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Electrophysiological correlates of active suppression and attentional selection in preview visual search

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ABSTRACT

Advance preview of a subset of distractor objects improves the efficiency of visual search performance, but the causes and mechanisms of such preview benefits remain unclear. Here, we employed event-related potential (ERP) markers of the selective processing of preview displays and full search displays in lateralised preview search tasks where only one side of the search displays was task-relevant. Preview displays elicited a sustained positivity contralateral to the relevant side (P_D component), indicative of the active suppression of distractor objects on this side. Lateralised ERP components to full search displays revealed qualitative differences between attentional selection processes on preview as compared to no-preview trials. When search displays were preceded by preview displays, attention was directly allocated to target objects, while distractors remained unattended. When all search display objects were presented simultaneously (no-preview), attention was directed non-selectively to objects on the task-relevant side, even when no target was present. These results suggest that behavioural preview effects in visual search can be accounted for by the inhibition of previewed distractors, and the subsequent rapid attentional selection of target objects on preview trials.

1. Introduction

Searching for target objects in cluttered visual scenes is often difficult. Different types of attentional control processes can facilitate search by biasing visual processing in favour of potentially relevant features or objects relative to other parts of the visual environment that can be ignored. Spatial attention prioritises locations in the visual field that are likely to contain a target object, and feature-based attention prioritises the processing of object attributes (such as a particular colour or shape) that are associated with the current target. Attentional selectivity also operates in the temporal domain, by facilitating the visual processing of the arrival of new visual objects signalled by abrupt onsets (e.g., Yantis and Jonides, 1984), as well as by biasing attention against returning to recently processed objects (i.e., inhibition of return; e.g., Posner et al., 1985). One specific benefit of attentional control in the time domain has been identified in visual search experiments that used preview procedures (e.g., Watson and Humphreys, 1997). In preview visual search, a subset of distractor objects are presented in advance before other objects (which can include the current search target) are added to this display. Search performance is more efficient in such preview trials relative to other trials where all objects are presented simultaneously in a single search display.

While the presence of robust preview benefits on visual search performance has been demonstrated in numerous experiments (see Watson et al., 2003, for review), the mechanisms that produce these benefits remain contentious. To provide a full account of the factors that are responsible for preview benefits, two questions have to be addressed. On the one hand, such an account needs to specify how previewed objects are processed in the interval between a preview and a subsequent full search display. On the other hand, it has to describe how the attentional processing of objects in a full search display differs as a function of the presence versus absence of a preview display. The standard explanation of preview benefits was provided by (Watson and Humphreys, 1997, 2000; see also Watson et al., 2003). According to their visual marking hypothesis, the locations of objects in a preview display are actively inhibited prior to the subsequent presentation of new objects that complete the full search display. Because they are inhibited, the ability of old objects to compete for attentional selection is reduced, making it more likely for attention to be allocated to new objects. Because targets will only ever be part of the new set of objects, this type of inhibitory visual marking effectively reduces search display set size, which will result in more efficient search performance (e.g., Treisman and Gelade, 1980).

Evidence in support of inhibitory visual marking processes during preview search comes from studies demonstrating impairments in the detection of dot probes at previewed distractor locations (Watson and

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Humphreys, 2000). Preview benefits are also reduced in size when observers have to perform a secondary task during the preview interval (Humphreys et al., 2002; Olivers and Humphreys, 2002), and are only observed when the interval separating preview and full search displays is at least 400 ms (see Watson et al., 2003, for review). These results all suggest the existence of active top-down inhibitory mechanisms that are activated by preview displays. Other studies, however, have challenged the purely location-based inhibition account of preview benefits postulated by visual marking, and suggested that these benefits are at least in part due to feature-based inhibitory processes (Olivers and Humphreys, 2002). Moreover, there is evidence from both behavioural studies (Humphreys et al., 2004) and from event-related potential (ERP) experiments (Belopolsky et al., 2005) that the inhibition of previewed distractors might be preceded by an initial facilitatory phase where these distractors are actively attended. Other findings suggest that preview benefits are mediated by visual working memory, as benefits tend to be larger when the number of previewed items do not exceed working memory capacity, and the size of these benefits is correlated with individual working memory capacity limits (Al-Aidroos et al., 2012). This apparent link between preview search and working memory is potentially important, since it could suggest that instead of being inhibited, previewed items are actively maintained during the preview period. Working memory representations of these items could, for example, act as negative templates during the processing of full search displays, biasing attention towards new objects (e.g., Arita et al., 2012). Finally, it is also possible that preview benefits are not related to the selective (inhibitory or facilitatory) processing of distractors during the preview period. These benefits could instead be the result of the temporal asynchrony between preview and search displays, and reflect the ability of new items to attract attention automatically (e.g., Jiang et al., 2002). For example, Donk and Theeuwes (2001) suggested that preview benefits found when the presentation of new stimuli is associated with a luminance onset disappear when these stimuli are equiluminant with their background (see also Kiss and Eimer, 2011, for corresponding behavioural and ERP results), although other studies have observed such benefits also with equiluminant stimulus objects (e.g., Braithwaite et al., 2005; Braithwaite et al., 2006).

In summary, the question whether preview benefits in visual search are the result of an active top-down inhibition or facilitation of previewed objects during the preview period remains debated. Furthermore, the question how attentional target selection processes differ between preview and no-preview trials has also not been resolved. The goal of the present study was to provide new insights into both of these issues by examining lateralised ERP components elicited in response to preview and full search displays (see Jacobsen et al., 2002, for an earlier ERP study of preview search that measured non-lateralised ERP components during the preview interval). Numerous previous studies have identified lateralised posterior ERP components that are associated with distractor inhibition and with the maintenance of visual objects in working memory, respectively. For visual search displays that contain salient but task-irrelevant distractor objects, an enhanced positivity is elicited over posterior brain areas contralateral to the side where these distractors are presented (e.g., Sawaki and Luck, 2010; Sawaki et al., 2012; Kiss et al., 2012; Burra and Kerzel, 2014). This component, referred to as distractor positivity (P_D), has been interpreted as an electrophysiological marker of the active suppression of distractor objects. There is considerable variation in the onset latencies of P_D components, which have been observed as early as 100–200 ms post-stimulus (e.g., Fortier-Gauthier et al., 2012), between 200 and 300 ms after search display onset (e.g., Hickey et al., 2009), or even later, at approximately 300–400 ms (e.g., Sawaki et al., 2012). The reasons for this temporal variability, and the question whether P_D components observed at different post-stimulus latencies reflect different forms of distractor inhibition, remain under discussion (see Gaspelin and Luck, 2018, for review). In addition, studies of visual working memory maintenance that employed lateralised change detection tasks, where observers have to memorize visual stimuli in one hemifield in order to match them to subsequent test stimuli, have observed a sustained contralateral negativity is observed during the retention period between memory and test displays (e.g., McCollough et al., 2007; Vogel and Machizawa, 2004). This contralateral delay activity (CDA) is sensitive to the number of visual objects that are currently stored, and to individual differences in working memory capacity, suggesting that it is an ERP correlate of the active maintenance of visual information in working memory. Here, we utilized the existence of lateralised posterior ERP components of opposite polarity associated with the inhibition of visual objects versus their selective maintenance in working memory, respectively, to test how previewed distractor objects are processed in the interval between preview and search displays. If the locations of distractor objects on the task-relevant side are actively inhibited, as postulated by the visual marking account, a contralateral positivity (P_D component) should be observed in response to preview displays. If these objects are selectively maintained in visual working memory, a contralateral negativity (CDA component) should be found instead. If the processing of previewed objects is neither suppressed nor facilitated, as proposed by those who attribute preview benefits to asynchronous onsets, no lateralised posterior ERP components should be elicited at all in response to preview displays.

To be able to measure these lateralised ERP components, we employed a variation of the preview search paradigm where only objects in one visual field were relevant. In Experiment 1, preview and full search displays contained an equal number of objects on the left and right side. Prior to each experimental block, participants were told that only stimuli in one visual hemifield would be task-relevant, and that items in the opposite hemifield could be ignored. The total number of stimuli on each side (four or eight) varied unpredictably within blocks. Participants searched for a target object defined by a colour-shape conjunction on the task-relevant side (e.g., blue diamond). When present, targets in full search displays were accompanied by partially matching distractors (e.g., blue circles, green diamonds). On preview trials, two or four distractors that all matched the target shape feature but not colour (e.g., green diamonds) were presented on each side for 1000 ms before the other items were added. On no-preview trials, all four or eight items on either side of the search display were presented simultaneously. To assess whether preview display items on the currently relevant side are selectively inhibited (as reflected by a P_D), selectively maintained in visual working memory (reflected by a CDA), or not selectively processed at all, we measured ERPs in response to preview displays at lateral posterior electrodes contralateral and ipsilateral to this relevant side.

The other question addressed in the present study was how the time course of attentional target selection processes differs between preview and no-preview trials. Preview benefits reflect the fact that search targets are found more rapidly when they are presented as part of a set of new items than when they appear simultaneously with all other search display items on no-preview trials. This suggests that the attentional processing of new items differs systematically between these two types of trials. Previous behavioural studies that have quantified these differences in terms of display set size effects (Watson and Humphreys, 1997) or target-distractor interference effects (Donk and Theeuwes, 2001) have remained inconclusive with respect to which stages of attentional selectivity are affected by the presence versus absence of preview displays. Here, we used ERPs to track the attentional processing of full search displays on preview versus no-preview trials in real time. To do this, we compared ERPs elicited at posterior electrodes contralateral and ipsilateral to the currently task-relevant hemifield. Previous ERP studies of visual search have identified two successive contralateral components that are linked to the selective attentional processing of candidate target objects. The rapid allocation of attention to such objects is reflected by the N2pc component. The N2pc is an enhanced contralateral negativity over posterior visual areas that emerges approximately 200 ms after search display onset (e.g., Eimer,

1996; Luck and Hillyard, 1994; Eimer and Kiss, 2008), and is generated within extrastriate ventral visual cortex (e.g., Hopf et al., 2000). This component is assumed to reflect a selective attentional bias in the online perceptual processing of candidate target objects, and is observed in all types of search tasks. Another contralateral ERP component that is typically maximal between 400 and 500 ms after search display onset (sustained posterior contralateral negativity/SPCN; Mazza et al., 2007; Jolicœur et al., 2008) follows the N2pc in search tasks where the discrimination between targets and distractors is more difficult or an in-depth processing of target features is required (e.g., Mazza et al., 2007). The SPCN has been linked to the attentional processing of target objects within working memory.

In the present study, we measured N2pc and SPCN components in response to full search displays on preview and on no-preview trials. If previewed items can be completely excluded from attentional processing, ERPs on preview trials should exclusively reflect attentional selection processes that operate among the set of new items on the task-relevant side. Within this set, target objects can be selected exclusively on the basis of unique colour, because all target-colour distractor objects are part of the preview display. In contrast, no such purely colour-based target selection is possible on no-preview trials where a target appears together with target-colour distractors in the same search displays. As a result, target selection should be faster on preview trials, resulting in earlier N2pc components relative to no-preview trials. When all search display items are presented at the same time, target selection processes might be substantially delayed, and thus operate primarily at post-perceptual memory-related stages. In this case, N2pcs should be small or absent and SPCN components should be elicited instead on no-preview trials. However, given that only one search display side was task-relevant in the current lateralised version of the preview search paradigm, it is possible that attention is first allocated non-selectively to all objects on the relevant side of full search displays before the target is selected. In this case, early N2pc components might be observed both on preview and no-preview trials. To investigate this possibility, we also measured lateralised ERP components on target-absent trials. If attention was initially allocated non-selectively to the relevant hemifield, N2pc components should be observed not only in response to search displays that contain a target object, but also for target-absent displays. Furthermore, such a failure to allocate attention selectively to target objects might only be more pronounced on no-preview trials.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve participants were recruited to take part in the experiment (*M* age = 30 years, SD = 6; 5 males; 2 left-handed). All reported normal or corrected-to-normal vision.

2.1.2. Stimuli and procedure

The experimental task was created and executed using E-Prime 2.0 software (Psychology Software Tools, Inc.). All stimuli were shown on a 24-in. BenQ monitor (60 Hz; 1920 × 1080 screen resolution) at a viewing distance of approximately 90 cm. The experiment was run on a SilverStone PC, with manual responses registered via a standard PC keyboard. All stimuli were presented on a black background, with a grey fixation dot (0.2° × 0.2° of visual angle) present constantly throughout blocks. Stimuli were coloured shapes. Two shapes (circles or diamonds; size: 1.08° × 1.08°) and two colours (blue and green; CIE colour coordinates: 0.169/0.152 and 0.296/0.604) were employed. The two stimulus colours were equiluminant (14 cd/m^2), as measured by a luminance meter (Konica Minolta CS-100A). Stimuli within preview and search displays were presented within two imaginary 4 × 4 grids to the left and right of fixation. The overall size of each grid was 5.28° × 5.28°, with a horizontal and vertical distance between possible object locations of 0.32°. The distance between the inner edge of each grid and the fixation dot was 0.89°. Locations of stimuli within grids were randomly generated on each experimental trial.

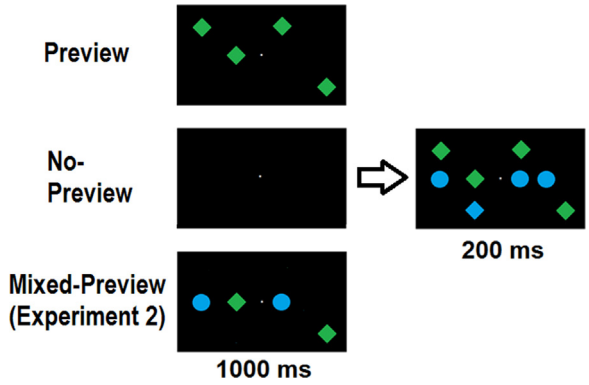

Fig. 1. Example experimental trial (not to scale) in Experiment 1, and an example of a trial in the mixed-preview blocks in Experiment 2. These examples show trials where the relevant set size of the full search display was 4 items. Experiment 1 also included trials where display set size was 8 items. Participants' task was to find target objects (e.g., blue diamonds) in one task-relevant visual hemifield (e.g., left). On preview trials, full search displays were preceded by preview displays including distractor items. On no-preview trials, all search display items were presented simultaneously. In Experiment 1, all preview displays contained identical distractor items. In Experiment 2, these uniform-preview displays and mixed-preview displays with physically different distractor items were presented in different blocks.

Participants' task was to respond to the presence or absence of a particular target object defined by a colour/shape combination (e.g., blue diamond) within search displays. They responded by pressing the '1' or '2' key on the numeric keypad with their right index and middle fingers to report the presence or absence of a target. Search displays on each trial ultimately included either 8 or 16 items. However, participants were instructed at the start of each experimental block to only monitor one visual field (e.g., left), thus creating effective search set sizes of 4 or 8 items. There were two presentation conditions (see Fig. 1). On *preview trials*, two displays were presented sequentially. Initially, a preview display containing a set of identical nontarget items (e.g., green diamonds) was presented for 1000 ms. These preview items always matched the target shape, but were always shown in the other nontarget colour. On set size four trials, two preview items appeared in the left and two in the right visual field. On set size eight trials, four preview items were presented on either side. At the end of the preview period, four or eight additional items were added to the search display, and the whole set of 8 or 16 items (on set size four and eight, respectively) remained on the screen for another 200 ms. All nontarget items added during this second period matched the target colour but not its shape (e.g., blue circles). The target object was included as part of this set on 50% of trials. *No-preview trials* were identical except that all search display items were presented simultaneously for 200 ms, preceded by a 1000 ms blank screen period. The interval between the presentation of a full search display and the start of the next trial was 2000 ms, and responses were recorded during this interval. Participants were instructed to maintain central fixation, and to refrain from responding during preview periods prior to the onset of full search displays.

Following practice, participants completed 16 experimental blocks of 48 trials. Effective search set size (4 or 8 items on the task-relevant side in the full search displays) was blocked, with six participants completing 8 set size four block prior to 8 set size eight blocks, and this order was reversed for the other six participants. The task-relevant side (left or right hemifield) changed after each block, and the side that was relevant in the first block of each set size condition was

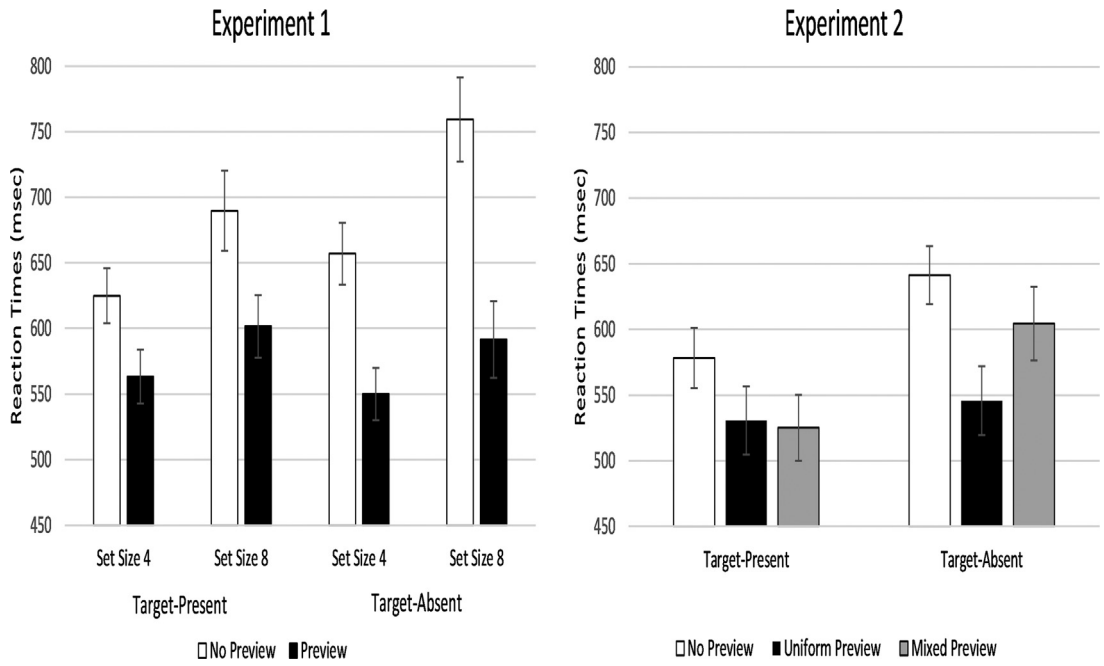

Fig. 2. Bar charts representing mean reaction time (RT) data in Experiments 1 (left panel) and 2 (right panel) on preview and no-preview trials. Preview effects are shown separately for target-present and target-absent trials, for display set sizes 4 and 8 (Experiment 1), and separately for uniform- and mixed-preview displays (Experiment 2).

counterbalanced across participants. In each block, preview and no-preview trials, and target-present and target-absent trials were equiprobable and randomly intermixed. Target identity was counterbalanced across participants, with three participants each searching for one of the four possible colour/shape combinations.

2.1.3. EEG recording and data analysis

EEG was DC-recorded from 27 scalp electrodes mounted on an elastic cap (sites: Fpz, F7, F8, F3, F4, Fz, FC5, FC6, T7, T8, C3, C4, Cz, CP5, CP6, P9, P10, P7, P8, P3, P4, Pz, PO7, PO8, PO9, PO10, and Oz). A 500-Hz sampling rate and 40 Hz low-pass filter were used. No other offline filters were applied. Channels were online referenced to an electrode attached to the left earlobe, and re-referenced offline to an average of both earlobes. Trials with incorrect responses, eye blinks (exceeding ± 60 μV at Fpz), eye-movements (exceeding ± 30 μV in the HEOG channels), and movement-related artifacts (exceeding ± 80 μV in all other channels) were rejected. ERPs were then computed separately in response to search displays and preview displays. Preview-related ERPs were computed within 1100 ms epochs (from 100 ms before to 1000 ms after the onset of preview displays) measured on preview trials. ERPs to search displays were based on 600 ms segments (from 100 ms before to 500 ms after search display onset). Averaged ERP waveforms for search displays were computed relative to 100 ms pre-stimulus baselines, separately for both set size conditions, preview and non-preview trials, target-present and target-absent trials, and for blocks where the left or right hemifield was task-relevant. ERPs to preview displays were calculated separately for both set size conditions and blocks where the left or right hemifield was task-relevant, averaged across target-present and target-absent trials. For both preview and search displays, lateralised ERP components were quantified on the basis of ERPs obtained at posterior electrode sites PO7 and PO8 contralateral and ipsilateral to the task-relevant visual field. Given the substantial onset latency variability observed for P_D components in previous studies, we employed a wide time window for ERPs elicited in response to preview displays (150–450 ms post-stimulus) to quantify this component. Additional analyses were then conducted for two narrow windows (150–300 ms and 300–450 ms, respectively), to assess whether P_Ds might be restricted to the early and late parts of this interval. For ERPs to full search displays, ERP mean amplitudes were computed within a 200–300 ms and 400–500 ms time window (for N2pc and SPCN components, respectively). Finally, N2pc onset latency differences between task conditions were assessed using a jackknife-based procedure (Miller et al., 1998), on the basis of difference waveforms obtained by through subtracting ipsilateral from contralateral ERPs. Grand averaged difference waves were computed for different conditions, each excluding one participant from the original sample. Onset threshold was calculated using an absolute criterion of −0.5 μV, with t-values corrected according to the formula described by Miller et al. (1998).

2.2. Results

2.2.1. Behavioural data

Reaction times (RTs) on trials with correct responses were entered into a 2 × 2 × 2 repeated-measures ANOVA with the factors Set Size (Four, Eight), Preview (No-Preview, Preview), and Target Presence (Present, Absent). There was a significant main effect of Set Size ($F(1,11) = 11.93$, $p = .005$, $\eta_p^2 = 0.52$), with RTs significantly delayed in set size eight blocks ($M = 661$ vs. 599 ms). The existence of preview benefits was confirmed by a significant main effect of Preview ($F(1,11) = 351.82$, $p < .001$, $\eta_p^2 = 0.97$), with shorter RTs on preview relative to non-preview trials ($M = 577$ vs. 683 ms). A significant Set Size x Preview interaction ($F(1,11) = 16.88$, $p < .005$, $\eta_p^2 = .61$) reflected the fact that preview benefits in set size four blocks (M diff = 84 ms; $t(11) = 9.83$, $p < .001$) were smaller than in set size eight blocks (M diff = 128 ms; $t(11) = 18.64$, $p < .001$). There was no main effect of Target Presence ($F(1,11) = 1.70$, $p > .20$). A Preview x Target Presence interaction ($F(1,11) = 59.47$, $p < .001$, $\eta_p^2 = 0.84$) indicated that preview benefits were smaller on target-present trials (M diff = 75 ms; $t(11) = 9.93$, $p < .001$) than on target-absent trials (M diff = 137 ms; $t(11) = 21.72$, $p < .001$). A marginal Set Size × Target Presence interaction ($F(1,11) = 4.80$, $p = .051$, $\eta_p^2 = 0.30$) indicated that increasing set size delayed RTs more strongly on target-absent trials than on target-present trials (M diff = 72 vs. 51 ms). Finally, there was a significant Set Size × Preview × Target Presence interaction ($F(1,11) = 5.73$, $p < .05$, $\eta_p^2 = 0.34$). This was due to the fact that the

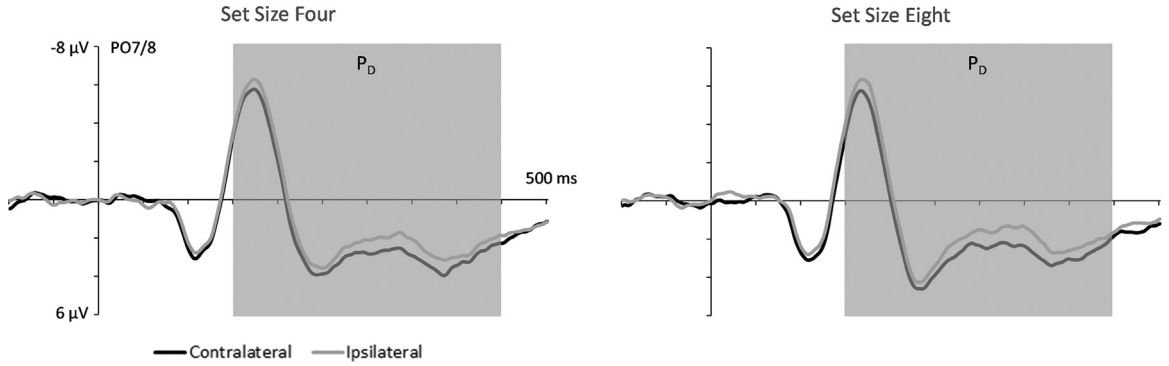

Fig. 3. Grand average ERPs obtained in Experiment 1 in the 500 ms interval after the presentation of a preview display at posterior electrode sites PO7/PO8 contralateral and ipsilateral to the task-relevant hemifield, separately for display set size conditions 4 and 8 (where preview displays contained two or four items on the task-relevant side, respectively).

increase of preview benefits in set size eight relative to set size four blocks was more pronounced on target-absent trials (61 ms) than on target-present trials (26 ms). All RT data is presented in Fig. 2.

A matching 2 × 2 × 2 ANOVA was conducted on error rate data. This showed a marginal main effect of Set Size ($F(1,11) = 3.99$, $p = .071$, $\eta_p^2 = 0.27$), but a significant main effect of Target Presence ($F(1,11) = 6.32$, $p < .03$, $\eta_p^2 = 0.37$), with more errors on target-present relative to target-absent trials ($M = 3.85$ vs. 2.46%). There was also a significant main effect of Preview ($F(1,11) = 6.53$, $p < .03$, $\eta_p^2 = 0.37$), with fewer errors on preview as compared to no-preview trials ($M = 1.85$ vs. 4.46%). A Set Size x Preview interaction ($F(1,11) = 6.84$, $p < .03$, $\eta_p^2 = 0.38$) reflected the fact that there was a reliable preview benefit for error rates in set size eight blocks (M diff = 4.25%; $t(11) = 2.72$, $p = .02$), but not in set size four blocks (M diff = 0.96%; $t(11) = 1.47$, $p = .17$). No other interactions were significant (Fs < 1).

2.2.2. Lateralised ERP components to preview displays

Fig. 3 shows ERPs elicited on preview trials in the 500 ms interval following the onset of preview displays at electrodes PO7/8 contralateral and ipsilateral to the currently task-relevant visual hemifield. ERPs are shown separately for set size four and set size eight blocks. A contralateral sustained positivity appears to be present in both types of blocks, with an onset of approximately 150 ms post-stimulus, overlapping with N1 components elicited by the preview displays. This was confirmed by statistical analyses. ERP mean amplitudes obtained 150–450 ms after preview display onset were entered into a 2 × 2 ANOVA with the factors Set Size (Four, Eight) and Laterality (Ipsilateral, Contralateral). This showed a highly significant main effect of Laterality ($F(1,11) = 22.93$, $p = .001$, $\eta_p^2 = 0.68$), with more positive ERP amplitudes at contralateral electrodes (M diff = 0.61 μV). This effect did not interact with Set Size ($F < 1$), and planned follow-up analyses confirmed that contralateral positivities of similar size were present in set size four blocks (M diff = 0.55 μV; $t(11) = 3.47$, $p = .005$) as well as set size eight blocks (M diff = 0.66 μV; $t(11) = 4.37$, $p = .001$). For a follow-up analysis, preview ERPs were quantified separately for the 150–300 ms and 300–450 ms time windows after preview onset, and analysed together, with the additional factor Time Window. There was no interaction between Laterality and Time Window ($F(1,11) = 1.11$, $p = .32$), thus confirming that this contralateral positivity was not restricted to either the early or later

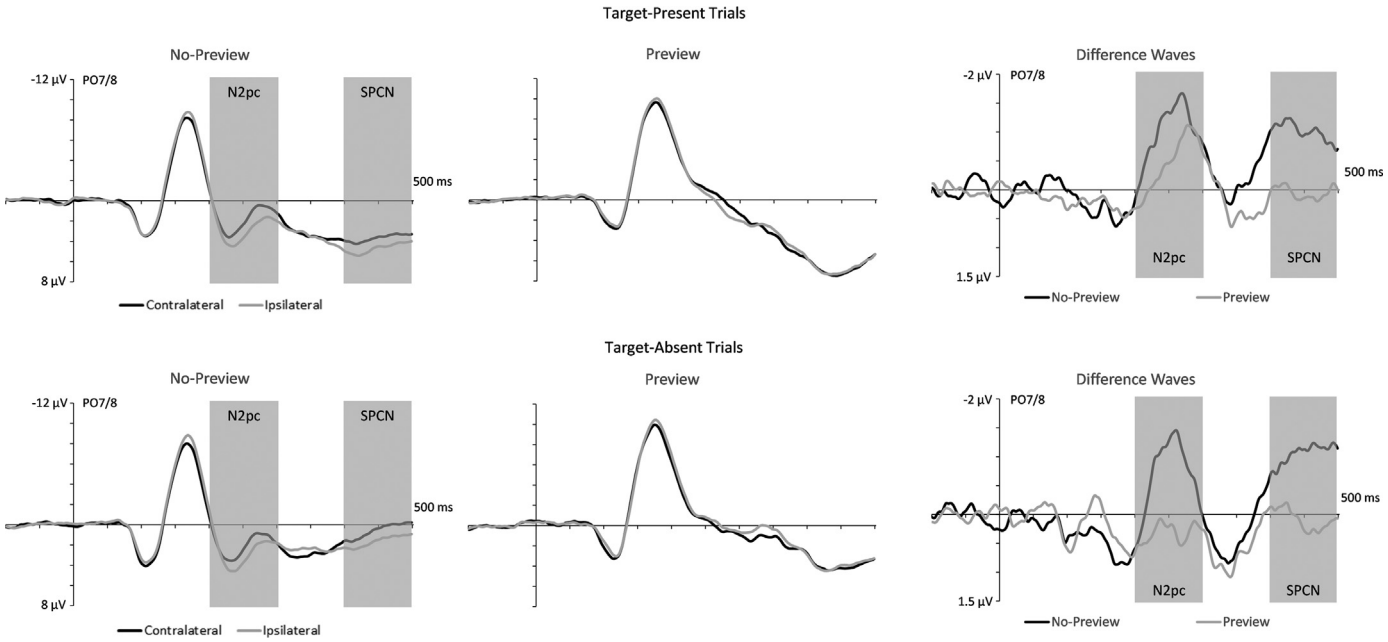

Fig. 4. Grand average ERPs obtained in Experiment 1 in the 500 ms interval following the presentation of full search displays at posterior electrode sites PO7/PO8 contralateral and ipsilateral to the task-relevant hemifield (collapsed across display set size 4 and 8). ERPs are shown for no-preview and preview trials, separately for target-present search displays (top panels) and target-absent search displays (bottom panels), together with the corresponding difference waveforms computed by subtracting ipsilateral from contralateral ERPs.

post-stimulus time interval.

2.2.3. Lateralised ERP components to search displays

Fig. 4 shows ERPs elicited by full search displays in the 500 ms interval following the onset of these displays at electrodes PO7/8 contralateral and ipsilateral to the currently task-relevant visual hemifield. ERPs are shown separately for no-preview and preview trials and for target-present and target-absent search displays, together with the corresponding contralateral-ipsilateral difference waveforms (right panels). Because an initial omnibus ANOVA with the factors Set Size, Preview, Target Presence, and Laterality showed no main effects of Set Size on N2pc and SPCN mean amplitudes (both $F < 1$), and no significant interaction involving the factor Set Size, the ERPs shown in Fig. 4 are averaged across set size four and eight blocks. As expected, N2pc components were elicited on target-present trials, but this component was smaller and delayed on preview as compared to no-preview trials. For target-absent search displays, a clear N2pc appears to be present only on no-preview trials but not on preview trials. Finally, there was a remarkable dissociation between preview and no-preview trials at the level of the SPCN component. This component was present on no-preview trials, both for target-present and target-absent displays, but was entirely absent on preview trials.

2.2.4. N2pc components

N2pc mean amplitudes measured in the 200–300 ms interval after search display onset were analysed separately for target-present and target-absent trials, with the factors Set Size, Preview, and Laterality. For target-present trials, a significant main effect of Laterality ($F(1,11) = 17.20$, $p < .005$, $\eta_p^2 = 0.61$), demonstrating the reliable presence of N2pc components, was accompanied by a significant interaction between Laterality and Preview ($F(1,11) = 9.48$, $p = .01$, $\eta_p^2 = 0.46$). N2pc components were reliably present on both no-preview trials ($t(11) = 4.07$, $p < .005$) and preview trials ($t(11) = 3.49$, $p = .005$), but were larger on no-preview trials (M diff = −1.01 μV vs. −0.45 μV). For target-absent trials, there was no significant main effect of Laterality ($F < 1$) but this was qualified by an interaction between Laterality and Preview ($F(1,11) = 13.83$, $p < .005$, $\eta_p^2 = 0.56$). Follow-up analyses revealed that a reliable N2pc was elicited by target-absent displays on no-preview trials (M diff = −0.70 μV; $t(11) = 2.30$, $p < .05$). In contrast, there was no N2pc but instead a trend towards a contralateral positivity in the N2pc time window for target-absent displays on preview trials (M diff = 0.32 μV; $t(11) = 2.11$, $p = .058$).

To assess the apparent onset latency delay of N2pc components to target-present displays on preview as compared to no-preview trials, N2pc onset latencies on these two types of trials were compared with a jackknife-based procedure, using an absolute onset criteria of −0.5 μV. This analysis confirmed that the N2pc was significantly delayed on preview as compared to no-preview trials (M = 252 vs. 215 ms; $t_c(11) = 2.42$, $p < .04$). Because N2pc components on no-preview trials were elicited both by target-present and target-absent search displays, we also assessed whether the onset of these N2pcs was at all affected by the presence versus absence of a target object in the full search display. A comparison of N2pc onset latencies on no-preview trials between target-present and target-absent displays revealed no reliable difference (M = 215 vs. 222 ms; $t_c(11) = 1.08$, $p > .30$).

2.2.5. SPCN components

ERP mean amplitudes measured in the 400–500 ms interval after search display onset were analysed in an omnibus ANOVA with the factors Set Size, Preview, Target Presence, and Laterality. There was no significant main effect of Laterality ($F(1,11) = 2.96$, $p = .11$), but a significant interaction between Laterality and Preview ($F(1,11) = 22.16$, $p = .001$, $\eta_p^2 = 0.67$). No other interactions involving Laterality as a factor were significant (all Fs < 2.09, p's > .17). Follow-up analyses confirmed that a reliable SPCN component was elicited on no-preview trials (M diff = −1.03 μV; $t(11) = 2.83$, $p < .02$), whereas this component was entirely absent on preview trials (M diff = 0.07 μV; $t < 1$).

2.3. Discussion of Experiment 1

The behavioural results of Experiment 1 confirmed the existence of substantial preview benefits in this lateralised preview search task, with shorter RTs on preview as compared to no-preview trials. As expected, RTs were delayed when the relevant display set size was larger (eight versus four items), and preview benefits were also larger for search displays with more relevant items. Preview benefits were also more pronounced on target-absent as compared to target-present trials. To identify the processes underlying these preview benefits, we measured lateralised ERP components at posterior electrodes, separately for preview and full search displays. The ERPs recorded in response to preview displays revealed the presence of a significant positivity contralateral to the task-relevant visual hemifield. As this P_D component is usually interpreted as reflecting the top-down inhibition of task-irrelevant items in visual search (Gaspelin and Luck, 2018), this observation provides new electrophysiological evidence that previewed distractors are indeed selectively processed during the preview period. In line with the visual marking hypothesis (Watson and Humphreys, 1997), the existence of a P_D suggests that these distractors were actively inhibited. Interestingly, however, there was no difference in the size of P_D components as a function of display set size, that is, P_D amplitudes did not reflect the number of previewed distractors or distractor locations (two versus four). A possible reason for the absence of such set size effects will be investigated in Experiment 2.

If previewed distractors are selectively inhibited prior to the presentation of full search displays, this should result in systematic differences in the subsequent attentional processing of objects on the task-relevant side in full search displays on preview as compared to no-preview trials. The pattern of lateralised ERP component elicited by these displays confirmed this. N2pc components emerged in response to target-present displays on both preview and no-preview trials. However, and perhaps counterintuitively, N2pc components on no-preview trials emerged reliably earlier than on preview trials, in spite of the fact that RTs to targets were shorter on preview trials. The existence of these behavioural preview benefits makes it very unlikely that the earlier onset of the N2pc on no-preview trials reflects a faster attentional selection of target objects on these trials. An alternative possibility is that, on no-preview trials, attention was initially allocated to all objects in the task-relevant visual hemifield, regardless of whether a target object was present. In line with this hypothesis, N2pc components were elicited by target-absent displays on no-preview trials, and emerged at the same time as the N2pc on target-present trials. In other words, early attentional allocation processes on no-preview trials were not sensitive to the presence versus absence of a target object on the task-relevant side. In contrast, there was no N2pc for target-absent displays on preview trials, demonstrating that the new items added to the previewed displays did not attract attention when they did not contain the target.

These N2pc results suggest that attentional selection processes differ qualitatively between preview and no-preview trials. When full search displays are preceded by a preview display, attention can be immediately allocated to the target object, presumably because only one of the new objects (i.e., the target) matches the target-defining shape. In previewed target-absent displays, the new objects were all perceptually identical distractors (e.g., a set of blue circles added to the previewed set of green diamonds), which can presumably be grouped and rejected as non-targets at an early pre-attentive stage of visual processing, thus preventing any shift of spatial attention towards the task-relevant side. In contrast, when all search display objects are presented simultaneously, attention is initially allocated rapidly but non-selectively to all display items on the task-relevant side. Additional evidence for a delay of target-selective attentional processes on no-preview trials was

provided by the SPCN components measured to full search displays. Reliable SPCN components were elicited by both target-present and target-absent displays on no-preview trials (see Fig. 4), suggesting that the presence or absence of a target could not be determined exclusively during the on-line perceptual processing of search display objects, but also required the maintenance of these objects in working memory (see also Mazza et al., 2007; Lee et al., in press, for further evidence for links between SPCN components and the sustained processing of search display objects). In contrast, no SPCN components were elicited on preview trials, indicating that target present/absent discriminations were made at early sensory-perceptual stages of visual processing, and did not involve the subsequent encoding of search display objects into visual working memory.

3. Experiment 2

In Experiment 1, the amplitude of P_D components triggered in response to preview displays was unaffected by the number of previewed distractors. This observation is not entirely in line with the claim that preview benefits are the result of location-based inhibitory visual marking mechanisms (Watson and Humphreys, 1997). In this case, P_D amplitudes should presumably have increased with the number of to-be-inhibited locations. One reason for the absence of display set size effects on P_D components in Experiment 1 was that all previewed distractors were physically identical (e.g., green diamonds). If visual marking was feature-based (e.g., Olivers and Humphreys, 2002; Andrews et al., 2011), the amount of inhibition applied to preview displays might depend exclusively on the number of different distractor features in these displays, and not on the number of distractor objects and locations (see also Olivers et al., 1999, for similar suggestions). This would explain why P_D amplitudes in Experiment 1 did not increase when the number of uniform previewed distractors was increased. Feature-based suppression may have been activated in parallel for all of these distractors, irrespective of how many of them were present in the preview displays. If this was the case, a different pattern of results should be observed when the number of different distractor features within preview displays is manipulated.

This was tested in Experiment 2, where two types of preview displays were employed. Uniform-preview displays were identical to the displays used in Experiment 1. Mixed-preview displays contained distractors that differed in their colour as well as shape (e.g., a green diamond and a blue circle). If P_D components triggered by these displays reflect feature-based distractor inhibition, these components should be larger for mixed-preview displays where different colours and shapes had to be inhibited. A no-preview condition was also included in Experiment 2, in order to confirm the existence of qualitatively different attentional selection processes on preview versus no-preview trials suggested by the N2pc and SPCN results of Experiment 1, and to test whether such preview effects differ when mixed as compared to uniform-preview displays are shown. As Experiment 1 revealed no systematic effects of display set size on lateralised ERPs to preview and full target displays, only a single set size condition (set size four) was employed in Experiment 2. Furthermore, the three preview conditions (no-preview, uniform-preview, mixed-preview) were now presented in different blocks.[1]

3.1. Method

3.1.1. Participants

Fourteen participants took part in Experiment 2. Two participants were excluded from analysis due to a large number of HEOG eye-movement artifacts during the preview period, leading to the rejection of over 50% of all preview period EEG epochs. The final sample included 12 participants (M age = 32 years, SD = 7; 3 males; all right-handed), who all reported normal or corrected-to-normal vision.

3.2. Stimuli and procedure

Stimuli and procedures were similar to Experiment 1 with the following exceptions. Search display set size was always four (i.e., 8 items appeared in a full search display but, as in Experiment 1, only one visual hemifield was task-relevant). Preview and no-preview trials were no longer randomly intermixed but were run within separate blocks. In preview blocks, there were two randomly intermixed types of preview displays. Uniform-preview displays were identical to the preview displays used in Experiment 1. Mixed-preview displays contained one preview item on either side that matched the target colour but not its shape (e.g., blue circle) and one item on each side that matched the target shape but not its colour (e.g., green diamond). On target-absent trials with mixed-preview displays, two different items (e.g., another blue circle and green diamond) were added to the preview display to generate a full search display. Two identical items (e.g., blue circles) were added on target-absent trials with uniform-preview displays.

Following practice, participants completed 12 experimental blocks of 48 trials. Eight blocks contained preview displays, and four blocks contained only no-preview trials. The task-relevant hemifield (left or right) was changed every 3 blocks. Within each 3-block run for a given relevant hemifield, the no-preview block was either the first or the third block, and this order was alternated across participants following an ABBA/BAAB format.

3.3. EEG recording and data analysis

Procedures were similar to Experiment 1. Averaged ERP waveforms in response to preview displays were separately computed for uniform- and mixed-preview displays. ERPs to full search displays were now computed separately for three preview conditions.

3.4. Results

3.4.1. Behavioural data

RTs on trials with correct responses entered into a 3 × 2 repeated-measures ANOVA with the factors Preview (No-Preview, Uniform-Preview, Mixed-Preview), and Target Presence (Present, Absent). There was a main effect of Preview ($F(2,22) = 42.52$, $p < .001$, $\eta_p^2 = 0.79$). RTs were shortest within uniform-preview displays (M = 538 ms), intermediate on trials with mixed-preview displays (M = 565 ms), and longest in no-preview blocks (M = 610 ms). Paired-sample t-tests showing that there were reliable RT differences between each of these three preview conditions (t's > 4.81, p's ≤ .001). There was also a main effect of Target Presence ($F(1,11 = 15.65$, $p < .005$, $\eta_p^2 = 0.59$), with shorter RTs on target-present relative to target-absent trials (M = 545 vs. 597 ms). A Preview x Target Presence interaction ($F(2,22) = 43.56$, $p < .001$, $\eta_p^2 = 0.80$) was also found. On target-present trials, there was no RT difference between trials with uniform- or mixed-preview displays (M = 531 vs. 525 ms; $t(11) = 1.75$, $p > .10$), and both types of displays produced a preview benefit relative to no-preview blocks (M = 578 ms; t's > 5.64, p's < .001). On target-absent trials, RTs were shorter on trials with uniform as compared to mixed-preview displays (M = 546 vs. 605 ms; $t(11) = 9.30$, $p < .001$), but a preview benefit relative to no-preview blocks (M = 641 ms) was present for both types of displays (t's > 3.10, p's ≤ .01).

[1] This difference to Experiment 1, where preview and no-preview trials were randomly mixed, was introduced for methodological reasons. In Experiment 1, preview displays were always physically homogeneous, while full search displays always included objects in two different colours and shapes. This perceptual difference made it easy for participants to discriminate between these two types of displays, and to only respond to full target displays, in spite of the fact that preview and no-preview trials were intermixed. The inclusion of mixed-preview displays in Experiment 2 made this discrimination more difficult, as found during pilot testing. To avoid any confusion between preview and full search displays in Experiment 2, preview conditions were thus blocked.

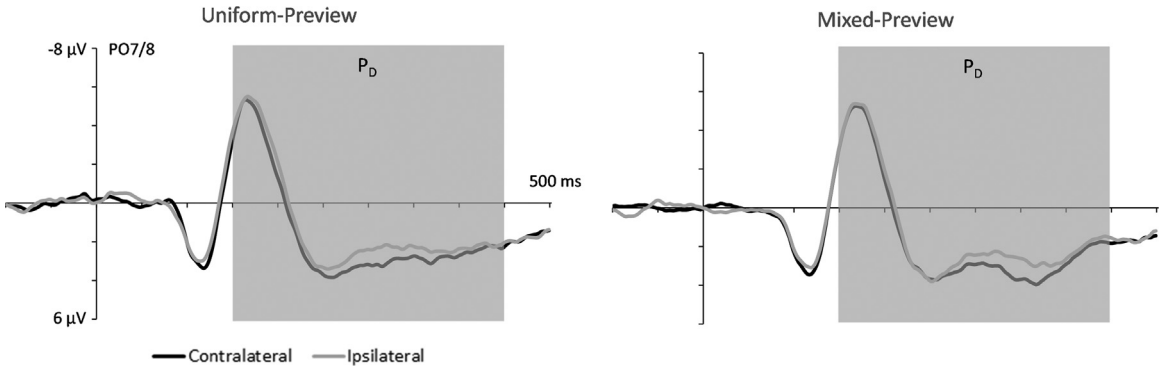

Fig. 5. Grand average ERPs obtained in Experiment 2 in the 500 ms interval after the presentation of a preview display at posterior electrode sites PO7/PO8 contralateral and ipsilateral to the task-relevant hemifield, shown separately for uniform- and mixed-preview displays.

A matching analysis of error rates showed a trend for a main effect of Preview ($F(2,22) = 3.14$, $p = .063$, $\eta_p^2 = 0.22$). Errors were lowest on trials with uniform-preview displays ($M = 1.54\%$), intermediate with mixed-preview displays (M = 2.00%), and largest in no-preview blocks ($M = 2.38\%$). In follow-up analyses, only the difference in error rates between the uniform-preview and no-preview conditions was significant ($t(11) = 2.80$, $p < .02$). There was a significant main effect of Target Presence ($F(1,11) = 5.86$, $p < .05$, $\eta_p^2 = 0.35$) where errors were more likely on target-present trials ($M = 2.33$ vs. 1.61%). There was no significant Preview × Target Presence interaction ($F(2,22) = 1.10$, $p > .30$).

3.5. Lateralised ERP components to preview displays

Fig. 5 shows ERPs elicited by preview displays in the 500 ms interval following the onset of uniform- or mixed-preview displays at electrodes PO7/8 contralateral and ipsilateral to the currently task-relevant visual hemifield. As in Experiment 1, a contralateral positivity was elicited in response to preview displays. This was confirmed in an analysis of ERP mean amplitudes obtained 150–450 ms after the onset of preview display with the factors Preview Type (Uniform, Mixed), and Laterality. A significant main effect of Laterality ($F(1,11) = 23.40$, $p = .001$, $\eta_p^2 = 0.68$) that did not interact with Preview Type ($F < 1$). Follow-up analyses confirmed that a contralateral positivity was triggered both by uniform (M diff = 0.47 μV; $t(11) = 5.42$, $p < .001$) and by mixed-preview displays (M diff = 0.39 μV; $t(11) = 2.66$, $p < .05$). As in Experiment 1, the follow-up analysis comparting preview ERPs measured during the 150–300 ms and 300–450 ms post-stimulus intervals found no interaction between Laterality and Time Window ($F < 1$), demonstrating that P_D components were not restricted to one of these time intervals.

3.6. Lateralised ERP components to search displays

Fig. 6 shows ERPs elicited by search displays at electrodes PO7/8 contralateral and ipsilateral to the currently task-relevant visual hemifield. ERPs are shown separately for target-present and target-absent search displays, and each of the three preview conditions (no-preview, uniform-preview, mixed-preview). The corresponding contralateral-ipsilateral difference waveforms are also shown. The pattern of N2pc and SPCN results was very similar to the pattern observed in Experiment 1. On target-present trials, N2pc components were elicited both when no preview display was presented and on preview trials. N2pcs were smaller and delayed for search displays that were preceded by a preview display, and were virtually identical on trials with uniform- and mixed-preview displays. For target-absent search displays, an N2pc was again elicited on no-preview trials but not on trials with uniform- or mixed-preview displays. The SPCN component was present on no-preview trials, and largely absent on preview trials, with the possible exception of target-absent trials with mixed-preview displays.

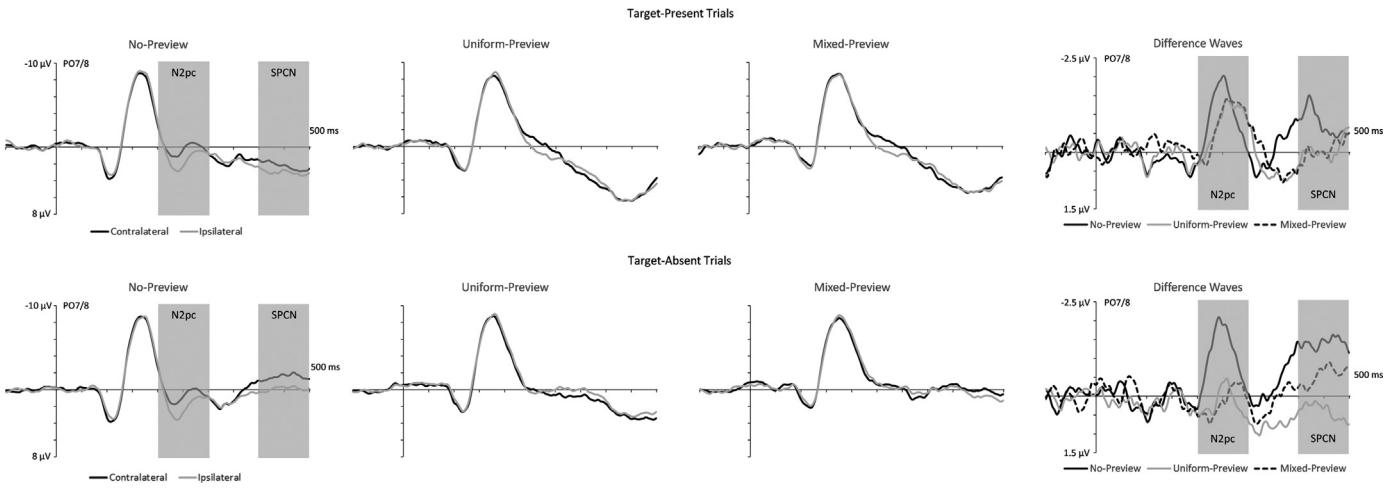

Fig. 6. Grand average ERPs obtained in Experiment 2 in the 500 ms interval following the presentation of full search displays at posterior electrode sites PO7/PO8 contralateral and ipsilateral to the task-relevant hemifield. ERPs are shown separately for target-present trials (top panels) and target-absent trials (bottom panels) in no-preview blocks, in blocks with uniform-preview displays, and blocks with mixed-preview displays. The corresponding contralateral-ipsilateral difference waveforms for these three preview conditions on target-present and target-absent trials are also shown.

3.6.1. N2pc components

N2pc mean amplitudes measured in the 200–300 ms interval after search display onset were analysed separately for target-present and target-absent trials, with the factors Preview and Laterality. For target-present trials, a main effect of Laterality ($F(1,11) = 15.21$, $p < .005$, $\eta_p^2 = 0.58$), reflected the presence of N2pc components. However, there was no interaction with Preview ($F < 1$); reliable N2pc components of similar size were elicited on no-preview (M diff = −0.98 μV), uniform-preview (M diff = −0.73 μV), and mixed-preview trials (M diff = −0.73 μV; t's > 2.56, p's < .03). For target-absent trials, there was no main effect of Laterality ($F(1,11) = 2.03$, $p > .15$, $\eta_p^2 = 0.16$), but a significant interaction between Laterality and Preview ($F(1,11) = 13.90$, $p < .001$, $\eta_p^2 = 0.56$). A reliable N2pc was elicited by target-absent displays in no-preview blocks (M diff = −0.1.07 μV; $t(11) = 3.89$, $p < .005$). In contrast, there was no evidence for the presence of N2pc components in preview blocks, either for trials with uniform-preview (M diff = 0.18 μV; $t < 1$) or for trials with mixed-preview displays M diff = 0.16 μV; $t(11) = 1.00$, $p > .30$).

A comparison of N2pc onset latencies (based on an absolute amplitude criterion of −0.5 μV) was conducted between target-present trials. As there was no numerical difference between the N2pc onset on uniform- versus mixed-preview displays (M = 233 vs. 233 ms; $t_c < 1$), data from these two types of trials were averaged and compared to the N2pc onset in no-preview blocks (M = 217 ms). This comparison confirmed that, analogous to Experiment 1, N2pc components emerged later on preview as compared to no-preview trials ($t_c(11) = 2.34$, $p < .04$). The comparison of N2pc onset latencies of N2pc components in no-preview blocks in response to target-present and target-absent search displays again revealed no difference (M = 217 vs. 213 ms; $t_c < 1$), indicating that the emergence of the N2pc was not triggered by the presence of a search target object.

3.6.2. SPCN components

ERP mean amplitudes measured in the 400–500 ms interval after search display onset were analysed in an ANOVA with the factors Preview, Target Presence, and Laterality. There was no main effect of Laterality ($F(1,11) = 2.76$, $p = .13$, $\eta_p^2 = .20$), but a reliable Laterality × Preview interaction ($F(2,22) = 15.06$, $p < .001$, $\eta_p^2 = 0.58$), as well as a significant three-way interaction ($F(2,22) = 4.98$, $p < .02$, $\eta_p^2 = 0.31$). To decompose these interactions, separate analyses were conducted for target-present and target-absent search displays. On target-present trials, a significant interaction between Laterality and Preview was present ($F(2,22) = 5.36$, $p < .02$, $\eta_p^2 = 0.33$). Pairwise comparisons found a marginally significant SPCN component on no-preview trials (M diff = −0.77 μV; $t(11) = 2.05$, p = .066), while this component was entirely absent on trials with uniform-preview displays (M diff = −0.07 μV; t < 1) or mixed-preview displays (M diff = −0.06 μV; $t < 1$). For target-absent trials, there was a significant main effect of Laterality ($F(1,11) = 7.83$, $p < .02$, $\eta_p^2 = 0.42$), as well as a Laterality x Preview interaction ($F(2,22) = 13.98$, $p < .001$, $\eta_p^2 = 0.56$). Follow-up analyses confirmed the presence of an SPCN in no-preview blocks (M diff = −1.41 μV; $t(11) = 3.94$, p < .005) and also in preview blocks when search displays were preceded by mixed-preview displays (M diff = −0.55 μV; $t(11) = 2.69$, p < .03). There was no SPCN component on target-absent trials with uniform-preview displays (M diff = 0.39 μV; $t(11) = 1.74$, $p > .10$).

3.7. Discussion of Experiment 2

As in Experiment 1, clear behavioural preview benefits were again found, with shorter RTs on preview relative to no-preview trials. The nature of the preview display (uniform versus mixed) had no effect on preview benefits on target-present trials, but these benefits were larger for uniform as compared to mixed-preview displays on target-absent trials. The differences of ERP components triggered by full target displays between preview and no-preview trials observed in Experiment 2 fully confirmed the findings of Experiment 1. In no-preview blocks, early N2pc components were triggered on both target-present and target-absent trials, again demonstrating that attention was initially allocated non-selectively to objects in the task-relevant hemifield, independently of whether these objects contained the target. These N2pcs were followed by SPCN components in no-preview blocks, as in Experiment 1, demonstrating that working memory was involved in the discrimination between targets and nontargets on the task-relevant side. In preview blocks, N2pcs were exclusively elicited on target-present trials, and there were no N2pc onset latency differences between uniform- and mixed-preview blocks. A difference between uniform- and mixed-preview blocks was found on target-absent trials at the level of the SPCN component. No SPCN was present on these trials in uniform-preview blocks, whereas a small but reliable SPCN was elicited by target-absent search displays in mixed-preview blocks (see Fig. 6, bottom right panel). In these blocks, the two new items added to target-absent displays were always physically different (e.g., a blue circle and a green diamond), and the decision that neither of them was the target may have involved their encoding into working memory on at least some trials. In line with this interpretation, target-absent RTs were reliably delayed in mixed as compared to uniform-preview blocks.

One main goal of Experiment 2 was to investigate whether the P_D components observed in Experiment 1 in response to preview displays reflect the feature-based inhibition of previewed distractors. If this was the case, P_Ds should have been larger in Experiment 2 for mixed-preview displays that contained physically dissimilar distractors relative to uniform-preview displays with homogeneous distractor objects. Reliable P_D components were found for both types of preview displays, confirming the findings of Experiment 1. However, there was no P_D amplitude difference between mixed- and uniform-preview blocks, which does not support the feature inhibition account. An alternative interpretation of the P_D components observed in the present study will be discussed below.

4. General discussion

The existence of preview benefits in visual search demonstrates that top-down control processes do not just guide attention to objects at particular locations (spatial attention) or to objects with specific target-defining attributes (feature-based attention), but also operate in the temporal domain. Search is more efficient when a subset of distractor objects is viewed in advance, but there is no agreement about the cognitive and neural mechanisms that are responsible for such preview benefits. Here, we measured lateralised ERP components in a modified version of the preview search paradigm where only stimuli in one visual hemifield were task-relevant, in order to address two questions. First, we investigated whether distractor objects in preview displays are actively inhibited, selectively maintained in working memory, or are not selectively processed at all during the preview period. Results were clear-cut. In both experiments, a contralateral positivity (P_D component) was elicited in response to preview displays. Given that the P_D is interpreted as an ERP marker of the inhibition of distractor objects in visual search (e.g., Gaspelin and Luck, 2018), these findings provide new support for the hypothesis that preview benefits are associated with active inhibitory mechanisms that are triggered in a top-down fashion during the preview period. These findings are in line with the suggestion that previewed distractors are subject to inhibitory visual marking (e.g., Watson et al., 2003), but not with suggestions that previewed items are attended (e.g., Belopolsky et al., 2005) or actively maintained in visual working memory (e.g., Al-Aidroos et al., 2012), in order to bias subsequent target selection processes away from these objects. Any attentional selection of previewed distractors on the task-relevant side should have elicited N2pc components, and their encoding into working memory should have been reflected by CDA components. In fact, there was no evidence for any posterior contralateral negativities in response to preview displays in either experiment. The presence

of P_D components to preview displays is also inconsistent with claims that preview benefits exclusively reflect the ability of new objects in full search displays to capture attention, and not any selective processing of distractor objects during the preview period (e.g., Donk and Theeuwes, 2001). In this case, no lateralised ERP components should have been triggered at all by the preview displays.

While the presence of P_D components to preview displays demonstrated in this study is broadly consistent with an inhibitory visual marking framework, other aspects of the P_D results observed here require further consideration. In Experiment 1, P_D amplitudes did not differ between preview displays that contained two or four distractors on the task-relevant side. If active inhibition had been applied separately to the location of each distractor object, as postulated by the visual marking hypothesis, P_D amplitudes should have increased as the number of to-be-inhibited object locations increased. Alternatively, P_D components might reflect feature-based inhibition, with P_D amplitudes increasing with the number of inhibited features. The P_D results observed in Experiment 2 did not provide any support for this possibility. Here, identical P_D components were elicited by uniform-preview displays where all distractors were identical, and by mixed-preview displays where distractors differed in their colour and shape. A third possibility is that the P_D components elicited by preview displays in the present study reflect a single inhibitory tag that is applied globally to all distractor objects in the task-relevant hemifield during the preview period. Such a hemifield-wide inhibition strategy was feasible in the current experiments where a modified preview search paradigm was used where only one display side was relevant. This lateralised preview search design was required in order to be able to measure lateralised ERP components to preview and full search displays. The question whether similar inhibitory processes are also activated in standard preview search tasks where target objects can appear in both hemifields will need to be investigated in future studies with alternative methods. Finally, it is important to note that in the present experiment, P_D components were observed during the interval following to-be-ignored preview displays, prior to the presentation of full search displays, whereas previous P_D studies measured this component in response to salient distractors in task-relevant search displays. It is possible that inhibitory processes activated during the preparation for an upcoming full search display during the preview period differ from the processes triggered by distractors in displays that can also contain a target. For these displays, distractor inhibition reflected by a P_D may not be elicited when a strong top-down task set for target features is activated (e.g., Barras and Kerzel, 2016). This was also the case in the present study, where target objects were defined by a feature conjunction. Thus, the presence of P_D components in response to preview displays suggests that top-down task sets do not prevent distractor inhibition during the preparation for an upcoming target selection task.

The second question addressed in the present study was how the presence versus absence of preview displays would affect the attentional processing of objects in full search displays. To assess this, we recorded lateralised ERP components associated with the allocation of attention to search display objects on the task-relevant side (N2pc), and with the subsequent encoding of these objects into visual working memory (SPCN) on preview and no-preview trials. The ERP results obtained in both experiments were highly consistent, and revealed marked differences in the time course of attentional selectivity on these two types of trials. On preview trials, attention was directly allocated to target objects, and not to any other items on the task-relevant side. This was demonstrated by the fact that N2pcs were exclusively elicited by target-present but not by target-absent displays. The onset latency of N2pc components to target-present displays on preview trials (252 ms and 233 ms in Experiments 1 and 2, respectively) indicates that target objects could be selected relatively rapidly on these trials (see also Kiss and Eimer, 2011, for comparable target N2pc onset latencies on preview trials under conditions where both display sides were task-relevant). Further evidence for an efficient selection of target objects on preview trials was provided by the observation that no SPCN components were elicited on these trials. This suggests that information about the presence or absence of a target was available during the perceptual processing of search display objects, and did not require their encoding into working memory.

A different temporal pattern of attentional selectivity was observed on no-preview trials. Here, N2pc components were triggered at the same time for target-present and target-absent search displays, demonstrating that attention was initially allocated to objects on the task-relevant display side, irrespective of whether the target was among these objects. Furthermore, reliable SPCN components were elicited in response to both target-present and target-absent search displays on no-preview trials, indicating that decisions about the presence versus absence of targets involved the activation of visual working memory. There are two possible accounts for the presence of N2pc and SPCN components to target-present as well as target-absent displays on no-preview trials. One possibility is that all search display objects on the task-relevant side were initially processed in parallel until a competitive attentional advantage for the target emerged. There is also an alternative serial selection scenario, which assumes that attention was initially allocated randomly to one of the objects on the relevant side, and then sequentially to other objects on this side until a target was found. Both a parallel and serial selection account imply that attentional processes on no-preview differed qualitatively from those on preview trials, where attention was directly allocated to target objects, and not to other objects on the task-relevant side. This difference in the target selectivity of attentional processing between these two types of trials can account for the behavioural preview benefits observed in both experiments.

In summary, the present study found ERP evidence for the suppression of previewed distractors, as well as systematic differences in the attentional processing of search displays on preview versus no-preview trials. Although it is tempting to interpret the latter as a direct consequence of the former, other factors such as the abrupt onset of new objects on preview trials may also convey competitive advantages to new objects on preview trials (e.g., Donk and Theeuwes, 2001; Jiang et al., 2002; Kiss and Eimer, 2011). Such non-inhibitory mechanisms could contribute to the behavioural preview benefits and their electrophysiological correlates demonstrated in the current study, above and beyond any benefits produced by distractor suppression during the preview period.

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