Target switch costs in visual search arise during the preparatory activation of target templates

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Abstract

Prior research on task switching has shown that the reconfiguration of stimulus-response mappings across trials is associated with behavioural switch costs. Here, we investigated the effects of switching representations of target-defining features in visual search (attentional templates). Participants searched for one of two colour-defined target objects that changed predictably every two trials (Experiment 1) or every four trials (Experiment 2). Substantial costs were observed for search performance on target switch relative to target repeat trials. Preparatory target template activation processes were tracked by measuring N2pc components (indicative of attentional capture) to a rapid series of task-irrelevant colour singleton probes that appeared during the interval between search displays, and either matched the currently relevant or the other target colour. N2pcs to relevant target colour probes emerged from 800ms before search display onset on target repetition trials, reflecting the activation of a corresponding colour template. Crucially, probe N2pcs only emerged immediately before target onset on target switch trials, indicating that preparatory template activation was strongly delayed. In contrast, irrelevant colour singleton probes did not trigger N2pcs on either repeat or switch trials, suggesting the absence of any target template inertia across trials. These results show that switching the identity of search targets delays preparatory target template activation and impairs subsequent attentional guidance processes. They suggest that performance costs on switch versus repeat trials are associated with differences in the time course of task preparation.

Key words

Selective attention, Visual search, Task switching, Attentional templates, Event-related potentials, N2pc

1 Introduction

The ability to change cognitive task settings and behavioural responses when this is required by a change in circumstances is a central function of human cognitive control (e.g., Shallice & Cooper, 2011). The evolution of cognitive control mechanisms has enabled humans to interact with the external world flexibly and adaptively, in ways that sets us apart from all other animals. In the lab, this remarkable ability is often studied by investigating how humans prepare to perform a specific task, and how they reconfigure a particular task set when their goals change. The task switch paradigm (Jersild, 1927; Allport, Styles, & Hsieh, 1994) has become a popular tool to explore the mechanisms involved in activating specific task sets and changing them when needed. In a typical task-switching experiment, participants are instructed to perform one of two possible tasks. On any given trial, the task either repeats or switches relative to the previous trial. The crucial finding in such experiments is that response times (RTs) are slower and errors often more frequent on switch trials as compared to repeat trials ("switch costs"; see Monsell, 2003; Vandierendonck, Liefooghe, & Verbruggen, 2010; Kiesel et al., 2010, for reviews).

The mechanisms that produce such switch costs have been investigated extensively because it is assumed that these costs reflect the operation of domain-general cognitive control processes that are involved in the selection and coordination of many different types of tasks. One widely used procedure to study task switches is the alternating-runs paradigm, where participants perform two tasks in a constant order (e.g., AABBAABB, see Rogers & Monsell, 1995). The comparison of trials where a task is repeated and trials where it changed revealed substantial behavioural switch costs, in spite of the fact that task switches were fully predictable. Such costs are assumed to reflect the time demands of preparatory endogenous

task-set reconfiguration processes (e.g., Monsell, Yeung, & Azuma, 2000; Meiran, Chorev, & Sapir, 2000). The observation that these costs become smaller but remain reliably present even when participants are given several seconds to prepare for each task (Rogers & Monsell, 1995) suggests that task switching cannot be fully completed on the basis of purely endogenous preparation mechanisms, but also includes a stimulus-driven component. To fully establish a task set, a new task has to be performed at least once (see also Rubinstein, Meyer, & Evans, 2001). In line with this hypothesis, experiments with longer alternating runs (e.g., AAAABBBB in Monsell, Sumner, & Waters, 2003) have found performance costs only for the first trial after a switch, but not on subsequent trials of the same run. It has also been suggested that such costs may emerge more passively, as a result of the persistence of a previously active task set (task-set inertia; e.g., Allport & Wylie, 1999). Any persisting irrelevant task set activation may interfere with the operation of a new task set, and thus produce switch costs that are unrelated to the preparatory activation of the other task (see Kiesel et al., 2010, for further discussion). Active endogenous task-set reconfiguration and passive task-set inertia are not mutually exclusive; it is possible that both contribute to empirically observed switch costs (Monsell, 2003; see also Imburgio & Orr, 2021).

Most previous investigations of the processes involved in switching between task sets used procedures where tasks were defined in terms of the rules that associate particular stimuli and responses (e.g., categorising digits with respect to their magnitude or parity, or categorising words in terms of their meaning or colour). However, there are many different types of task sets, which raises the question how task switching operates in such different contexts. For example, an important function of cognitive control is the guidance of selective attention in line with current intentions, which requires task sets that specify the relevance of particular objects or object features in a given context (e.g., Folk, Remington, & Johnston,

1992). For example, in visual search tasks, where multiple stimuli are present in a single display, targets are defined by one or more attributes that distinguish them from distractors. Such target-defining features are usually known in advance and are assumed to be represented as attentional templates (e.g., Duncan & Humphreys, 1992). Such templates can be activated prior to the onset of a search display, in order to guide attention to objects with target-matching features and facilitate the detection of search targets. Target templates are a particular type of task set that specifies object attributes that are relevant for current search goals, rather than mappings between stimuli and responses, as investigated in most previous task switching experiments (see Rushworth et al., 2002, for a study where both types of task settings were combined). Thus, the question arises whether switching between target templates also induces behavioural switch costs, and which mechanisms are responsible for such costs.

Several previous visual search studies have used tasks where participants had to find one of several possible target objects, and these studies have typically revealed performance costs on trials where the identity of the target changed relative to target repetition trials (e.g., Christie, Livingstone, & McDonald, 2015, Experiment 2; Found & Müller, 2004; Juola, Botella, & Palacios, 2004; Olivers & Meeter, 2006; Dombrowe, Donk, & Olivers, 2011; Grubert & Eimer, 2013). It remains unknown which mechanisms are responsible for these target switch costs, and at which stage they are generated (see Ort & Olivers, 2020, for discussion). Because target identity changed unpredictably across trials in most of these previous studies, participants could not strategically activate a particular target template while preparing for the next search episode. However, in tasks where the identity of an upcoming search target is predictable, target switch costs may be produced by processes that take place during the search preparation period, analogous to the processes investigated in standard task switching

experiments. They could be the result of less efficient endogenous template activation prior to target switch versus repeat trials. Such template switch costs would be analogous to the endogenous task-set reconfiguration processes postulated in the task switching literature (e.g., Monsell, Yeung, & Azuma, 2000). But target switch costs could also be produced by the persistence of a previously active target template (i.e., task-set inertia; e.g., Allport & Wylie, 1999) interfering with the activation of the currently relevant template.

To investigate these possibilities, search tasks have to be employed where target switch and target repeat trials are fully predictable. The goal of the present study was to use such tasks in order to obtain new insights into preparatory target template activation and reconfiguration processes in visual search. To track target template activation processes in real time, we employed a rapid serial probe presentation (RSPP) paradigm that we used in several previous studies (Grubert & Eimer, 2018; 2020; 2023). In these experiments, participants searched for targets defined by a specific constant colour. Search displays were preceded by a series of irrelevant probe displays that appeared in rapid succession throughout the interval between successive search displays. Some of these probe displays included a colour singleton item that matched the current target colour. These colour probes will capture attention only when a corresponding target colour template is active, but not at other times. To track the time course of target template activation by measuring probe-induced attentional capture, we recorded event-related potentials (ERPs) and computed N2pc components separately for each successive probe presented between two search displays. The N2pc is a negativity at posterior scalp electrodes triggered contralateral to attended objects in multi-stimulus displays. It usually emerges about 200ms after stimulus onset, is generated in ventral extrastriate visual areas (Hopf et al., 2000), and reflects the rapid allocation of attention to candidate target objects (e.g., Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999;

see Eimer, 2014, for a review). In our previous RSPP experiments, target colour probes triggered N2pc components from about 1000ms prior to the onset of the next search display, indicating that a corresponding colour template was active during this period. Manipulating the predictable interval between two search displays changed the temporal pattern of probe N2pcs (Grubert & Eimer, 2018). They were triggered earlier when this interval was short than when it was longer, demonstrating that target template activation processes are sensitive to temporal expectations about search display onset. Importantly, no probe N2pcs were elicited by colour singleton probes that did not match the current target colour.

In one previous experiment (Grubert & Eimer, 2020), we employed this probe procedure in a task where observers searched for one of two colour-defined targets. Target identity swapped on each trial (ABAB) and probes matching either of these two colours were randomly intermixed. Here, N2pcs emerged for both target colour probes during search preparation, indicating that both colour templates were active concurrently, even though only one of them was relevant for the next search episode. The co-activation of both templates in this experiment might have been a strategic choice, as target colour changed on every trial (see also Grubert et al., 2017). Alternatively, it could have been the result of task-set inertia, that is, the persistence of the target colour template that was relevant on the preceding trial, analogous to the persistence of previously relevant stimulus-response mappings postulated by Allport and Wylie (1999).

The ABAB design employed in this previous experiment (Grubert & Eimer, 2020) did not allow to compare and contrast target template activation processes prior to target switch and target repeat trials. In the current study, we therefore used an alternating-runs procedure analogous to Rogers and Monsell (1995). As before, search displays included one of two

possible colour-defined targets, but target identity now either repeated or switched across successive trials, in a fully predictable fashion. This allowed participants to activate a corresponding target colour template in a preparatory fashion prior to the presentation of each search display. In Experiment 1, the target identity changed every second trial (i.e., AABB), so that target colour repetitions and switches occurred on half of all trials. Colour singleton probe displays were presented every 200ms in the interval between two search displays, and each singleton probe was equally likely to match either of the two possible target colours (see Figure 1 for illustration).

With this AABB design, we could measure behavioural template switch costs for search performance, and also track the activation of both target colour templates, separately for target switch and target repeat trials. Analogous to the findings by Rogers and Monsell (1995), we expected RTs to be slower and error rates higher on switch relative to repeat trials. The critical new question was whether target template activation processes observed during the preparation for the upcoming search episode would also differ between these two types of trials, as reflected by systematic differences in the pattern of probe N2pc components. If there are switch costs for the activation of the colour template that is relevant for the next search display, this should be indicated by a delay in the emergence of N2pc components triggered by the corresponding colour singleton probes on switch as compared to repeat trials, and/or an attenuation of N2pc amplitudes on switch trials. Furthermore, the presence of task-set inertia should be reflected by the presence of N2pcs in response to singleton probes that match the currently irrelevant target colour, indicating the persistent activation of the corresponding target template. Such an effect should be primarily or even exclusively observed prior to target switch trials.

2 Experiment 1

2.1 Methods

2.1.1 Participants

Twenty-two paid participants were tested in Experiment 1. The experiment was approved by the Ethics Committee of the Psychology Department at Durham University and was conducted in accordance with the Declaration of Helsinki. Participants gave informed written consent prior to testing. Four participants were excluded from analysis due to excessive eye movement artefacts (>40% of trials were lost during artefact rejection). The remaining 18 participants were between 19 and 47 years of age (mean=30.5, SD=8.6). Fourteen participants were female and four were male. All participants were right-handed and had normal or corrected-to-normal vision and normal colour vision (tested with the Ishihara colour vision test; Ishihara, 1972). The sample size of 18 was calculated by means of an a priori power analysis using MorePower 6.0.1 (Campbell & Thompson, 2012) to detect an interaction in a 2x2x7x2 factorial repeated measures ANOVA (within-subjects) with an assumed alpha of .05, power of .85, and a large effect size of 0.80[1].

2.1.2 Stimuli and procedures

Participants were sat in a dimly lit and sound attenuated Faraday cage with a 90cm viewing distance from the monitor. Stimuli were presented on a 22-inch MSI Optix G272 LCD monitor with a 100-Hz refresh rate and a resolution of 1920×1080 pixels. PsychoPy (psychophysics software in Python; Peirce et al., 2019) was used on an LG Pentium PC running

[1] *A large effect size was expected to replicate partial eta squared values (η_p^2) of .14, which we measured in a previous RSPP experiment in which participants searched for two alternating target colours (3-way interaction between Laterality*Probe type*Probe number in Experiment 1 of Grubert & Eimer, 2020; p.1531).).*

under Windows 10 to control stimulus presentation, timing, and response collection. Figure 1 illustrates the time course of stimulus events. All stimuli were presented on a black background with a constant central grey fixation point (CIE x,y colour coordinates: .327/.348; 0.2°x0.2° of visual angle). Each block contained 12 trials with eight stimulus displays that were presented in a continuous serial presentation stream. Each stimulus display was presented for 50ms and followed by a 150ms blank (200ms stimulus onset asynchrony; SOA). The first seven displays in each trial each contained a probe display (probes 1 to 7), the eighth displays contained both the response-relevant search display and a probe display (probe S[earch] [2]).

Search arrays were presented at an eccentricity of 1.4° from central fixation and contained six vertically (0.2°x0.6°) or horizontally (0.6°x0.2°) oriented bars at the 1, 3, 5, 7, 9, and 11 o'clock positions of an imaginary circular clock face. The orientations of the six bars were selected independently and randomly in each search display. Each bar had a different colour which was randomly allocated from the set of red (.610/.321), green (.273/.624), blue (.172/.181), yellow (.435/.490), cyan (.222/.313), and pink (.483/.246). All colours were equiluminant (~11.9cd/m^2). Each participant was assigned two of these colours as possible target colours. Each of the six possible target colour pairs (red/green, red/blue, red/yellow, green/blue, green/yellow, blue/yellow) was assigned to three participants. The other two colours (cyan and pink) served as nontarget colours only. Participants' task was to report the orientation (vertical/horizontal) of the target colour bar in each trial by pressing the up/down arrow keys on a standard keyboard. Critically, the response-relevant target colour switched after every second trial (e.g., red in trials 1 and 2, green in trials 3 and 4, red in trials 5 and 6,

[2] In our previous work (e.g., Grubert & Eimer, 2018), probes that were presented together with the search displays (probe S) never triggered reliable N2pc components. However, these probes were still included in the present experiments to maintain a temporally consistent visual pattern of probe presentations throughout each block.

etc.). Since search displays always contained both target colours participants had to keep track of the target colour sequence. There were no cues indicating the upcoming target colours during a block, but participants received a reminder about the target colour sequence and the first relevant target colour in the first trial of the new block in the block breaks. The target colour sequence (e.g., red/green or green/red) was randomised between participants but remained the same for each participant during the whole experiment. The locations of the two target colour bars were determined randomly and independently of each other in each trial. The response-to-key mapping (vertical/horizontal response on arrow up/down key) and the hand-to-key mapping (left/right hand on arrow up/down key) was counterbalanced across participants but was kept constant for each participant for the duration of the whole experiment.

Probe displays that were presented prior to search (probes 1-7) or together with search (probe S) contained six items composed of four closely aligned dots, two on the vertical, and two on the horizontal axis (0.1°x0.1° for each dot, 0.25°x0.25° for each four-dot probe item). The probe items were also presented at the 1, 3, 5, 7, 9, and 11 o'clock positions of an imaginary circular clock face, but closer to fixation (at an eccentricity of 0.5°) than the search bars. One of the probe items was a colour singleton that randomly matched one of the two possible target colours among five uniformly grey probe items. These grey probes were always equal in luminance to the colour singleton probe (~11.9cd/m^2). Probe singletons that matched the colour of the upcoming search target were *relevant target colour probes*, and probes that did not match this colour but instead the other possible target colour that was relevant before the last colour switch were *irrelevant target colour probes*. The probe singleton locations were selected randomly and independently in each probe display, with the following two restrictions: Successive singleton probes were equally likely to appear on same

or opposite display sides, but immediate repetitions of the exact probe location (on the imaginary clock face) were not allowed. As a result, each probe display was equally likely to be preceded and followed by probe displays that contained a colour singleton on the same or the opposite side. This was done to ensure that lateralised responses to any particular probe singleton would remain unaffected by any lateralised response triggered by singletons in temporally adjacent probe displays. Participants were informed that probe displays were task-irrelevant and should be ignored.

Experiment 1 contained 70 blocks of twelve trials each. Blocks were short to minimize the presence of blinks within each block. In each block, the twelfth search display was followed by seven additional probe displays to keep stimulus conditions during the post-target response interval identical across all trials in a block. Each block thus contained twelve search displays and 91 probe displays (13 for each of the seven probes). The first trial in each block was excluded from all analyses, because it could not be classified as a target colour repetition or switch trial. Each block therefore included six repetition and five switch trials. Before the experiment proper, participants practised the task until they felt comfortable with it (usually after two to four blocks). These data were not recorded.

2.1.3 EEG recording and data analyses

EEG was DC-recorded from 25 scalp sites (standard positions of the extended 10/20 system), sampled at 500Hz, and digitally low-pass filtered at 40Hz (no other filters were applied after data acquisition). Impedances were kept below 5kΩ. The left earlobe served as online reference during data acquisition, but all channels were re-referenced offline to linked earlobes. The EEG was segmented into 500ms time windows including a 100ms pre-stimulus baseline and a 400ms ERP time window following the onset of a particular stimulus display

(probes 1 to 7, search display). Data from the first and last seven probe displays in each block, and from trials with anticipatory (<200ms), very slow (>1500ms), missing or incorrect responses were excluded from analysis. So were segments that contained eye movements (±30µV in the bipolar HEOG channel), blinks (±60µV at Fpz), and muscular movements (±80µV in all channels). Artefact rejection resulted in an exclusion of 8.4% of all segments (SD=6.6%; ranging between 2.1% and 25.6% across participants). The remaining segments were averaged separately for each probe display (probes 1-7) in which the probes were in the left versus right hemifield. Separate averages were computed for relevant and irrelevant target colour probes in target colour repetition versus switch trials. In addition, averages were also computed for search displays with a target in the left or right hemifield.

N2pc components to probes were quantified based on ERP mean amplitudes obtained at lateral posterior electrodes PO7 and PO8, contralateral and ipsilateral to the side of a probe, within an 80ms time window starting at 190ms after the respective probe display onset. As in our previous work using analogous rapid serial probe presentation procedures (Grubert & Eimer, 2018), the start of this time window was determined by measuring the point in time (rounded to the nearest 10) when the ascending flank of the averaged probe N2pc (pooled across all relevant target colour probes in Experiment 1) reached 50% of the peak amplitude (at -0.10µV). N2pc components to target bars in the search displays were computed within the same 190-270ms post-stimulus time window for consistency. Target N2pc onset latencies were substantiated by means of jackknife-based procedures (Miller et al., 1998). Eighteen grand-average difference waves (contralateral minus ipsilateral ERPs at PO7/8) were computed separately for targets in colour repetition versus switch trials, each excluding one different participant from the original sample. N2pc onset latencies were defined as the point in time when each subsample difference wave reached an absolute onset criterion of -0.8µV

(50% of the peak amplitude of the pooled target N2pc in Experiment 1; see Grubert & Eimer, 2018, 2020, 2023, for identical procedures). All *t*-tests on jack-knifed N2pc onset latencies were power-corrected as suggested by Miller et al., (1998) and are denoted with t_c. Generally, all *t*-tests reported are two-tailed and Bonferroni and Greenhouse-Geisser corrected were necessary. Effect sizes are reported in terms of Cohen's *d* (Cohen, 1988), with a confidence interval of 95%, for *t*-tests, and partial eta squared (η_p^2) for *F*-tests and power corrected t_c-tests.

2.2 Results

2.2.1 Behavioural results

Trials with anticipatory (<200ms) or exceedingly slow (>1500ms) reaction times (RTs) were excluded from analysis (0.7% of all trials). Typical target colour switch costs were observed both in RTs and error rates (see Figure 2, top panel). Mean RTs were 54ms faster in target colour repetition (629ms) as compared to switch trials (683ms), $t(17)=5.8, p<.001, d=.67$, and error rates were 4.4% lower (6.5% vs 10.8%), respectively, $t(17)=6.1, p<.001, d=.95$.

2.2.2 N2pc components for probe displays

To measure the time course of template activation prior to search, N2pcs elicited by probes that matched the relevant (upcoming) or the irrelevant (previous) target colour were extracted by computing ERPs at posterior sites PO7/8, contralateral and ipsilateral to the side of a probe, separately for each of the seven successive probes in a trial (probes 1-7) in target colour repetition versus switch trials. For illustration, these ERPs are shown in Figure 3 for relevant target colour probes 1-7 in colour repetition trials. ERPs for all other types of probes are included in the Supplementary Materials. The time course of the successive probe N2pcs

is easier to see in Figures 4 and 5 which show probe N2pc difference waves (obtained by subtracting ipsi- from contralateral ERPs at PO7/8) in a temporally continuous fashion, separately for relevant (Figure 4) and irrelevant (Figure 5) target colour probes in colour repetition (top panels) and switch trials (bottom panels), respectively. Note that N2pc components were extracted individually for each probe (probes 1-7) and that Figures 4 and 5 were compiled to show these probe N2pcs in a successive fashion for illustration purposes only. Each figure starts with the activity triggered in response to probe 1 (100ms prior to 350ms after onset of probe 1) which was the first probe presented directly after a previous search display. For the subsequent probes (probes 2-7), 200ms intervals (150ms to 350ms after onset of each respective probe) are shown sequentially with interpolated data points between adjacent intervals. The onset of each probe is marked with a vertical line, and the N2pc time window for each probe (190-270ms post-stimulus) is shaded in grey. As probes were presented every 200ms, each individual probe was therefore presented within the N2pc time interval of its immediately preceding probe.

In line with our previous RSPP findings (Grubert & Eimer, 2018; 2020; 2023), Figure 4 (top panel) shows that relevant target colour probes triggered N2pc components at intermediate and late stages during the search preparation period. These N2pcs were largest for probe 7, just before the next search display. Probes that were presented earlier in the trial did not trigger any N2pcs. Importantly, this pattern looked fundamentally different when relevant target colour probes were presented in colour switch trials (Figure 4, bottom panel). Here, only probe 7, which immediately preceded the search display, triggered an N2pc, whereas no clear N2pc was present for any of the preceding probes. Furthermore, irrelevant target colour probes (Figure 5) never triggered any N2pcs, neither in colour repetition (top panel) nor switch trials (bottom panel).

Statistical analyses confirmed these informal observations. ERP mean amplitudes measured at PO7/8 in the 190-270ms post probe time windows were fed into a repeated-measures omnibus ANOVA with the factors Trial Type (colour repetition versus switch), Probe Colour (relevant versus irrelevant target colour probe), Probe Number (Probe 1, 2, 3, 4, 5, 6, 7), and Laterality (electrode contralateral versus ipsilateral to the hemifield of a probe). The main effect of Laterality just failed to reach significance, $F(1,17)=3.6$, $p=.076$, $\eta_p^2=.17$, but there was interaction between Laterality and Probe Number, $F(6,102)=7.0$, $p<.001$, $\eta_p^2=.29$, confirming that N2pc amplitudes differed between probes at different temporal positions. Laterality did interact with Trial Type and Probe Colour, $F(1,17)=5.0$, $p=.039$, $\eta_p^2=.23$, and there was also a significant four-way interaction, $F(7,98)=2.3$, $p=.034$, $\eta_p^2=.14$. This suggests that the temporal pattern of probe N2pcs differed between relevant and irrelevant target colour probes, and that this was further modulated by whether these probes were presented in colour repetition or switch trials.

To assess differences between colour repetition and switch trials more directly, two follow-up ANOVAs were conducted separately for relevant and irrelevant target colour probes, with the factors Trial Type (colour repetition versus switch), Probe Number (Probe 1-7), and Laterality (contralateral versus ipsilateral activity). For relevant target colour probes, there was a main effect of Laterality, $F(1,17)=5.2$, $p=.036$, $\eta_p^2=.23$, and an interaction between Laterality and Probe Number, $F(6,102)=10.6$, $p<.001$, $\eta_p^2=.40$, confirming that probe N2pc amplitudes differed across the preparation period. Importantly, there was also a significant three-way interaction, $F(6,102)=2.3$, $p=.043$, $\eta_p^2=.12$, indicating that the temporal pattern of probe N2pcs differed between target colour repetition versus switch trials. This was confirmed by follow-up ANOVAs comparing ipsi-and contralateral activity in colour repetition versus switch trials separately for each individual probe location. For probes 1, 2, and 3, there was no

reliable contralateral negativity, all $F(1,17)<1$, $p>.452$, $\eta_p^2<.03$, and no interactions involving the factor Laterality, all $F(1,17)<1.1$, $p>.327$, $\eta_p^2<.06$, confirming that these early relevant target colour probes did not trigger N2pcs, regardless of whether they were presented in colour repetition or swich trials. In contrast, Laterality did interact with Trial Type for relevant target colour probes 4, 5, and 6, all $F(1,17)>5.2$, $p<.037$, $\eta_p^2>.23$. These probes produced reliable N2pc components only in colour repetition trials (-0.34µV, -0.25µV, and -0.33µV, respectively), all $t(17)>2.5$, $p<.021$, $d>.27$, but not in colour switch trials, all $t(17)<1$, $p>.471$, $d<.01$. Finally, for probe 7, there was a main effect of Laterality, $F(1,17)=20.4$, $p<.001$, $\eta_p^2>.55$, but no interaction with Trial Type, $F(1,17)<1$, $p=.969$, $\eta_p^2<.01$. These probes triggered reliable N2pc components, both $t(17)>4.2$, $p=.001$, $d>.58$, which were virtually identical in size (-0.63µV), $t(17)<1$, $p>.969$, $d<.01$, irrespective of whether they were presented in colour repetition or switch trials.

The ANOVA for irrelevant target colour probes did not produce any reliable main effects or interactions involving the factor Laterality, all $F(1,17)<2.0$, $p>.084$, $\eta_p^2<.10$, confirming that none of these probes triggered an N2pc, regardless of whether they were presented in colour repetition or switch trials.

2.2.3 N2pc components in the search displays

N2pcs elicited by search targets in colour repetition versus switch trials were measured at PO7/8 in the 190-270ms time window after search display onset. These ERPs, together with the respective N2pc difference waves, are shown in Figure 6 (top panel). A repeated-measures ANOVA with the factors Trial Type (colour repetition versus switch) and Laterality (contralateral versus ipsilateral activity) revealed a main effect of Laterality, $F(1,17)=41.4$, $p<.001$, $\eta_p^2=.71$, and a significant interaction, $F(1,17)=12.9$, $p=.002$, $\eta_p^2=.43$, demonstrating

that reliable target N2pcs were triggered both in repeat and switch trials, both $t(17)>4.6$, $p<.001$, $d>.24$, but that N2pc amplitudes were larger in colour repetition trials (-1.2µV versus -0.8µV, respectively). Matching the behavioural RT pattern, the N2pc also emerged earlier in colour repetition as compared to colour switch trials (204ms versus 231ms), $t_c(17)=2.9$, $p=.012$, $\eta_p^2=.42$[3].

2.3 Discussion of Experiment 1

As expected, search performance was impaired on target switch as compared to target repeat trials, with slower RTs and higher error rates. The presence of such target switch costs is analogous to the costs observed for predictable changes of stimulus-response mappings (e.g., Rogers & Monsell, 1995). They also mirror the target switch costs observed in previous visual search tasks (e.g., Olivers & Meeter, 2006; Grubert & Eimer, 2013), and demonstrate that such costs occur even when a change of target identity is fully predictable. Notably, these behavioural costs were accompanied by corresponding modulations of N2pc components triggered by search targets on switch versus repeat trials. These N2pcs were smaller and emerged significantly later on switch trials, indicating that the allocation of attention to target objects was slower and less efficient on these trials.

The critical new finding of Experiment 1 concerned the temporal pattern of probe N2pc components observed prior to switch or repeat trials, which revealed clear switch-induced costs for the preparatory activation of target colour templates. On target repeat trials, this template was active from about 800ms prior to search display onset, as reflected by the presence of reliable N2pc components to singleton probes that matched this target colour

[3] The same jack-knifed onset latency analysis was also conducted with a relative onset criterion (50% of each subsample's peak amplitude, as recommended by Kiesel et al., 2008). Results were identical: Target N2pcs were faster in colour repetition (206ms) than switch trials (228ms), $t_c(17)=2.3$, $p=.040$, $\eta_p^2=.31$.

from probe 4 onwards. On target switch trials, the activation of the template for the new target colour was considerably delayed. Here, a reliable N2pc was only present for the target colour probe that immediately preceded the search display, but not for any earlier probe. This difference suggests that the need to change a colour-specific target template across successive trials delays the point in time at which this template is activated during search preparation.

This delay could in principle be caused by task-set inertia on switch trials, as the continued persistence of the previously relevant target template may interfere with the activation of a new template. However, the N2pc results of Experiment 1 provide no evidence for this hypothesis. Any continued activation of the target template for the currently irrelevant target colour should have been reflected by reliable N2pc components triggered by the corresponding colour singleton probe during the preparation period, in particular on switch trials. However, N2pcs for irrelevant target colour probes were entirely absent, not only on repeat but also on switch trials. Thus, there was no evidence that any task-set inertia across successive trials might have contributed to the observed switch costs.

The absence of any N2pcs for irrelevant target colour probes may seem surprising, given that our previous experiment which employed an ABAB design (Grubert & Eimer, 2020) observed clear N2pcs for probes that matched either the preceding or the upcoming target colour, indicating that both colour templates (including the template that was not relevant for the next search episode) were activated in parallel. Given this apparent discrepancy (which will be further considered in the General Discussion), it is important that the results of Experiment 1 are replicated before any firm conclusions about the factors responsible for search target switch costs can be drawn.

One goal of Experiment 2 was to provide such a replication. The other goal was to investigate the impact of the number of task repetitions on the activation of target templates and the possible emergence of task-set inertia. The task setup and experimental logic were the same as in Experiment 1, except that the length of each alternating run with the same search target colour was increased from two to four (i.e., AAAABBBB). As noted before, Monsell et al. (2003) employed an analogous manipulation and found behavioural switch costs only for the first trial after a switch, suggesting that task sets are fully established after a new task has been performed once. In Experiment 2, we investigated whether this also applies to switches between templates for target features.

To confirm the main results of Experiment 1, we first compared N2pc components triggered by relevant target colour probes on switch trials and on first colour repetition trials that immediately followed the target colour switch. The central question was whether the delay of preparatory target template activation on switch trials (as reflected by the later emergence of probe N2pcs) found in Experiment 1 would also be observed in Experiment 2.

The four-trial alternating runs procedure in Experiment 2 made it possible to investigate whether task-set inertia in target template activation might emerge when the previous template remained continuously relevant across multiple trials. If this was the case, evidence for inertia (i.e., reliable probe N2pcs for irrelevant target colour probes) might be observed for target switch trials in Experiment 2, as these trials where always preceded by four (as compared to two) trials where this colour was relevant. Furthermore, increasing the number of target colour repetitions might also differentially affect the activation of target colour templates across successive repeat trials. To test this, we compared the temporal

pattern of target colour probe N2pcs elicited prior to the first, second, and third colour repetition of a particular search target.

3 Experiment 2

3.1 Methods

3.1.1 Participants

Nineteen new participants were paid to participate in Experiment 2. All participant procedures were identical to Experiment 1. One participant was excluded due to excessive eye movement activity (>40% trials lost during artefact rejection). The remaining 18 participants were between 18 and 47 years of age (mean=27.5, SD=7.5). Fourteen participants were female and four were male. One participant was left-handed, the remaining 17 participants were right-handed. All participants had normal or corrected-to-normal vision and normal colour vision (as tested with Ishihara, 1972).

3.1.2 Stimuli and procedures

All experimental procedures were identical to Experiment 1 with the following exceptions: Each block now contained 16 trials and the response-relevant target colour switched after every fourth trial (e.g., red in trials 1-4, green in trials 5-8, red in trials 8-12, green in trials 13-16). Search displays contained both the relevant and irrelevant target colour bar together with four differently coloured nontarget bars of the colour set, as described in Experiment 1. As in Experiment 1, probes 1-7 and probes S were randomly shown in either of the two target colours and were either relevant target colour probes (that matched the upcoming target colour) or irrelevant target colour probes (that matched the previous target colour that was relevant before the last colour switch). Experiment 2 contained 64 blocks of

16 trials each. The sixteenth search display was followed by seven additional probe displays for constant response conditions, so that each block contained 16 search displays and 135 probe displays (17 for probes 1 to 7, and 16 for probe S).

3.1.3 EEG recording and data analyses

All EEG procedures were identical to Experiment 1. During artefact rejection, 3.3% of all segments were excluded from analysis in Experiment 2 (SD=2.3%; ranging between 0.9% and 9.4% across participants). Averaged ERP waveforms were computed for probes 1-7 in the left or right hemifield, separately for relevant and irrelevant target colour probes. Separate averages were computed for colour switch trials (i.e., the first trial with a new target colour after four successive trials with the other target colour), and for the 1st, 2nd, and 3rd colour repetition trial before a target colour switch. Apart from allowing the assessment of possible effects of successive target colour repetitions on target template activation, this also kept the signal-to-noise ratio equivalent across all types of trials. All data analysis procedures were identical to Experiment 1. In addition, Bayesian statistics (Rouder et al., 2009) were used in JASP to evaluate empirical evidence in favour of the null hypothesis. Substantial evidence for the null hypothesis is marked by Bayes factors (BF_{01}) > 3 (Jeffreys, 1961), indicating that the empirical data are more than three times more likely under the null hypothesis as compared to the alternative hypothesis.

3.2 Results

3.2.1 Behavioural results

After exclusion of all trials with anticipatory or slow responses (0.6% of all trials), RTs in correct trials and error rates were subjected to two repeated measures ANOVAs with the

factor trial type (1st colour repetition, 2nd colour repetition, 3rd colour repetition, versus colour switch). Both ANOVAs revealed main effects, both $F(3,51)>14.8$, $p<.001$, $\eta_p^2>.46$, indicating that RTs and error rates differed between these four types of trials. As can be seen in Figure 2 (bottom panel), RTs were slower and errors more frequent in colour switch trials (RT: 649ms; error rate: 9.1%) relative to trials where the target colour was repeated for the first, second or third time (RTs: 600ms, 607ms, and 608ms; error rates: 4.8%, 5.4%, and 5.2%). Follow-up t-tests confirmed that the corresponding RT and error rate differences were significant, all $t(17)>4.0$, $p<.007$, $d=.95$. In contrast, there were no further benefits for performance when the same target colour was repeated for the second or third time. RTs and error rates were numerically even higher for these trials relative to 1st colour repetition trials, but these differences were not reliable, all $t(17)<2.2$, $p>.222$, $d<.15$.

3.2.2 N2pc components for probe displays

Figure 7 shows probe N2pc difference waves (obtained by subtracting ipsi- from contralateral ERPs at PO7/8) in the same temporally continuous fashion as in Figures 4 and 5. The top and middle panel show N2pcs in response to relevant target colour probes in 1st target colour repetition and switch trials, respectively. The temporal pattern of probe N2pcs in these two types of trials was identical to the results observed in Experiment 1, with clear N2pcs emerging from probe 4 onwards on repetition trials, but only for probe 7 on switch trials. For relevant target colour probes 1-3, there was no main effect or interactions involving the factor Laterality, all $F(1,17)<1$, $p>.361$, $\eta_p^2<.05$, demonstrating that these early probes did not trigger any N2pcs. An ANOVA conducted for probes 4-6 produced a main effect of Laterality, $F(1,17)=7.2$, $p=.016$, $\eta_p^2=.30$, but importantly, also a significant interaction between Trial Type and Laterality, $F(1,17)=6.1$, $p=.024$, $\eta_p^2=.27$. Follow-up comparisons confirmed that relevant

target colour probes 4, 5, and 6 produced reliable N2pcs in 1st colour repetition trials (-0.3µV, -0.3µV, and -0.5µV, respectively), all $t(17)>2.2$, $p<.041$, $d>.10$, but not in colour switch trials, all $t(17)<1$, $p>.418$, $d<.01$. In contrast, and as in Experiment 1, relevant target colour probes 7 triggered reliable N2pcs both in colour repetition (-0.6µV) and switch trials (-0.5µV), both $t(17)>2.7$, $p>.014$, $d>.32$, which did not differ from each other, $t(17)<1$, $p>.375$, $d<.01$.

To assess the existence of target template inertia effects on switch trials after the same colour template had been involved in search preparation and target selection in four successive trials, we analysed N2pcs to irrelevant target colour probes on these trials (as shown in Figure 7, bottom panel). A repeated-measures ANOVA with the factors Probe Number (1-7) and Laterality, did not produce a main effect of Laterality, $F(1,17)<1$, $p=.944$, η_p^2 <.01, and also no interaction involving the factor Laterality, $F(6,102<1$, $p=.746$, η_p^2 =.03. In other words, there was no evidence for any residual activation of the corresponding colour template, even though this template had been activated in the four preceding trials[4]. Further support for the null hypothesis was provided by the corresponding Bayes factors for both the main effect, BF_{01}=4.9, and interaction, BF_{01}=20.0.

Finally, we also analysed possible effects of successive target colour repetitions on the activation of the corresponding relevant colour template. ERPs in response to relevant target colour probes in 1st, 2nd, and 3rd colour repetition trials were analysed in a repeated-measures ANOVA with the factors Trial Type (1st, 2nd, 3rd colour repetition), Probe Number (probe 1-7), and Laterality. Both the main effect of Laterality, $F(1,17)=5.4$, $p=.033$, η_p^2=.24, and the interaction between Probe Number and Laterality reached significance, $F(6,102)=4.3$, $p=.001$,

[4] As would be expected, there were also no N2pcs for irrelevant target colour probes on 1st, 2nd, and 3rd target colour repetition trials, i.e., no increased contralaterality at PO7/8 and no interactions involving the factor laterality, all $F<1$, $p>.336$, η_p^2 <.06. The corresponding continuous probe N2pc difference waveforms for these trials are included in the Supplementary Materials, for completeness.

η_p^2=.20, reflecting the absence of N2pcs for early probes (see above). However, and importantly, Trial Type did not interact with Probe Number and Laterality, $F(1,17)<1$, p=.965, η_p^2=.02, BF_{01}=172.2, demonstrating that successive repetitions of the same target colour did not affect the temporal pattern probe N2pcs during search preparation. The continuous N2pc difference waves in response to relevant target colour probes on 2nd and 3rd colour repetition trials are included in the Supplementary Materials.

3.2.3 N2pc components in the search displays

Target N2pcs in colour repetition versus switch trials are shown in Figure 6 (bottom panel). To equate the signal-to-noise ratio between the two trial types, only 1st colour repetition trials were included in the target N2pc analyses. A repeated-measures ANOVA with the factors Trial Type (1st colour repetition versus switch) and Laterality (contralateral versus ipsilateral activity) revealed a main effect of Laterality, $F(1,17)=32.93$, $p<.001$, η_p^2=.66, and a significant interaction, $F(1,17)=12.2$, p=.003, η_p^2=.42. Substantial N2pcs were triggered both in colour repetition and switch trials, both $t(17)>4.1$, $p<.002$, $d>.33$, but N2pcs triggered in colour repetition than switch trials were larger (-1.1µV versus -0.6µV, respectively). N2pcs in colour repetition as compared to switch trials were also triggered earlier (218ms versus 245ms), $t_c(17)=4.1$, p=.001, η_p^2=.59[5].

3.3 Discussion of Experiment 2

The results of Experiment 2 were clear-cut. First, and most importantly, the pattern of probe N2pc components observed on target colour switch and repetition trials fully confirmed the results of Experiment 1. Again, probe N2pcs were reliably present on switch trials only for

[5] The same latency analysis with a relative 50% onset criterion also revealed faster target N2pcs in colour repetition (228ms) than switch trials (242ms), $t_c(17)=2.4$, p=.028, η_p^2=.34." (p.18)

the probe display that immediately preceded the search display. In contrast, they emerged from probe 4 onwards on the first repeat trial following a target switch. Behaviourally, there were again clear behavioural performance costs on target switch relative to target repeat trials, and these costs were again mirrored by smaller and delayed target N2pc components on switch trials. Notably, there were no further performance improvements for the second and third repetition of a given target colour relative to its first repetition. This is in line with the results found by Monsell et al. (2003) for successive repetitions of S-R mappings, and suggests that analogous to such mappings, target templates are also fully activated after they have been used once to guide target selection. Further support for this conclusion comes from the comparison of probe N2pcs on successive target colour repetition trials in Experiment 2, which found no difference in preparatory template activation prior to the first, second, and third repetition of a particular target.

Finally, Experiment 2 obtained no evidence for any task-set inertia effects for target template activation processes on switch trials. Even though the previous target colour had been relevant on four successive trials, there was no indication that the corresponding colour template was partially activated on switch trials. Analogous to Experiment 1, there were no N2pc components in response to irrelevant target colour probes at any point during the preparation period, indicating that these probes failed to attract attention throughout this interval.

4 General Discussion

The goal of the present study was to provide new insights into the mechanisms involved in switching target templates in visual search. In tasks where observers search for one of several possible target objects, performance may be impaired on trials where the

identity of the target changes relative to target repeat trials, even when the identity of the next target is fully predictable. Such search target switch costs might be similar to the behavioural task switch costs observed in many previous experiments (e.g., Monsell, 2003), in that they are produced, at least in part, by processes that operate during the preparation for an upcoming task. Preparatory target template activation processes might differ between target switch and target repeat trials, and this could result in performance costs, analogous to the task-set reconfiguration mechanisms investigated in previous research on task switching (e.g., Rogers & Monsell, 1995).

To compare and contrast preparatory target template activation processes on target switch and repeat trials, we employed the alternating runs procedure introduced by Rogers and Monsell (1995). Participants searched for targets that were defined by one of two possible colours, which changed predictably on every second trial (Experiment 1) or every fourth trial (Experiment 2). To track target template activation in real time, N2pc components were recorded in response to brief probe displays which appeared in rapid succession between search displays, and contained a colour singleton item that either matched the upcoming target colour or the other currently irrelevant colour.

Similar to our previous studies that employed analogous RSPP procedures (Grubert & Eimer, 2018; 2020; 2023), probes that matched the fully predictable upcoming target colour triggered N2pc components when they appeared during the 800ms interval prior to the arrival of the next search display. This temporal pattern was observed prior to target colour repetition trials. It demonstrates that these probes attracted attention, and that a corresponding colour-specific target template was active at the moment when they were presented. This is in line with previous experiments where observers always searched for a single colour-defined target

(e.g., Grubert & Eimer, 2018) and shows that target templates are activated in a transient fashion during the preparation for each new search episode. The critical new finding of the present study was that the emergence of probe N2pc components was strongly delayed prior to target colour switch trials. Here, an N2pc was only observed for the final probe display that appeared 200ms prior to search display onset, but not in response to any of the preceding probes. This temporal dissociation in the pattern of probe N2pcs between target colour switch and repetition trials was observed in Experiment 1, and was replicated in Experiment 2, where the length of alternating runs was increased from two to four trials.

The marked difference in the temporal pattern of target colour probe N2pcs elicited prior to the onset of the next search display on target colour switch versus repetition trials strongly suggests that target templates are activated at a later point in time during the preparation for a target switch trial relative to a target repeat trial. The delayed emergence of target colour probe N2pcs on colour switch trials might reflect the time demands of target template reconfiguration processes, analogous to the task-set reconfiguration processes studied by Rogers and Monsell (1995). There were also clear behavioural target switch costs in both experiments, for RTs as well as error rates (see also Olivers & Meeter, 2006; Grubert & Eimer, 2013, for similar observations), in spite of the fact that the identity of the next target was fully predictable on all trials, and sufficient time was available between search displays to activate a corresponding target colour template. The delay of N2pc components to target colour probes on switch as compared to repetition trials observed in both experiments (about 600ms) was considerably larger than the switch costs for RTs (about 50ms) and target N2pc onset latencies (25-30ms). This delay was also larger than the template switch times estimated by Dombrowe et al. (2011) in an eye tracking study on the basis of saccade accuracy and latency on target colour switch versus repetition trials (about 250ms). These differences

suggest that task switching has substantially stronger effects on the time course of preparatory search template activation than on the timing of subsequent attentional guidance and target selection processes.

In spite of differences in their magnitude, it is plausible to assume that behavioural target colour switch costs are at least in part the result of temporal template switch costs (i.e., delayed activation of target templates on switch trials) during the search preparation period. Alternatively, both these costs could also have been produced by a form of task-set inertia (e.g., Allport & Wylie, 1999), that is, a competition between the currently relevant target colour template and the residual activation of the previously relevant colour template. Such template inertia effects will be reflected by the presence of N2pc components to singleton probes that match the irrelevant target colour. These N2pcs should have been observed specifically on target switch trials, indicating that the corresponding colour template remained partially activated on these trials. However, no evidence for the presence of any target template inertia was found in either experiment. Singleton probes that matched the currently irrelevant target colour did not trigger N2pc components on switch trials at any point during the preparation interval. This was the case in Experiment 1 for switch trials that followed two repetitions of the other target colour, and in Experiment 2 after four repetitions of the other target colour. These observations strongly suggest that target template activation processes were colour-selective throughout, without any residual template inertia on target switch trials[6]. Thus, the presence of performance costs and the delay of target colour probe N2pcs on these trials cannot be attributed to any residual activation of previously relevant colour

[6] The absence of any N2pcs to singleton probes that matched the currently irrelevant target colour also demonstrates that probe N2pc components were not associated with any salience-driven exogenous attentional capture triggered by colour singletons in probe displays (see also Grubert & Eimer, 2018, 2023, for further demonstrations that distractor-colour singleton probes do not trigger N2pcs).

templates. In other words, search templates were switched off rapidly and fully during the preparation period of switch trials (see also Grubert et al., 2017; Olivers & Eimer, 2011, for additional electrophysiological and behavioural evidence for a fast de-activation of target templates that are no longer relevant).

The complete absence of N2pc components to irrelevant target colour probes in the current study may seem surprising, given that a previous study (Grubert & Eimer, 2020) obtained clear evidence for the parallel activation of two colour templates during search preparation. In this earlier study, two target colours alternated across successive trials, and probes that matched the previous or the upcoming target colour both triggered reliable N2pcs during the preparation period. In contrast to this study, where all trials were effectively target switch trials, the current experiments used an alternating runs procedure with predictable target switch and repeat trials. This difference may have resulted in observers adopting different search preparation strategies. Both target templates may have been activated concurrently when target colours swapped between consecutive trials, whereas only the relevant target colour template may be activated during search preparation when search targets always repeat at least once. It is interesting to note that observers chose to activate only the current target template in the current study, even though this single-template strategy resulted in sizeable behavioural costs on target switch trials. It is possible that maintaining a single template is less demanding than the co-activation of two templates, and/or that any performance costs on switch trials are compensated for by substantial benefits on target colour repetition trials. The availability of different target template activation strategies, the factors that determine which strategy will be adopted in a particular task context, and the behavioural consequences of these choices, need to be investigated systematically in future research.

A crucial question posed by the present results concerns the relationship between the target template switch costs observed during the preparation for search and the target switch costs found for search performance. The temporal pattern of relevant target colour probe N2pcs observed in both experiments shows that preparatory target templates are activated earlier on colour repetition as compared to switch trials. However, these templates appeared to have been activated equally strongly on colour repetition and switch trials immediately prior to the presentation of the next search display, as reflected by the absence of any amplitude differences of the N2pc to probe 7. If target templates were equally active on all trials at the moment a search display was presented, it would be reasonable to assume that there should be no systematic difference in their ability to guide attention towards target locations. In fact, the pattern of target N2pc components suggested that this was not the case, and that search guidance was more effective on repeat trials. In both experiments, target N2pcs were smaller and emerged significantly later on colour switch as compared to repetition trials, indicative of target switch costs at the level of template-guided attentional target selection. These observations suggest that the quality of search guidance may not be exclusively determined by the activation state of a target template when the search display is presented but is also affected by the temporal profile of template activation processes. Guidance appears to be more effective when the relevant target colour template has been activated earlier.

It should also be noted that the preparation for search does not just involve the activation of templates for target-defining features such as colour, but also the activation of templates for response-relevant features (e.g., target orientation, as in the present study). Observers are only fully prepared for an upcoming search task when both a template for the guidance of search and a template for target discrimination and response selection are

activated (see Wolfe, 2023, for a similar distinction between guiding and target templates). Preparatory guidance templates may generally be activated prior to target templates because they are required for the guidance of attention at an early stage of the upcoming search process. If this is the case, the delayed activation of guidance templates observed in the current study on switch trials may be accompanied by an even later activation of target templates. This could result in costs for target identification and response selection on switch relative to repeat trials. In short, switch-related delays of preparatory target template activation processes could affect both the guidance of attention and the subsequent processing of target objects, and behavioural target switch costs could be generated at either or both of these stages.

In summary, the current study obtained new insights into the mechanisms involved in the preparatory activation of search target templates and the switch between templates across successive trials. Using on-line electrophysiological markers of target template activation, we demonstrated strong temporal template switch costs during search preparation, reflected by considerable delays in the activation of target colour templates on switch trials. In contrast, there was no evidence that any target template inertia on switch trials could have contributed to the target switch costs observed for search performance. We suggest that the delay in the activation of target templates on switch trials can adversely affect early attentional guidance mechanisms as well as subsequent target identification and response selection processes.

Data Availability

The data supporting the findings of this study are available upon request.

Author Contributions

AG: Conceptualisation, Operationalisation, Data Analysis, Manuscript Preparation; ZW: Data Acquisition, Manuscript Preparation; ME: Conceptualisation, Operationalisation, Manuscript Preparation

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Declaration of Competing interests

The authors report no conflict of interest.

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Figures

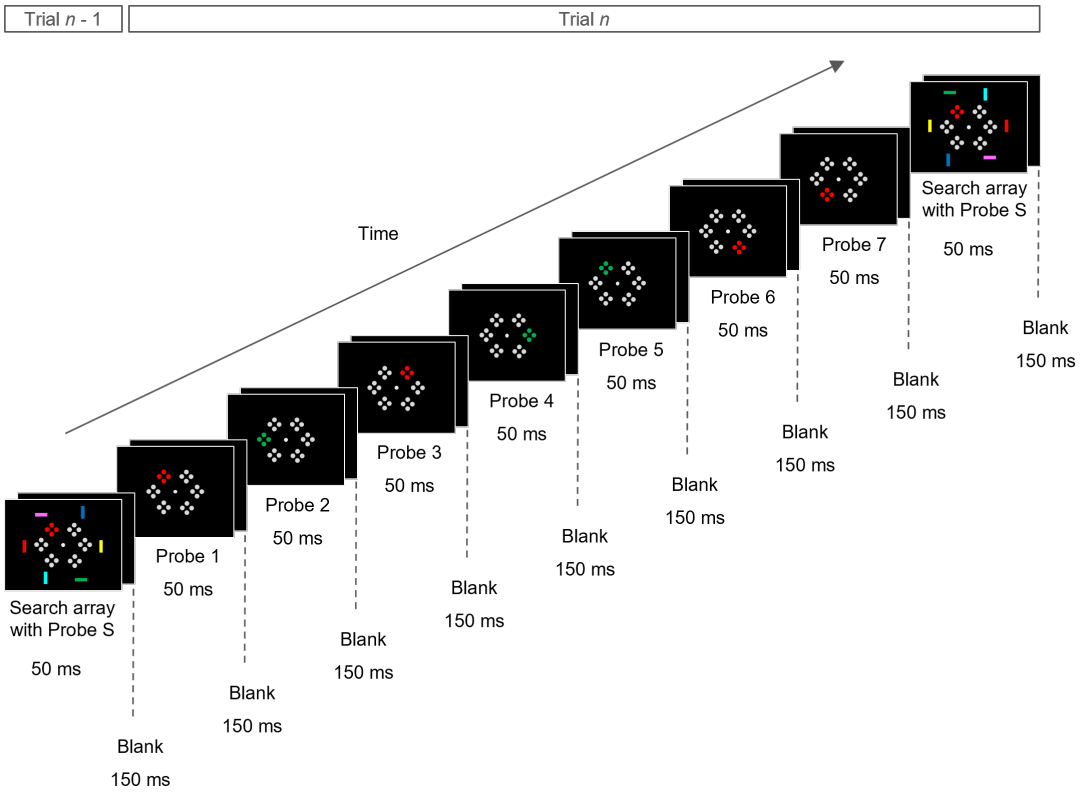

Figure 1. Schematic illustration of the stimuli and presentation times in Experiment 1 and 2. Search displays contained two colour-defined target bars (e.g., red, green) and four nontarget bars in four different nontarget colours (e.g., blue, yellow, pick, cyan). Importantly, only one of the two target colour bars was response relevant in each trial. In Experiment 1, the colour of the response relevant target changed after every second trial (e.g., red in trials 1-2, green in trials 3-4, red in trials 5-6, etc.), while it changed after every fourth trial in Experiment 2 (e.g., red in trials 1-4, green in trials 5-8, red in trials 8-12, etc.). Probe displays contained a colour singleton that randomly matched one of the two possible target colours amongst five grey items. Probe displays were presented every 200ms in the interval between two search displays (probes 1-7) and simultaneously with a search display (probe S). The items in the probe and search arrays were arranged on imaginary circles at an eccentricity of 0.5° and 1.4° from central fixation, respectively.

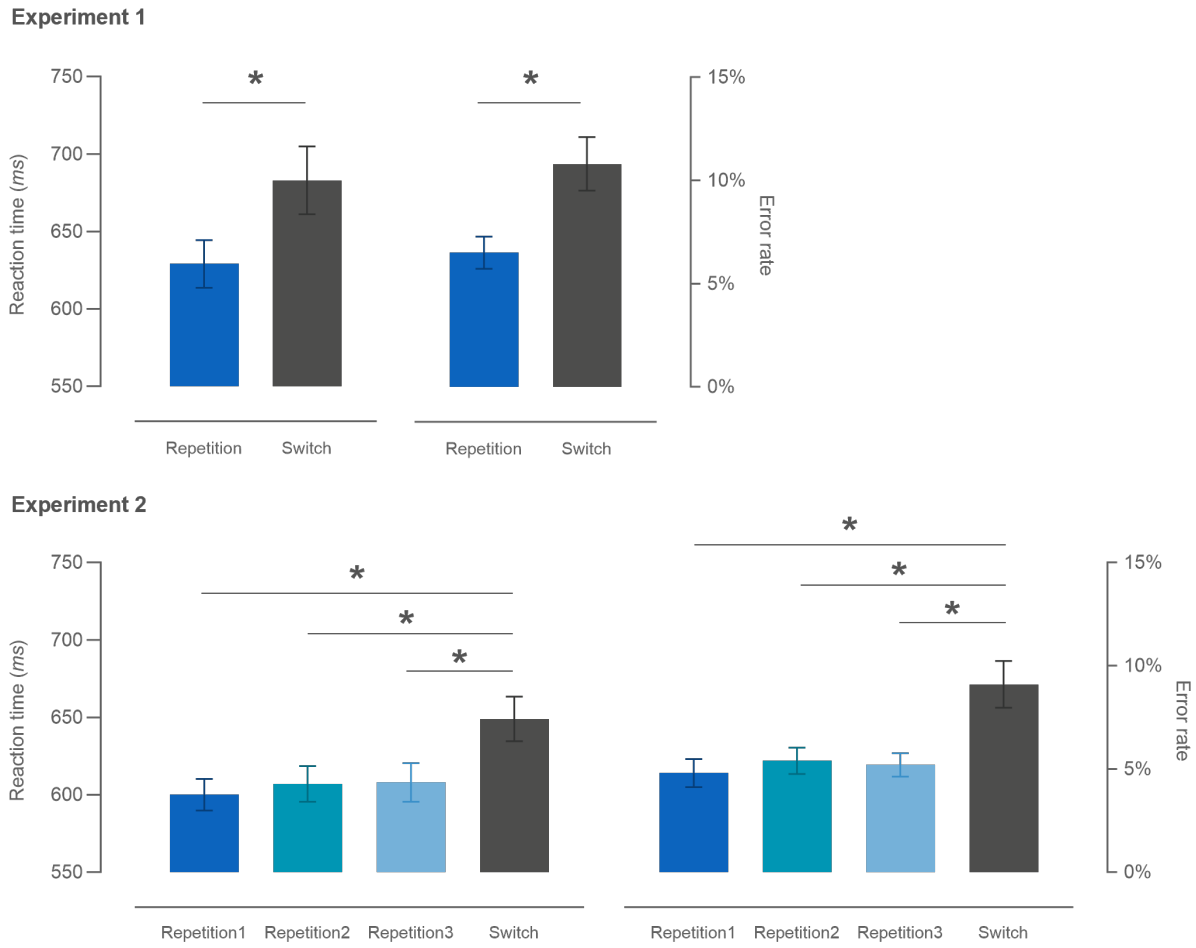

Figure 2. Reaction times (measured in milliseconds; left axes) and error rates (percentage of all trials; right axes) measured in colour repetition versus switch trials of Experiment 1 (top panel) and 1st, 2nd, and 3rd colour repetition trials versus switch trials in Experiment 2 (bottom panel). Statistically reliable differences are marked by asterisks.

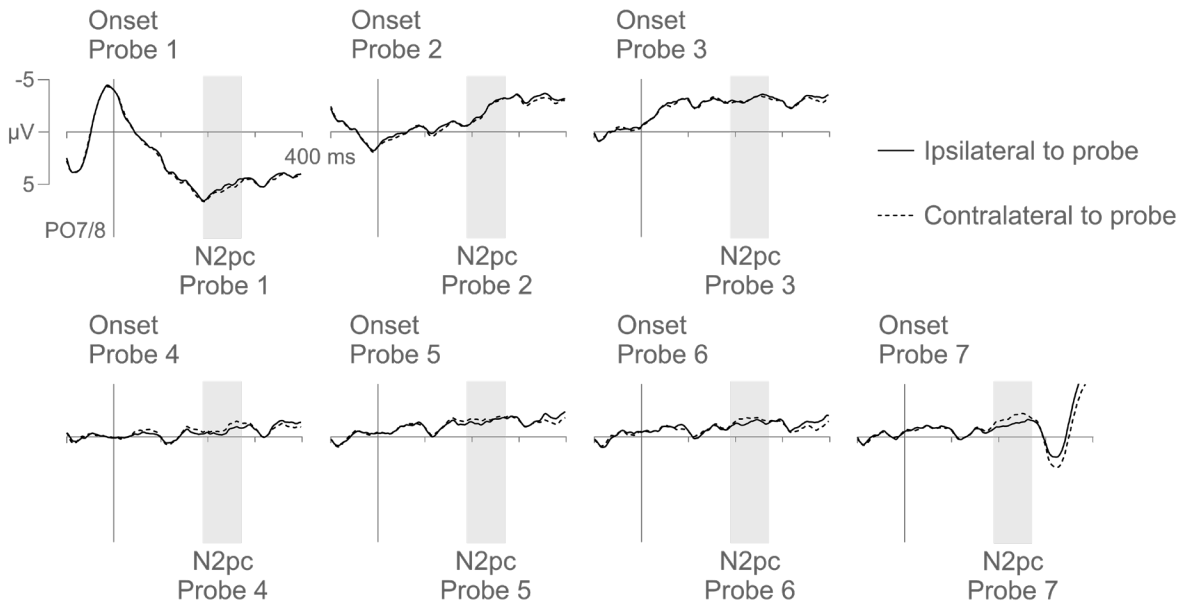

Figure 3. Grand-averaged ERPs elicited by relevant target colour probes in colour repetition trials of Experiment 1 at electrodes PO7/8 contralateral and ipsilateral to colour singleton probes in each of the seven probe displays presented between consecutive search displays. Probe 1 is the first probe to follow the previous search display and probe 7 is the probe to immediately precede the next search display. Shaded areas mark N2pc time windows (190-270ms after onset of each individual probe).

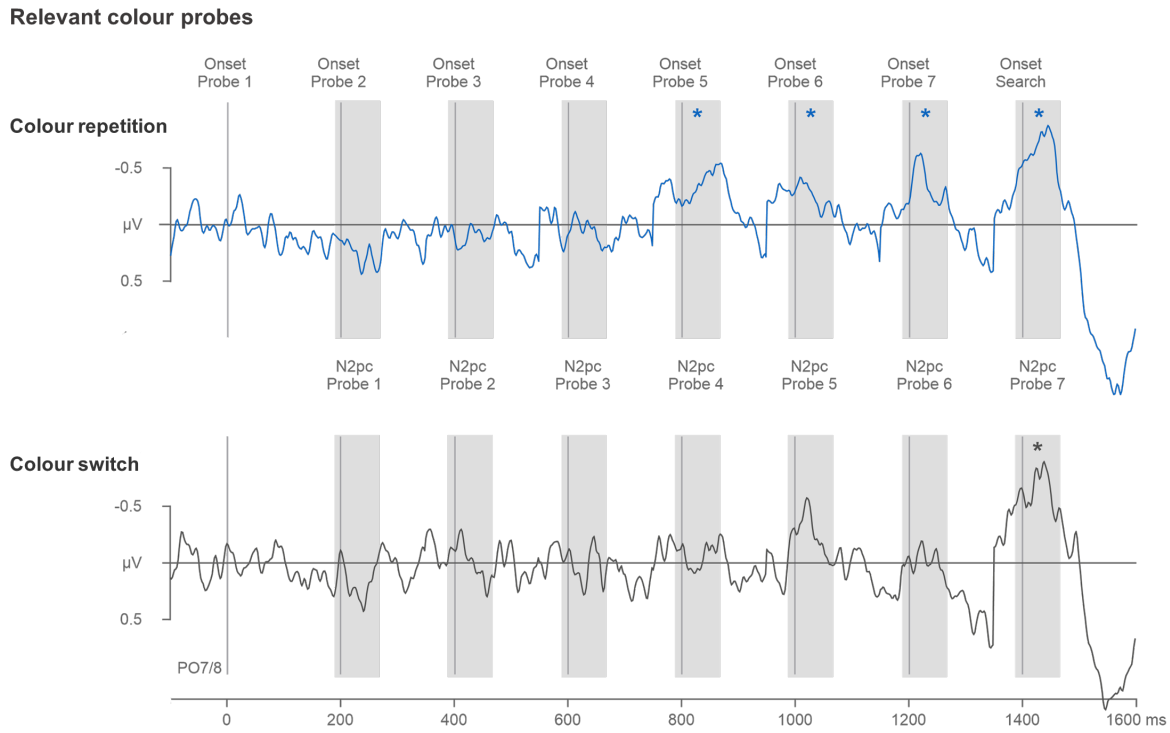

Figure 4. N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs for relevant target colour probes in colour repetition (top panel) and switch trials (bottom panels) of Experiment 1. Difference waves for the seven probes presented between search displays (probes 1-7) are shown in a temporally continuous fashion in 200ms segments (150-350ms) after onset of each probe. N2pc components were extracted individually for each probe, the successive presentation of the probe N2pcs is for illustration purposes only. Probe onsets are indicated by vertical lines, and probe N2pc time windows by shaded areas (190-270ms after onset of each individual probe). Note that the onset of each probe coincides within the N2pc window for the preceding probe. Statistically reliable probe N2pcs are marked by asterisks.

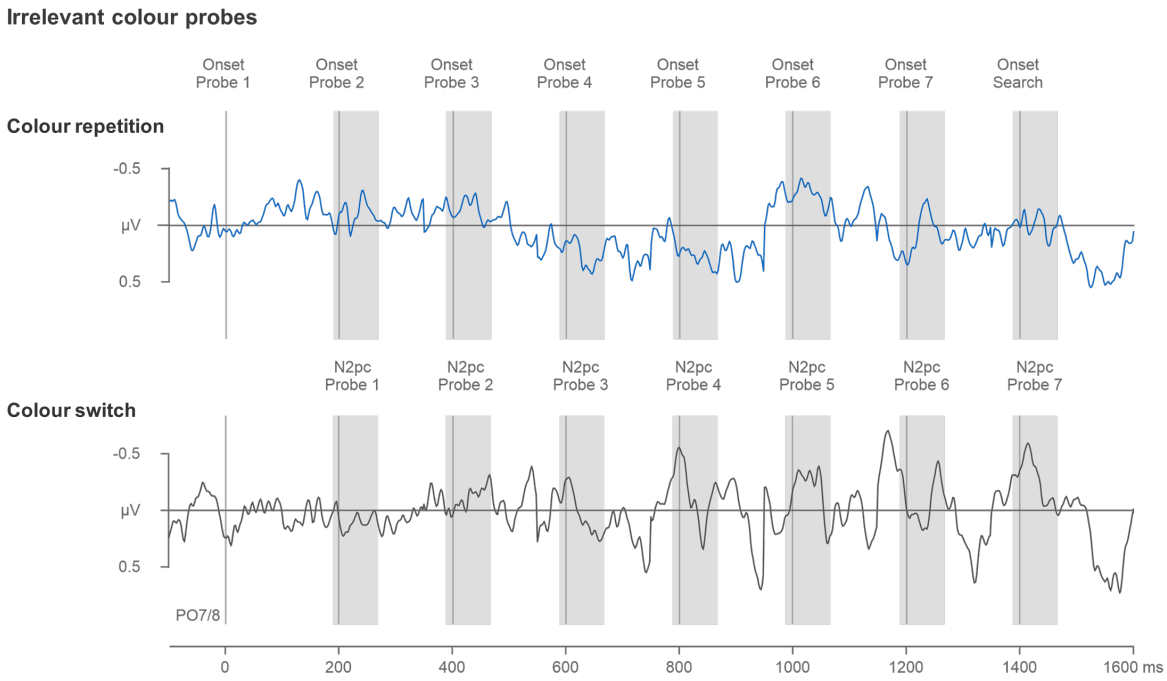

Figure 5. N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs for irrelevant target colour probes in colour repetition (top panel) and switch trials (bottom panels) of Experiment 1. Difference waves triggered by individual probes are shown in the same continuous fashion as in Figure 4. Probe onsets are indicated by vertical lines, and probe N2pc time windows by shaded areas (190-270ms after onset of each individual probe). None of these probes triggered reliable N2pcs.

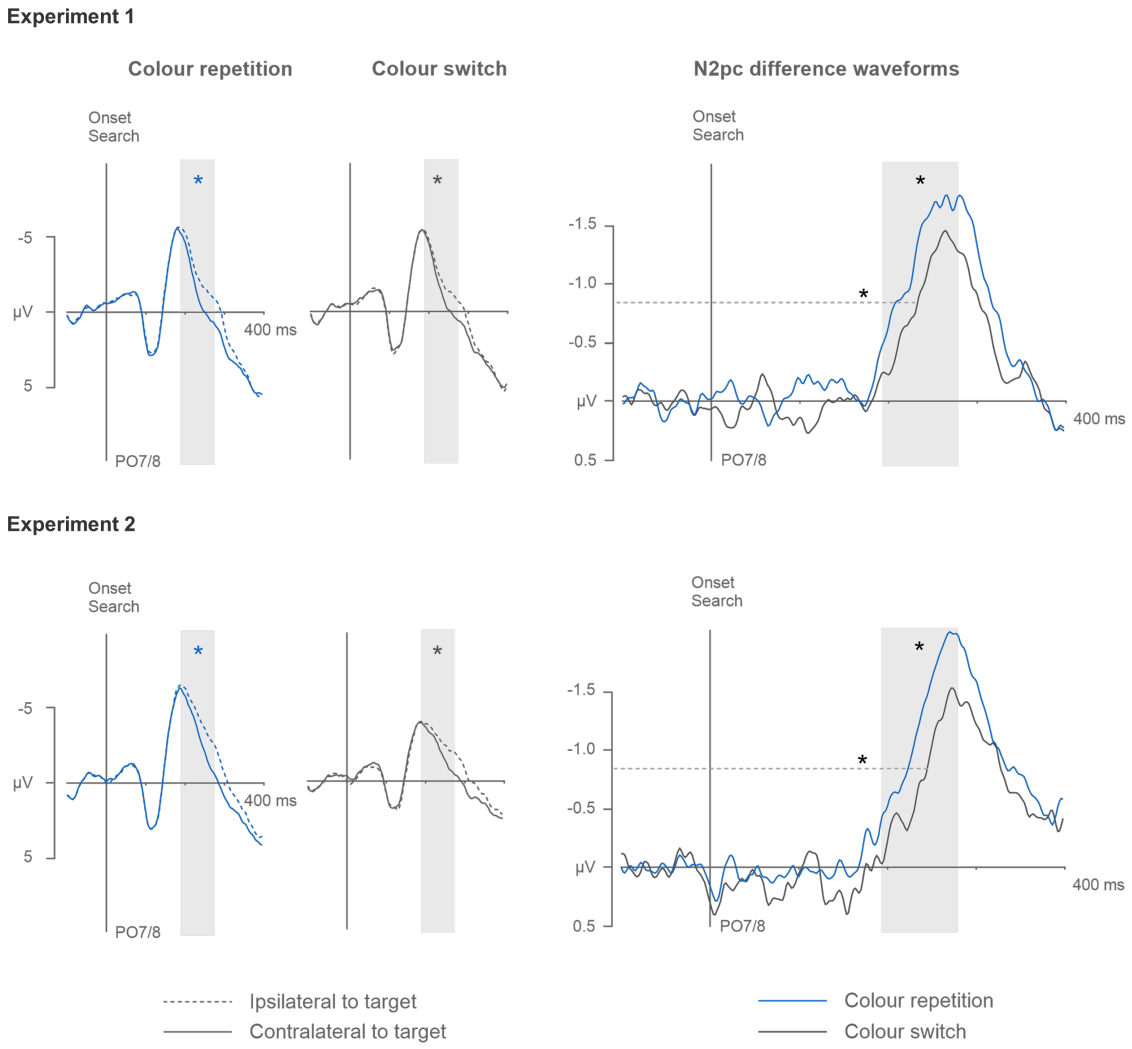

Figure 6. Grand-averaged ERPs elicited in the search displays in colour repetition and switch trials of Experiment 1 (top panel) and Experiment 2 (bottom panel) at electrodes PO7/8 contralateral and ipsilateral to the response-relevant target (left panels), together with the corresponding contralateral-ipsilateral N2pc difference waveforms (right panel). In Experiment 2, to equate the signal-to-noise ratio between the two trial types, only 1st colour repetition trials were included in the target N2pc analyses. Shaded areas indicate N2pc time windows (190-270ms after search display onset). Asterisks in the ipsi/contralateral panels (left) indicate significant N2pcs. Asterisks in the difference wave panels (right) represent significant differences in mean amplitudes and onset latencies (measured at -0.8µV, as indicated by the dashed horizontal lines).

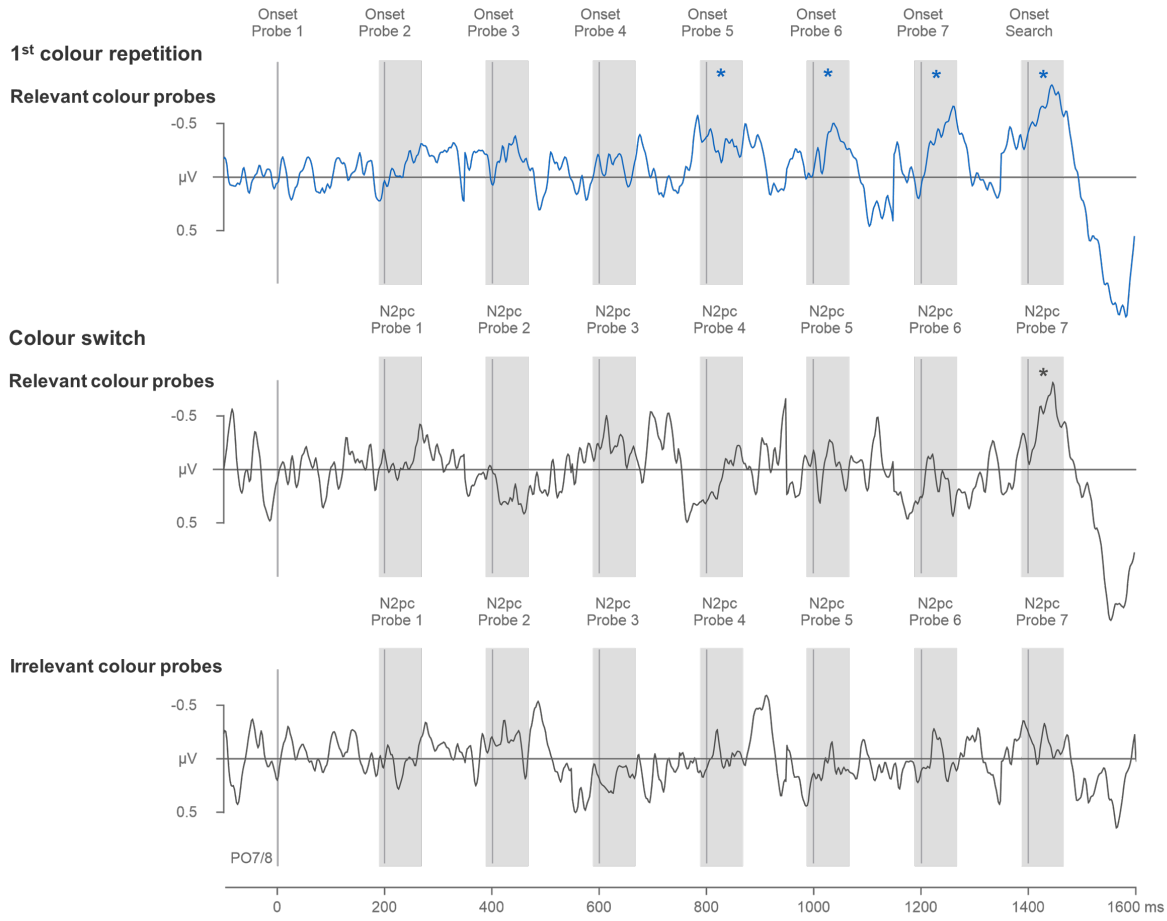

Figure 7. N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs for relevant target colour probes in 1st colour repetition trials (top panel) and in switch trials (middle panel), and for irrelevant target colour probes in switch trials (bottom panel) of Experiment 2. Difference waves triggered by individual probes are shown in the same continuous fashion as in Figure 4 and 5. Probe onsets are indicated by vertical lines, and probe N2pc time windows by shaded areas (190-270ms after onset of each individual probe). Statistically reliable probe N2pcs are marked by asterisks.