the target is found and the current selection goal has been achieved. In these blocks, participants had to select the target object in the first display and to ignore the other target-colour item in the second display that was presented 100 ms later. N2pc components were only elicited by targets in the first display, but not by target-colour items in the subsequent task-irrelevant display. There was no polarity reversal of N2pc waveforms in trials where the two target-colour items appeared on opposite sides in the two displays (Figure 3), suggesting that the irrelevant target-colour item in the second display did not attract attention. This was confirmed in the horizontal/vertical presentation condition, where horizontal target-colour items in the second display of D1 blocks did not elicit an N2pc (Figure 4).

The absence of an N2pc to template-matching but task-irrelevant objects that were presented 100 ms after a target search display suggests that once the task goal has been achieved by selecting the target object in the first display, the corresponding attentional template is deactivated rapidly, and therefore no longer facilitates attentional capture by template-matching items in the subsequent display. However, before accepting this conclusion, it is important to consider other evidence from Experiment 1, which suggests that irrelevant target-colour items in the second display were not completely excluded from spatially selective processing in D1 blocks. The presence of significant behavioural congruency effects (i.e., faster RTs to targets that matched the category of the target-colour item in the other irrelevant display than to category-mismatching targets) demonstrated that the alphanumerical identity of the nominally irrelevant target-colour items was registered. This was not only the case in D2 blocks where these items attracted attention, as reflected by N2pc components, but also in D1 blocks, where they failed to elicit an N2pc.

The presence of behavioural congruency effects in D1 blocks is not necessarily inconsistent with the hypothesis that irrelevant target-colour items were successfully prevented from attracting attention. Visual search for letters among digits, or vice versa, is generally very efficient (e.g., Egeth, Jonides, & Wall, 1972), which suggests that the alphanumerical category of letters and digits can be detected rapidly and in parallel at pre-attentive processing stages (Duncan, 1980). Along similar lines, attentional blink experiments have reported evidence for the semantic analysis of unattended words (e.g., Luck, Vogel, & Shapiro, 1996; Martens, Wolters, & Van Raamsdonk, 2002). Such findings show that the processing of category and other semantic stimulus attributes does not depend on focal attention – at least not the attentional selection processes that are reflected by the N2pc.

The presence of behavioural congruency effects for irrelevant target-colour items in D2 blocks could suggest that even though these items were apparently unable to rapidly attract attention, their identity was still encoded into working memory. Indeed, these items elicited reliable SPCN components (as shown in Figure 5, top panel), as in several previous ERP studies of attentional target selection (e.g., Mazza et al., 2007; Jolicoeur et al., 2008). The SPCN is usually interpreted as reflecting the sustained activation of working memory representations during the identification and categorization of visual objects, analogous to the contralateral delay activity (CDA) that is observed during the delay period of visual working memory tasks (e.g., Vogel & Machizawa, 2004). While N2pc components are triggered by target objects both in simple detection and more complex target discrimination tasks, SPCN components are only elicited in tasks that require an in-depth analysis of target features (Mazza et al., 2007). This suggests that these two components reflect dissociable processes associated with the rapid attentional selection of target objects versus the sustained processing of selected objects in working memory (see also Eimer, 2014, 2015a, for a detailed discussion of such dissociations between ERP markers of object selection and identification processes). The presence of lateralised SPCN components for task-irrelevant target-colour items in D1 blocks shows that the location of these items was registered, and suggests that they were encoded into working memory, which may also explain why these items produced behavioural congruency effects. These observations are problematic for the hypothesis that attentional templates are immediately deactivated once the target in the first display has been selected. If this were the case, template-matching items in the task-irrelevant second display should no longer have been able to trigger a spatially selective

SPCN component. Experiment 2 was conducted to further investigate this issue. Stimulation parameters were identical to the horizontal/vertical blocks of Experiment 1, except that now all search display items were immediately followed by pattern masks (see Figure 6). Because masking limits the time available for the perceptual extraction of identity information (Scheerer, 1973; Turvey, 1973; Kolers, 1968), the inclusion of backward masks in Experiment 2 should make it less likely that the identity of task-irrelevant items in D1 blocks would be represented in working memory when not immediately attended. If this was the case, these items should not elicit behavioural congruency effects in Experiment 2, and should also no longer trigger any SPCN components.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Fifteen different participants were paid to participate in Experiment 2. Three of them were excluded from analyses due to excessive EEG artefacts resulting in an exclusion of more than 60% of all trials. The remaining twelve participants were aged between 20 and 41 years (mean age 31.3 years). Six were female; one was left-handed. All participants had normal or corrected-to-normal vision, including colour vision (tested with the Ishihara colour vision test; Ishihara, 1972).

3.1.2. Stimuli and procedure

These were identical to the horizontal/vertical condition of Experiment 1, with the exception that the two consecutive search displays in each trial were each presented for 30 ms and were immediately followed by a mask display (30 ms duration). There was a 40 ms blank screen between the offset of the mask for D1 and the onset of the D2 display, resulting in the same 100 ms SOA between D1 and D2 as in Experiment 1. The masking stimuli were hash marks (0.9° x 0.9°) which were presented at the same locations and in the same colours as the preceding letters/digits in the D1 and D2 displays (see Figure 6 for illustration). Experiment 2 comprised 12 blocks with 64 trials, resulting in a total of 768 trials. As in Experiment 1, there were six consecutive blocks where D1 or D2 was the task-relevant display, with task order (D1 blocks preceded by D2 blocks, or vice versa) counterbalanced across participants.

3.1.3. EEG recording and data analysis

Recording and analysis procedures were the same as in Experiment 1. After exclusion of trials with incorrect, anticipatory, very slow, or missing responses, and of trials with EEG artefacts, 81.1% and 84.5% of all trials were retained for D1 and D2 blocks, respectively (ranging from 60.9% to 97.1% across participants). EEG on these remaining trials was segmented into 800 ms epochs, from -100 ms to 700 ms relative to the onset of the first display, separately for each combination of relevant display (D1 or D2), display sequence (horizontal display first or second: H1 or H2), and side of horizontal target-colour object (left or right). As in Experiment 1, N2pc mean amplitudes to horizontal target-colour items in the first and second display were measured in the 190-270 ms and in the 290-370 ms time window after onset of the first display, respectively. SPCN components were computed during the 400-700 ms time window after onset of the first display for H2 trials in D1 and D2 blocks separately.

3.2. Results

3.2.1. Behavioural results

Trials with anticipatory (< 200 ms) and slow (> 1500 ms) reaction times (RTs) were excluded from analysis (less than 1.5% of all trials). Mean RTs and error rates, separately for blocks in which the first or second display was task-relevant, are shown in Figure 2 (top panel). A repeated-measures ANOVA with the factors relevant display (D1 versus D2) and display sequence (horizontal → vertical versus vertical → horizontal) showed that mean correct RTs did not differ significantly between D1 and D2 blocks (583 versus 616 ms), *F*(1,11) = 1.8, *p* = .207. There was also no main effect of display sequence and no significant interaction, both *F*(1,11) < 1.6, *p* > .253. Error rates showed the same pattern. Although error rates were numerically increased in D2 as compared to D1 blocks (6.2 versus 5.4%), this difference was not statistically reliable, *F*(1,11) = 4.4, *p* = .060. There was no effect of display sequence and no interaction, both *F*(1,11) < 1. In contrast to Experiment 1, faster

RTs on congruent relative to incongruent trials were only observed in D2 blocks where the second display was task-relevant (601 versus 633 ms), *t*(11) = 3.6, *p* = .005, *d* = .45. No reliable congruency effect was present in D1 blocks where the second display could be ignored (579 versus 587 ms), *t*(11) = 1.5, *p* = .161 (Figure 2, bottom panels). A direct comparison between these two types of blocks confirmed that congruency effects were reliably larger in D2 relative to D1 blocks (32 ms versus 7 ms), *t*(11) = 2.7, *p* = .021, *d* > 1. The same pattern was observed for error rates, with reliable congruency effects in D2 (4.3 versus 7.2%), *t*(11) = 2.3, *p* = .043, *d* = .60, but not in D1 blocks (5.6 versus 6.0%), *t*(11) < 1. However, the difference in the size of these congruency effects on error rates between D1 and D2 blocks was not reliable, *t*(11) = 1.7, *p* = .108.

3.2.2. ERP results

N2pc components. Figure 7 shows grand-average ERPs triggered at electrodes PO7 and PO8 contra- and ipsilateral to horizontal target-colour items on trials where this item appeared in the first display (H1 trials, left panels) and trials where it appeared in the second display (H2, right panels). ERPs are shown separately for D1 blocks where the first display was task-relevant (top panel) and for D2 blocks (middle panel). Difference waveforms obtained by subtracting ipsilateral from contralateral ERPs, separately in H1 and H2 trials of D1 and D2 blocks are presented in the bottom panels. The N2pc pattern was essentially the same as in Experiment 1. In H1 trials, an N2pc was elicited both when this item was response-relevant (D1 blocks) and when it had to be ignored (D2 blocks), while in H2 trials, an N2pc was only elicited when the horizontal target-colour item in the second display was response-relevant (D2 blocks), but not in D1 blocks.

Two repeated measures ANOVAs with the factors relevant display (D1 versus D2) and laterality (electrode contralateral versus ipsilateral to the horizontal target-colour item) were conducted separately on N2pc mean amplitudes to horizontal target-colour items in the first (190-270 ms post-stimulus) and second display (290-370 ms after the onset of the first display). Both ANOVAs revealed main effects of laterality, both *F*(1,11) > 44.8, *p* < .001, $\eta_p^2 > .79$, confirming the presence of reliable N2pc components. Importantly, there were also significant interactions between laterality and relevant display, both *F*(1,11) > 12.8, *p* < .005, $\eta_p^2 > .53$, as N2pc components to horizontal target-colour items in D1 and D2 displays were reliably larger in the blocks in which these respective displays were task-relevant. For horizontal target-colour items in the first display, follow-up analyses with paired *t*-tests showed that N2pc components were reliably present not only when this display was relevant (-1.8 µV), $t(11) = 7.5$, $p < .001$, $d = .33$, but also in D2 blocks where it had to be ignored (-1.1 µV), $t(11) = 6.2$, $p < .001$, $d = .20$ (see Figure 7, bottom left panel). N2pc onset latencies on H1 trials did not differ between D1 and D2 blocks (218 versus 211 ms), $t_c(11) < 1$. For horizontal target-colour items in the second display, reliable N2pc components were present in D2 blocks when they were task-relevant (-1.0 µV), $t(11) = 10.0$, $p < .001$, $d = .24$. As in Experiment 1, no reliable N2pc was elicited by these items in D1 blocks when they could be ignored (-0.3 µV), $t(11) = 1.9$, $p = .082$ (see Figure 7, bottom right panel). In D2 blocks, N2pc components to horizontal target-colour items in the first versus second display did not differ in terms of mean amplitudes, $t(11) = 1.1$, $p = .295$. Their onset latency difference was 118 ms (211 ms versus 339 ms), $t_c(11) = 15.4$, $p < .001$, $\eta_p{}^2{}_c = .96$, which roughly matched the objective 100 ms SOA time between the two successive displays.

SPCN components. Figure 5 (bottom panel) shows difference waves obtained by subtracting ipsi- from contralateral ERPs at PO7/8 for trials with a horizontal target-colour item in the second display during an extended 700 ms post-stimulus time window, separately for blocks where D1 or D2 was task-relevant. N2pc components were only reliably elicited by these objects in D2 blocks (see N2pc results), but subsequent SPCN components were again present both in D1 and in D2 blocks. A repeated measures ANOVA on SPCN mean amplitudes (measured during the 400-700 ms time-window relative to the onset of the first display), revealed a main effect of laterality, $F(1,11) = 55.8$, $p < .001$, $\eta_p^2 < .84$, confirming the reliable presence of SPCN components to horizontal target-colour items in the second display. There was an interaction between laterality and relevant display (D1 versus D2), $F(1,11) = 12.0$, $p = .005$, $\eta_p^2 < .52$, reflecting the larger SPCN components when D2 was task-relevant. However, follow-up t-tests demonstrated that SPCN components were elicited by target-colour items in D2 displays not only when they were task-relevant (D2 blocks; -2.4 µV), $t(11) = 5.8$, $p < .001$, $d = .71$, but also when they had to be ignored (D1 blocks; -0.9 µV), $t(11) = 6.2$, $p < .001$, $d = .30$.

3.3. Discussion of Experiment 2

The N2pc results obtained in Experiment 2 fully confirmed the observations from Experiment 1. In D2 blocks where target-colour items in the second display were task-relevant, reliable N2pc components were elicited not only by these items but also by the nominally task-irrelevant target-colour items in the first display. In D1 blocks where the first display was relevant, target-colour items in the second display failed to elicit an N2pc component, indicating that these items did not trigger rapid attentional orienting processes. This asymmetry again demonstrates that template-matching but task-irrelevant items will capture attention only before but not after the current search goal has been achieved.

All display items were followed by backward masks in Experiment 2, in order to reduce the likelihood that the identity of irrelevant target-colour items would be encoded into working memory when they did not immediately attract attention. In contrast to Experiment 1, behavioural congruency effects for these items were now only found in D2 blocks, and these effects were no longer present in D1 blocks. The fact that the presence versus absence of these congruency effects in D2 versus D1 blocks in Experiment 2 was mirrored by the presence versus absence of N2pc components to irrelevant target-colour items provides additional evidence that there were indeed systematic differences in the rapid allocation of attention to these two types of items. When these items captured attention (in D2 blocks), their alphanumerical category was registered, even though they were immediately followed by pattern masks. This suggests that the facilitation of sensory processing by focal attention was sufficient to counteract the adverse effects of these masks on the processing of stimulus identity. In contrast, when these items failed to attract attention (in D1 blocks) sensory facilitation was absent, and backward masks therefore interfered more strongly with the encoding of category-related information.

In spite of the fact that irrelevant target-colour items in the second display triggered neither N2pc components nor behavioural congruency effects in the D1 blocks of Experiment 2, they still gave rise to a sustained contralateral negativity that started around 300-350 ms after the onset of the second search display (see Figure 5, bottom panel). Even though this SPCN component was attenuated relative to D2 blocks where these items were task-relevant, it remained reliably present, suggesting that some spatially selective activation of visual working memory was still triggered by these items. The implications of this dissociation between N2pc and SPCN components to template-matching but task-irrelevant target-colour items in D1 blocks for template-guided attentional control processes will be considered below.

4. General Discussion

Attentional templates are set up during the preparation for a particular search task and specify the target-defining features for this task. Once such a template is activated, attention can be allocated rapidly and in parallel to multiple template-matching objects at different locations in the visual field (Eimer & Grubert, 2014; Grubert & Eimer, 2015). Even task-irrelevant objects will capture attention if they match the currently active search template (e.g., Folk et al., 1992; Eimer & Kiss, 2008). The aim of the current study was to investigate whether template-matching nontarget objects that appear immediately after a target will still capture attention in a task-set contingent fashion, or whether this type of attentional capture can be prevented once a target has been found and the search goal has been achieved. We measured N2pc components as markers of rapid attentional allocation processes in response to two target-colour objects in two displays that were separated by a 100 ms SOA, in blocks where participants were instructed to selectively attend to one of these objects and to ignore the object in the other display.

As expected, N2pc components were triggered by target-colour items in the currently task-relevant display. Furthermore, irrelevant target-colour items in the first display also elicited N2pc components in D2 blocks where participant were instructed to respond to the target in the second display. This demonstrates that irrelevant template-matching items captured attention when they were presented prior to a task-relevant search display, during the period when the search goal was not yet achieved. This is in line with previous findings from spatial cueing studies of task-set contingent attentional capture, and shows that for as long as a feature-specific target template is active, attentional selection cannot be confined to a particular set of template-matching objects that appear at a specific moment in time (e.g., to targets but not cues, as in Folk et al., 1992; to items in the second but not in the first display, as in the present study).

The central new finding of the current study was that target-colour items in the second display only elicited N2pc component when they were task-relevant, but not in D1 blocks when they had to be ignored and were presented after the target item had already been encountered, despite the fact that the second display appeared only 100 ms after the first display. The observation that task-irrelevant target-colour items in the second display failed to trigger N2pc components in both experiments strongly suggests that these items no longer rapidly attracted attention to their location once the search goal for the current trial was achieved. This could suggest that attentional templates can be deactivated very rapidly, within 100 ms after the selection of the current target. However, this conclusion is not in line with other findings of the present study. In both experiments, target-colour objects in the second display elicited longer-latency SPCN components in D1 blocks. Because the SPCN is elicited contralateral to the visual field where these objects appeared, its presence demonstrates that the location of these objects was being registered, resulting in a spatially selective modulation of visual processing that emerged around 300-350 ms after the onset of the second display. If search templates had been switched off entirely immediately after the target had been found, template-matching objects in the second display should no longer have been able to trigger a contralateral ERP component such as the SPCN. As SPCN components are usually interpreted as a marker of the activation of representations in visual working memory (e.g., Mazza et al., 2007; Jolicoeur et al., 2008), their presence in response to irrelevant target-colour objects in D1 blocks suggests that even though these objects failed to capture attention, they were still encoded into working memory. The fact that, in Experiment 1, the second object still exerted congruency effects on the response to the first target further corroborates this view.

The dissociation between the absence of N2pc components and presence of SPCN components that was found for template-matching nontarget objects in D2 blocks in both experiments demonstrates that task instructions to selectively attend versus ignore these objects can have different effects on different stages of spatially selective attentional processing. It suggests that the rapid allocation of spatial attention to template-matching but task-irrelevant objects can be prevented immediately after a search goal has been achieved, but that these objects still remain able to attract attention at subsequent memory-related processing stages. According to this interpretation, attentional templates remain activated for an extended period after the target for the current trial has been selected, resulting in reliable SPCN components for a subsequently presented template-matching nontarget. However, the spatial orienting mechanisms that are responsible for the rapid allocation of attention to these objects can be temporarily prevented once the target has been found. In other words, what is being affected by task instructions is not the activation state of attentional templates as such, but instead the access of these templates to rapid attentional orienting processes. Once the current search goal has been achieved, the link between these processes and the target template is temporarily blocked, so that template-matching objects are no longer able to trigger task-set contingent attentional capture. However, such spatial orienting towards target-matching objects can then still occur at a later stage, on the basis of a short-lived memory representation of all stimuli included in a particular display. In this context, the SPCN would then reflect attentional orienting processes within this large-capacity visual memory store (e.g., Landman, Spekreijse, & Lamme, 2003).

Instead of interpreting the late contralateral negativity elicited by template-matching objects in the second display in D1 blocks as an SPCN component, this negativity might also reflect a substantially delayed N2pc. This would imply that spatial orienting to these items was not completely prevented, but was initiated later than would normally be observed. While this possibility cannot be ruled out conclusively, previous studies have found that N2pc components can be delayed by up to 30 ms during multiple target selection (e.g., Pomerleau et al., 2014; Lagroix et al., 2015). In contrast, the contralateral negativity for template-matching nontargets in D1 blocks emerged at least 100 ms later than the typical N2pc component, which makes it more likely that this effect is an SPCN that is associated not with attentional capture but with the activation of working memory.

Before we can conclude that the absence of N2pc components to template-matching items in the second display in D1 blocks reflects the successful prevention of rapid attentional capture when observers are instructed to ignore these items, alternative interpretations of this result need to be considered. In D2 blocks, template-matching but task-irrelevant objects always appeared prior to targets. In contrast, in D1 blocks the target always appeared in the first display before the task-irrelevant object. The lack of an N2pc to irrelevant template-matching items in D1 blocks could therefore be related to the additional demands associated with the concurrent processing of the preceding target object (e.g., its selection and subsequent encoding into working memory; its categorization as letter or digit and the subsequent selection of the associated manual response). These ongoing target-related processes may have produced an attentional blink for the second template-matching item (Raymond, Shapiro, & Arnell, 1992; Dell'Acqua, Sessa, Jolicœur, & Robitaille, 2006), and this may have been responsible for the lack of an N2pc to these objects in D1 blocks. Along similar lines, the presence of an N2pc to template-matching irrelevant items in D2 blocks might reflect the fact that attention could be allocated to these items prior to the start of any resource-demanding processing of target objects in the second display. However, there are several reasons to assume that these temporal asymmetries between D1 and D2 blocks are not responsible for the different pattern of N2pc results observed in these blocks. First, it should be noted that the attentional blink usually does not occur for a second target object when this object is presented immediately after the first target ("lag-1 sparing"; e.g., Olivers, Van der Stigchel, & Hulleman, 2007), which was the case in the present study. Furthermore, the results from the D2 blocks of the current study show that two attentional selection processes of two target-colour items can be triggered in rapid succession, and that these two processes both give rise to solid N2pc components. If allocating attention to a template-matching object in the first display always resulted in an inhibition of a second attentional selection process, the N2pc to target objects in the second display should have been strongly attenuated in these blocks, which was clearly not the case. Finally, and most importantly, in earlier N2pc studies that used analogous D1-D2 presentation sequences (Eimer & Grubert, 2014; Grubert & Eimer, 2015; Jenkins et al., in press), both displays contained task-relevant objects that had to be identified. When these two displays were separated by an SOA of 100 ms, as in the present study, target objects in the second display elicited solid N2pc components that were equal in size to the N2pc triggered by targets in the first display (as illustrated in Figure 1D). This was the case in spite of the fact the second selection process was activated during the time when the first target object was encoded into working memory and identified. These observations suggest that the attentional processing of one target object does not necessarily prevent the concurrent allocation of attention to another template-matching object in a subsequent display. It is conceivable that in these previous studies, participants opted to postpone any in-depth processing of the first target object until the second target had been presented, while targets in the first display were processed immediately in the D1 blocks of the current study where the second display was known to be task-irrelevant. This theoretical possibility cannot be ruled out on the basis of the present data, but it is important to note that it still assumes a considerable degree of top-down temporal control over the attentional processing of target objects, which will then affect the ability of other template-matching objects to capture attention.

If the absence of an N2pc to template-matching but task-irrelevant objects in D1 blocks cannot be accounted for by the attentional demands associated with the concurrent attentional processing of a preceding target item, this leaves the alternative hypothesis that attentional capture by template-matching nontarget objects can be prevented when these objects are presented after the current search goal has been achieved. There are a variety of processes that might implement this type of attentional control, and we now discuss one possible inhibition-related mechanism. Instructing participants to attend to a colour-defined target object in the first display and to ignore target-colour objects in a subsequent display, or vice versa, may affect the size of the attentional window that is established once the first display is encountered. The attentional window is the area of the visual field where template-matching or otherwise salient visual objects can attract attention. This window can be narrowed or widened in line with current task demands, and salient stimuli that appear outside this window do not capture attention (e.g., Belopolsky, Zwaan, Theeuwes, & Kramer, 2007). In tasks where two task-relevant objects appear in rapid succession (e.g., Eimer & Grubert, 2014), participants are likely to maintain a wide attentional window after the first template-matching object has been encountered, because a second task-relevant object is known to appear shortly at a different location. This would also apply to the D2 blocks of the present study, where only the second target-colour item was task-relevant. In contrast, when observers know that only the first template-matching object is relevant and the second object has to be ignored (as in the current D1 blocks), they can adopt a different control setting where a narrow focus of attention on the location of the target object in the first display is rapidly established. As a result, subsequent template-matching objects at locations outside this narrow attentional window are no longer able to capture attention. The observation that N2pc components to target-colour objects in the first display were larger in D1 blocks where these objects were task-relevant than in D2 blocks is in line with this hypothesis that the attentional window was more narrowly focused on these objects in D1 blocks. Importantly, this task-dependent control of the attentional window appears to only affect rapid attentional capture (as reflected by N2pc components), but not longer-latency attentional processes that are associated with the SPCN. This suggests that this type of attentional control is relatively short-lived, and that attention becomes available again once the target has been processed, after around 300-350 ms (see also Findlay & Walker, 1999, for an analogous rapid and temporary inhibition mechanism in eye movement control, where saccades towards possible target objects can be prevented through the activation of fixation cells). Because individual search displays were presented for only 20 ms in the current study, any allocation of attention to template-matching objects that takes place after the transient inhibitory phase will therefore not affect on-line perceptual processing, but instead operate at a later stage where display items are temporarily held in a visual short-term memory store (see also Sligte, Vandenbroucke, Scholte, & Lamme, 2010, for similar suggestions). In this context, the SPCN component would reflect an attentional activation of particular template-matching representations within this store, in line with the hypothesis that spatial attention is responsible for the active maintenance of task-relevant items in visual working memory (e.g., Postle, Awh, Jonides, Smith, & D'Esposito, 2004; Awh, Vogel, & Oh, 2006; see also Eimer, 2015b, for further discussion).

In summary, the present results have provided new insights into the top-down control of template-guided attentional selection processes. When feature-specific target templates are active and the current search goal has not yet been achieved, both targets and template-matching nontarget objects will attract attention. Once a target has been selected, template-matching nontargets can be prevented from capturing attention, indicating that links between target templates and rapid attentional orienting processes can be rapidly inhibited when this is required by task instructions. However, this type of inhibitory control is transient, and template-guided attentional mechanisms may again become available during subsequent memory-related processing stages.

Acknowledgement. This work was supported by grant ES/L016400/1 from the Economic and Social Research Council (ESRC), UK, Open Research Area grant NWO 464-13-003, NL, and European Research Council Consolidator grant ERC-CoG-2013-615423.

References

Awh, E., Vogel, E., & Oh, S.-H. (2006). Interactions between attention and working memory. *Neuroscience, 139*, 201-208.

Belopolsky, A. V., Zwaan, L., Theeuwes, J., & Kramer, A. F. (2007). The size of an attentional window modulates attentional capture by color singletons. *Psychonomic Bulletin & Review*, *14*, 934-938.

Bundesen, C., Habekost, T., & Kyllingsbaek, S. (2005). A Neural Theory of Visual Attention: Bridging Cognition and Neurophysiology. *Psychological Review, 112*, 291-328.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Dell'Acqua, R., Sessa, P., Jolicœur, P., & Robitaille, N. (2006). Spatial attention freezes during the attentional blink. *Psychophysiology, 43*, 394-400.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience, 18*, 193-222.

Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. *Psychological Review, 87*, 272-300.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review, 96*, 433-458.

Egeth, H., Jonides, J., & Wall, S. (1972). Parallel processing of multi-element displays. *Cognitive Psychology, 3*, 674-698.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology, 99*, 225-234.

Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive Sciences, 18*, 526-535.

Eimer, M. (2015a). EPS mid-career award 2014: the control of attention in visual search - cognitive and neural mechanisms. *The Quarterly Journal of Experimental Psychology, 68*, 2437-2463.

Eimer, M. (2015b). *Visual working memory and attentional object selection.* In: Jolicoeur, P., Lefebvre, C., & Martinez-Trujillo, J. (Eds). Mechanisms of sensory working memory, Attention and Performance XXV; Chapter 8 (pp.90-104). Amsterdam: Elsevier.

Eimer, M., & Grubert, A. (2014). Spatial attention can be allocated rapidly and in parallel to new visual objects. *Current Biology, 24*, 193-198.

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience, 20*, 1423-1433.

Eimer, M., Kiss, M., & Nicholas, S. (2011). What top-down task sets do for us: An ERP study on the benefits of advance preparation in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1758-1766.

Eimer, M., Kiss, M., Press, C., & Sauter, D. (2009).The roles of feature-specific task set and bottom-up salience in attentional capture: An ERP study. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1316-1328.

Findlay, J. M., & Walker, R. (1999). A model of saccade generation based on parallel processing and competitive inhibition. *Behavioral and Brain Sciences*, *22,* 661-674.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 1030-1044.

Folk, C. L., Remington, R. W, & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 317-329.

Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 847-858.

Grubert, A., & Eimer, M. (2015). Rapid parallel attentional target selection in single-color and multiple-color visual search. *Journal of Experimental Psychology: Human Perception and Performance, 41*, 86-101.

Grubert, A., & Eimer, M. (2016). The speed of serial attention shifts in visual search: Evidence from the N2pc component. *Journal of Cognitive Neuroscience, 28*, 319-332.

Hickey, C., Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and distractor processing in visual search. *Journal of Cognitive Neuroscience, 21*, 760-775.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience 18*, 604-613.

Hopf, J. M., Luck, S. J., Girelli, M., Hagner, T., Mangun, G. R., Scheich, H., & Heinze, H. J. (2000). Neural sources of focused attention in visual search. *Cerebral Cortex, 10*, 1233-1241.

Ishihara, S. (1972). *Tests for color-blindness*. Tokyo: Kanehara Shuppan.

Jenkins, M., Grubert, A., & Eimer, M. (in press). Rapid parallel attentional selection can be controlled by shape and alphanumerical category. *Journal of Cognitive Neuroscience.*

Jolicoeur, P., Brisson, B., & Robitaille, N. (2008). Dissociation of the N2pc and sustained posterior contralateral negativity in a choice response task. *Brain Research, 1215*, 160-172.

Kolers, P. A. (1968). *Some psychological aspects of pattern recognition*. In P.A. Kolers & N. Eden (Eds.), Recognizing patterns. Cambridge, MA: MIT Press

Lagroix, H. E., Grubert, A., Spalek, T. M., Di Lollo, V., & Eimer, M. (2015). Visual search is postponed during the period of the AB: An event-related potential study. *Psychophysiology, 52*, 1031-1038.

Landman, R., Spekreijse, H., & Lamme, V. A. F. (2003). Large capacity storage of integrated objects before change blindness. *Vision Research*, *43*, 149–164.

Lamy. D., Leber, A., & Egeth, H. E. (2004). Effects of task relevance and stimulus-driven salience in feature-search mode. *Journal of Experimental Psychology: Human Perception and Performance, 30*, 1019–1031.

Lien, M.-C., Ruthruff, E., Goodin, Z., & Remington, R. W. (2008). Contingent attentional capture by top-down control settings: Converging evidence from event-related potentials. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 509-530.

Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1000-1014.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature, 382*, 616-618.

Martens, S. Wolters, G., & van Raamsdonk, M. (2002). Blinks of the mind: Memory effects of attentional processes. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1275-1287.

Mazza, V., Turatto, M., Umiltà, C., & Eimer, M. (2007). Attentional selection and identification of visual objects are reflected by distinct electrophysiological responses. *Experimental Brain Research, 181*, 531-536.

Miller, J., Patterson, T., & Ulrich, R. (1998). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology, 35*, 99-115.

Olivers, C. N. L, & Eimer, M. (2011). On the difference between working memory and attentional set. *Neuropsychologia, 49*, 1553-1558.

Olivers, C. N. L., Peters, J., Houtkamp, R. & Roelfsema, P.R. (2011). Different states in visual working memory: when it guides attention and when it does not. *Trends in Cognitive Sciences, 15*, 327-334.

Olivers, C. N., Van Der Stigchel, S., & Hulleman, J. (2007). Spreading the sparing: Against a limited-capacity account of the attentional blink. *Psychological research*, *71*, 126-139.

Pomerleau, V. J., Fortier-Gauthier, U., Corriveau, I., McDonald, J. J., Dell'Acqua, R., & Jolicœur, P. (2014). The attentional blink freezes spatial attention allocation to targets, not distractors: Evidence from human electrophysiology. *Brain Research*, *1559*, 33-45.

Postle, B. R., Awh, E., Jonides, J., Smith, E. E., & D'Esposito, M. (2004). The where and how of attention-based rehearsal in spatial working memory. *Cognitive Brain Research, 20*, 194–205.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of experimental psychology: Human perception and performance*, *18*, 849-860.

Scheerer, E. (1973). Integration, interruption and processing rate in visual backward masking. 1. Review. *Psychologische Forschung, 36*, 71-93.

Sligte, I. G., Vandenbroucke, A. R., Scholte, H. S., & Lamme, V. A. (2010). Detailed sensory memory, sloppy working memory. *Frontiers in Psychology*, *1*, 1-10.

Treisman, A. (1988). Features and objects: *The fourteenth Bartlett memorial lecture. Quarterly Journal of Experimental Psychology, 40A*, 201-237.

Turvey, M. (1973). On peripheral and central processes in vision: Inferences from an information-processing analysis on masking with patterned stimuli. *Psychological Review, 80*, 1–52.

Ulrich, R., & Miller, J. O. (2001). Using the jackknife-based scoring method for measuring LRP onset effects in factorial designs. *Psychophysiology, 38*, 816-827.

Vogel, E. K., & Machizawa, M. G. (2004). Neural activity predicts individual differences in visual working memory capacity. *Nature, 15*, 748-751.

Wolfe, J. M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review, 1*, 202-238.

Wolfe, J.M. (2007). *Guided Search 4.0: Current Progress with a model of visual search*. In W. Gray (Ed.), Integrated Models of Cognitive Systems (pp. 99-119). New York: Oxford.

Wolfe, J.M., Horowitz, T.S. (2004). What attributes guide the deployment of visual attention and how do they do it? *Nature Reviews Neuroscience, 5*, 1-7.

Woodman, G. F., & Luck, S. J. (1999). Electrophysiological measurement of rapid shifts of attention during visual search. *Nature, 400*, 867-869.

Woodman, G. F., & Luck, S. J. (2003). Serial deployment of attention during visual search. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 121-138.

Figure legends

Figure 1. Top panels: Schematic illustrations of the time course of stimulus events in the bilateral (A) and horizontal/vertical (C) presentation conditions employed by Eimer and Grubert (2014) and in the current experiments. Two consecutive displays, each containing a target-colour and a distractor-colour item, were presented in rapid succession. In the bilateral condition (A), target-distractor pairs were shown on the horizontal meridian, and the two targets appeared on the same or on different display sides. In the horizontal/vertical condition (B), one target-distractor pair was presented on the horizontal and the other on the vertical meridian, and the horizontal target could appear in the first or second display. Bottom panels: N2pc results found by Eimer & Grubert (2014), all time-locked to the onset of the first display. ERP waveforms elicited at lateral occipitotemporal electrode pairs PO7 and PO8 ipsilateral and contralateral to target objects are shown together with the corresponding contralateral-ipsilateral difference waveforms. For opposite-side targets in the bilateral condition (B), ERPs swapped polarity. In the horizontal/vertical condition (D), horizontal targets in the first and second display both elicited N2pc components. See text for details. The grey bars on the x-axes represent the respective N2pc time widows.

Figure 2. Mean correct response times (RTs, in milliseconds) and error percentages in blocks where the first or second display was task-relevant (top panel) and RT and error congruency effects (congruent/incongruent = same/different alphanumerical identity of the two consecutive target-matching objects) separately for blocks in which the first or second display was task-relevant (bottom panels). For Experiment 1, results are shown separately for the bilateral and horizontal/vertical presentation conditions. In Experiment 2 only the horizontal/vertical presentation condition was tested. Error bars reflect mean standard errors. Asterisks reflect significant differences.

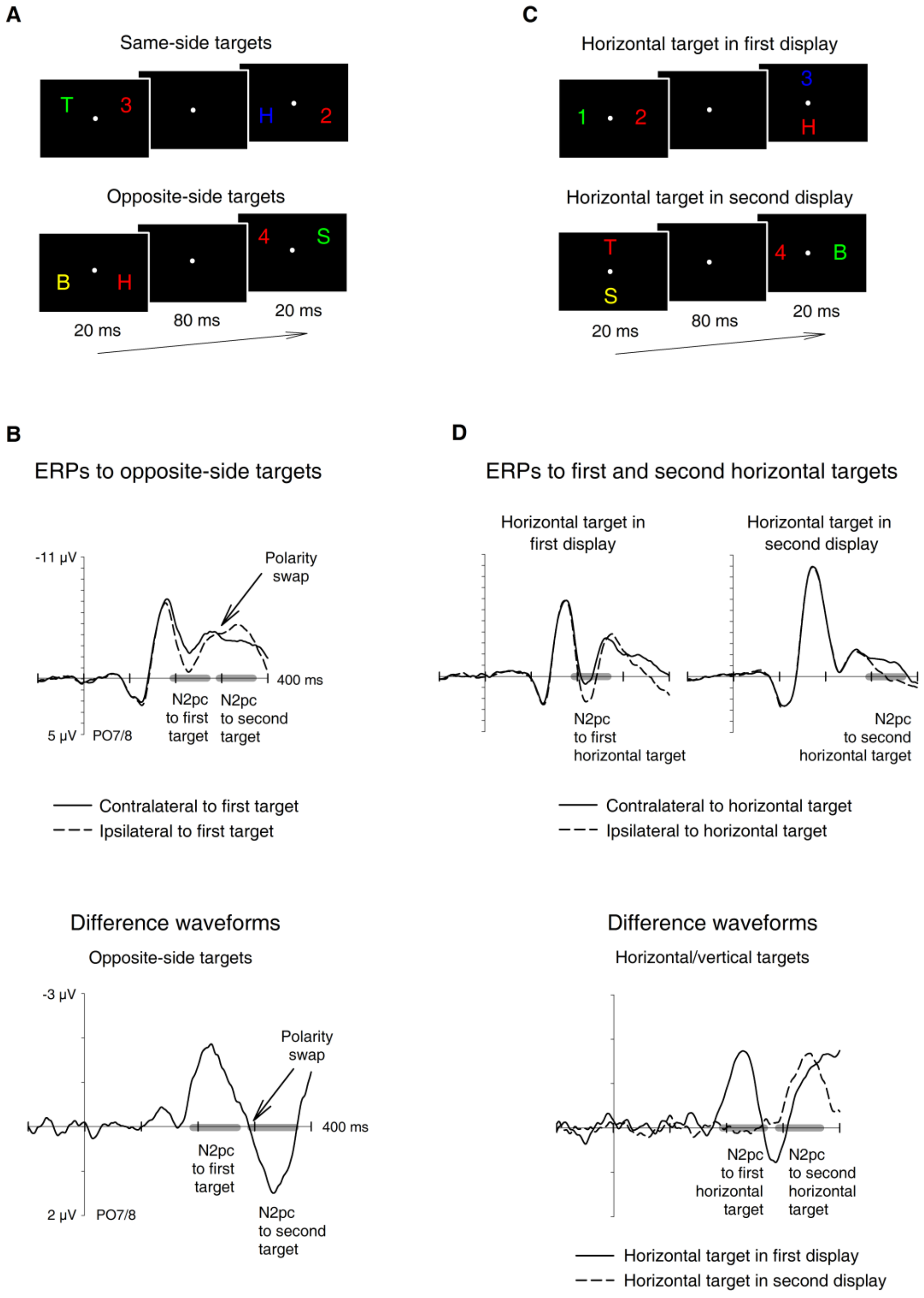
Figure 3. N2pc results obtained for opposite-side target-colour items in the bilateral presentation condition of Experiment 1. Top panels show grand-average ERP waveforms measured in the 500 ms interval after the onset of the first display at posterior electrodes PO7 and PO8 contralateral and ipsilateral to the target-colour item in the first display, separately for blocks in which the first (D1 blocks) or second display (D2 blocks) was response-relevant. The bottom panel presents N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs, separately for D1 and D2 blocks. The grey bars on the x-axes represent the respective N2pc time widows.

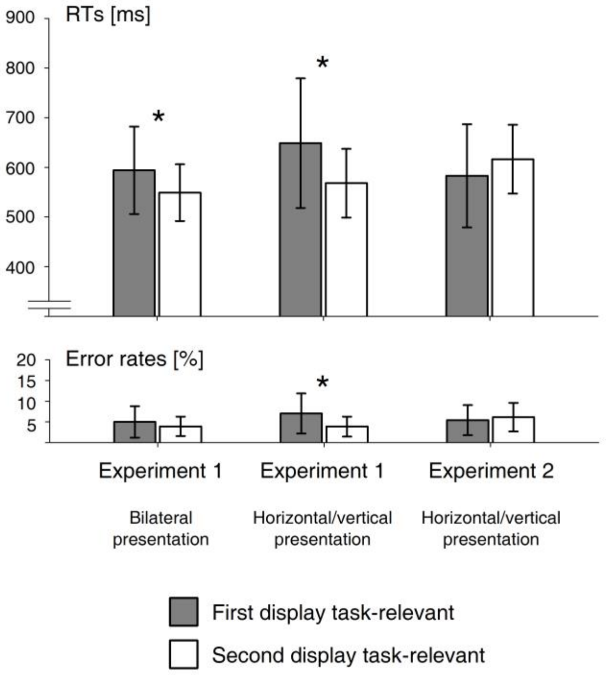
Figure 4. N2pc results obtained in the horizontal/vertical presentation condition of Experiment 1. Grand-average ERP waveforms measured in the 500 ms interval after the onset of the first display at posterior electrodes PO7/PO8 contralateral and ipsilateral to the side of the horizontal target-colour item are shown for trials where this item was presented in the first (H1 trials; left panels) or second display (H2 trials; right panels), separately for blocks where the first (D1 blocks; top panels) or second (D2 blocks; middle panels) target-colour item was response-relevant. Bottom panels show the corresponding N2pc difference waves obtained by subtracting ipsilateral from contralateral ERPs, separately for H1 and H2 targets in D1 and D2 blocks. The grey bars on the x-axes represent the respective N2pc time windows.

Figure 5. N2pc and SPCN difference waveforms elicited by target-colour items in the second display in D1 and D2 blocks of the horizontal/vertical presentation conditions of Experiment 1 (top panel) and Experiment 2 (bottom panel). These waveforms correspond to the N2pc difference waves shown in Figures 3 and 6 (bottom right panels), except that contralateral ERP components are now shown for an extended 700 ms interval after the onset of the first display. The grey bars on the x-axes represent the respective N2pc and SPCN time windows.

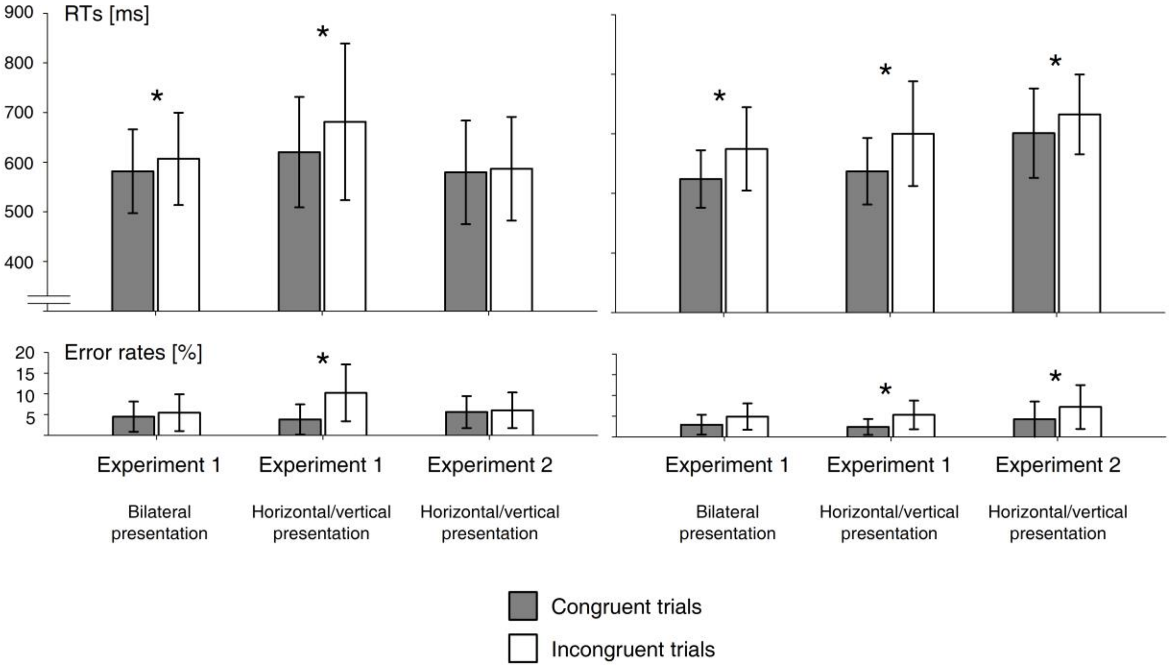
Figure 6. Schematic illustrations of the time course of stimulus events in Experiment 2. Stimulation procedures were identical to the horizontal/vertical presentation condition of Experiment 1, except that search arrays were now presented for 30 ms and were immediately followed by mask displays (30 ms duration).

Figure 7. N2pc results obtained in Experiment 2. Grand-average ERP waveforms measured in the 500 ms interval after the onset of the first display at posterior electrodes PO7/PO8 contralateral and ipsilateral to the side of the horizontal target-colour item are shown for trials where this item was presented in the first (H1 trials; left panels) or second display (H2 trials; right panels), separately for blocks where the first (D1 blocks; top panels) or second (D2 blocks; middle panels) target-colour item was response-relevant. Bottom panels show corresponding N2pc difference waves obtained by subtracting ipsilateral from contralateral ERPs, separately for H1 and H2 targets in D1 and D2 blocks. The grey bars on the x-axes represent the respective N2pc time windows.


A
Same-side targets
T
3
H
2
Opposite-side targets
B
H
4
S
20 ms
80 ms
20 ms
C
Horizontal target in first display
1
2
3
H
Horizontal target in second display
T
S
4
B
20 ms
80 ms
20 ms
B
ERPs to opposite-side targets
-11 µV
5 µV
PO7/8
Polarity swap
400 ms
N2pc to first target
N2pc to second target
Contralateral to first target
Ipsilateral to first target
D
ERPs to first and second horizontal targets
Horizontal target in first display
Horizontal target in second display
N2pc to first horizontal target
N2pc to second horizontal target
Contralateral to horizontal target
Ipsilateral to horizontal target
Difference waveforms
Opposite-side targets
-3 µV
2 µV
PO7/8
Polarity swap
400 ms
N2pc to first target
N2pc to second target
Difference waveforms
Horizontal/vertical targets
N2pc to first horizontal target
N2pc to second horizontal target
Horizontal target in first display
Horizontal target in second display



Reaction times and error rates

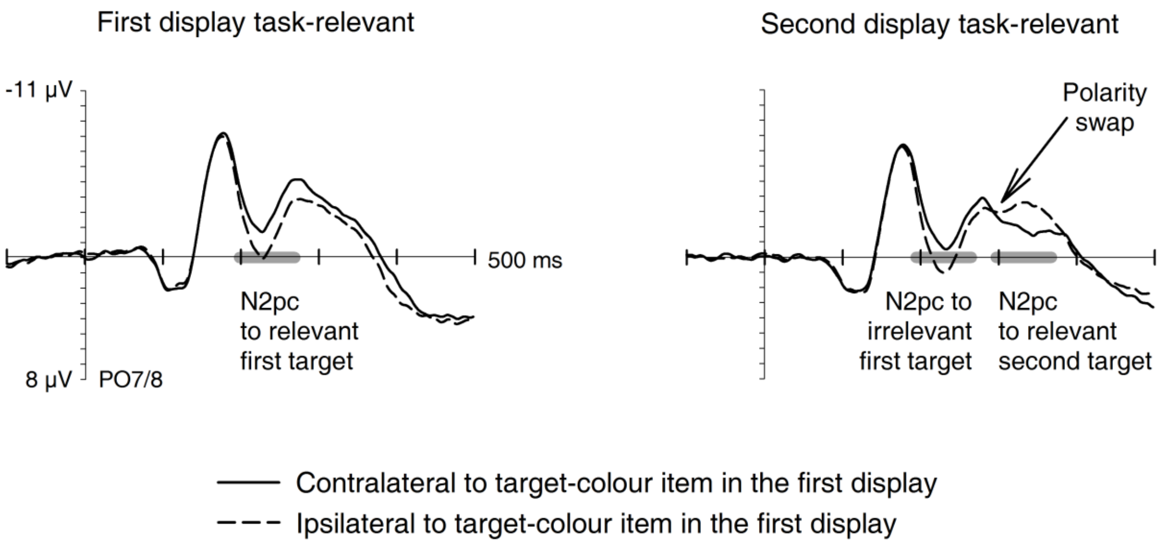


Congruency effects

First display task-relevant

Second display task-relevant

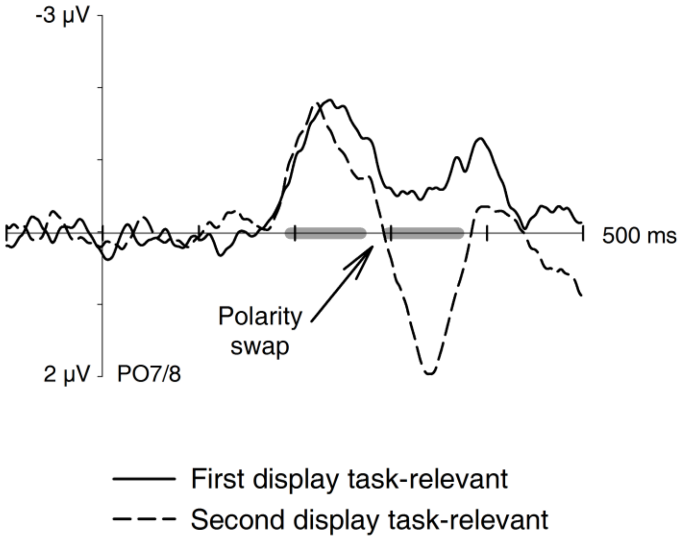
ERPs to opposite-side targets


First display task-relevant

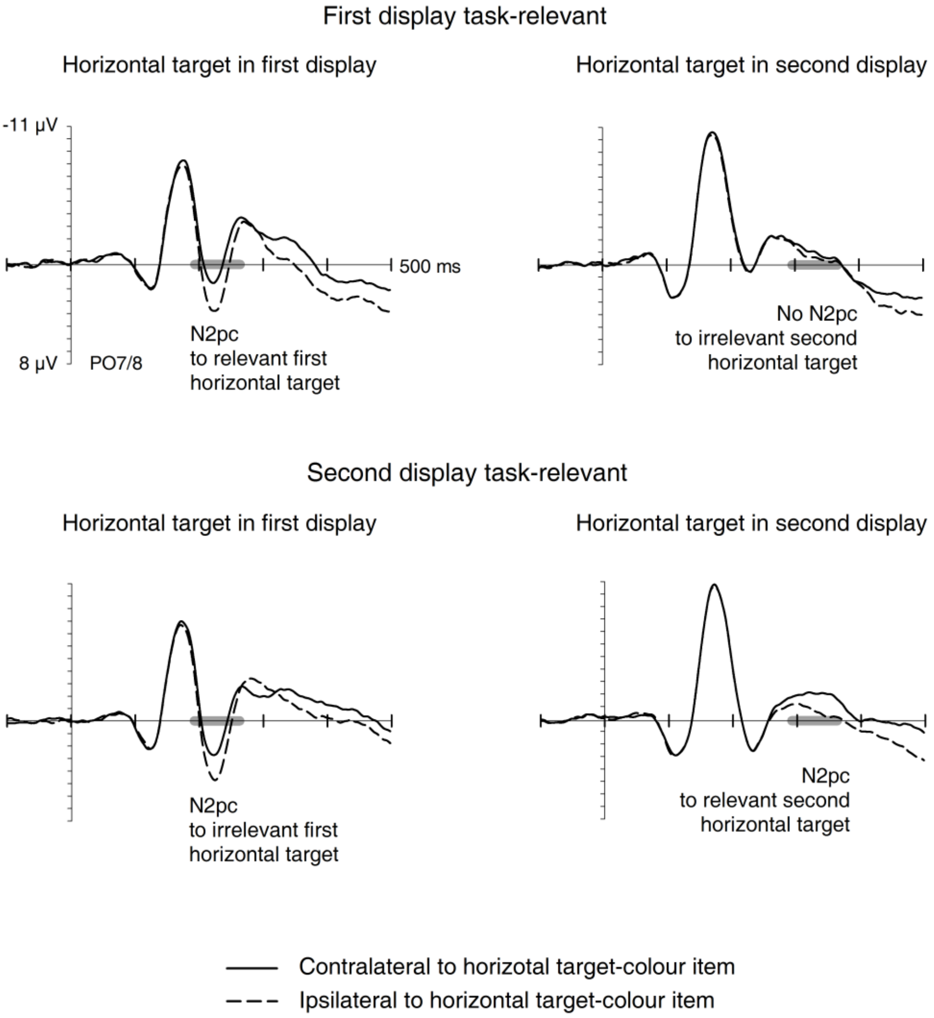
Second display task-relevant

Difference waveforms

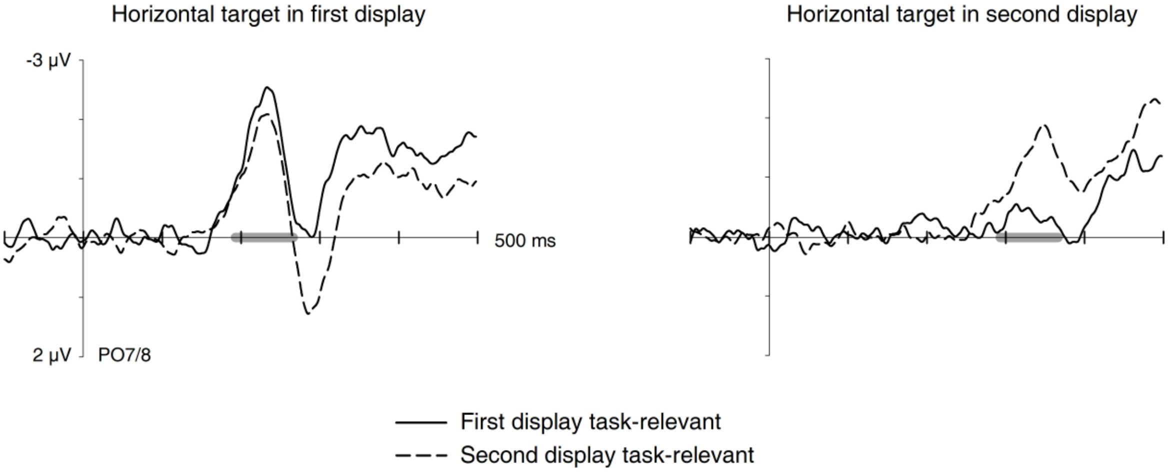
Opposite-side targets



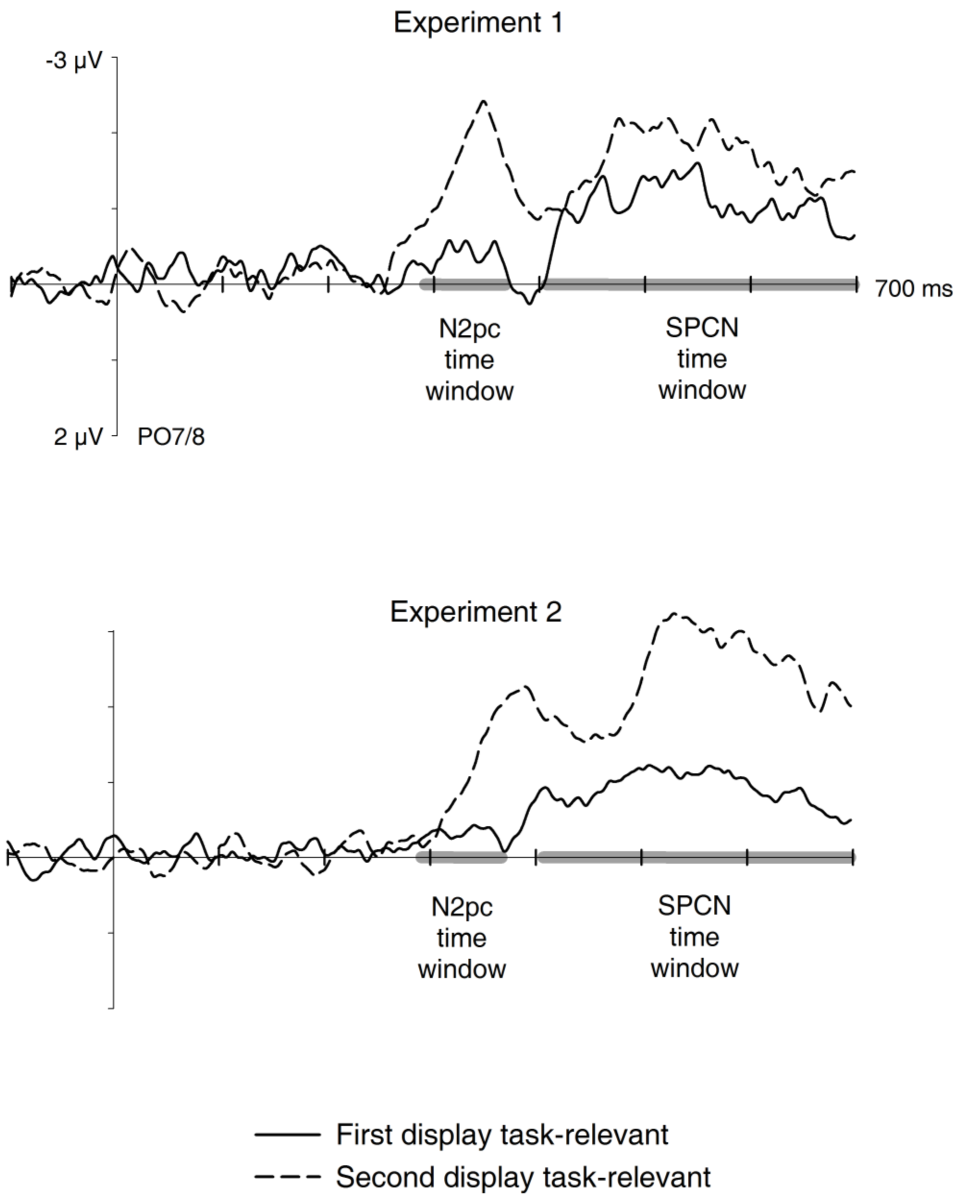
ERPs to first and second horizontal targets



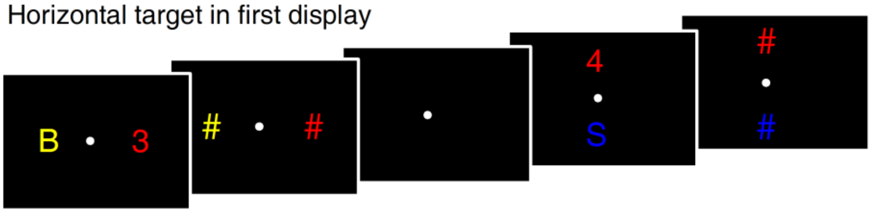
Difference waveforms



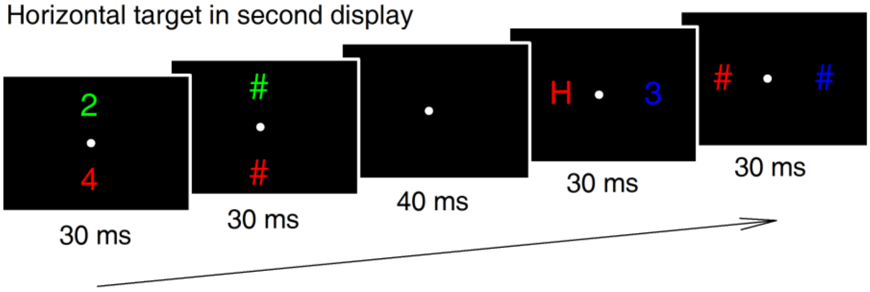
Difference waveforms to horizontal targets in second display



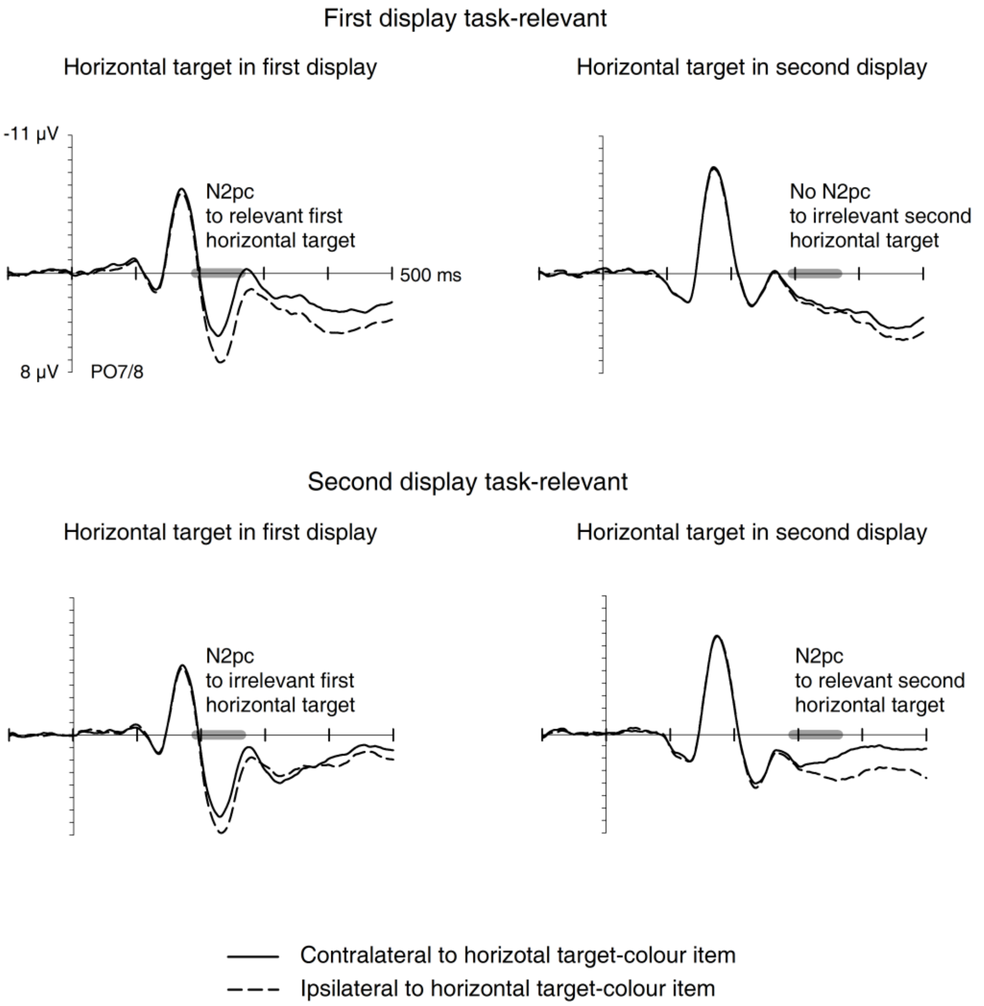
Horizontal target in first display



Horizontal target in second display



ERPs to first and second horizontal targets



Difference waveforms