

Attentional capture during visual search is attenuated by target predictability: Evidence from the N2pc, Pd, and topographic segmentation

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Abstract

Attentional capture by salient distractors has been confirmed by the occurrence of an N2pc to the salient distractor. To clarify some failures to replicate this finding, we varied target predictability to induce different search modes. In the unpredictable target condition, the target shape varied randomly from trial to trial, favoring singleton detection mode. In the predictable target condition, the target shape remained the same in a block of trials, favoring feature search mode. With unpredictable targets, we observed an N2pc toward the salient color distractor, confirming attentional capture in singleton search mode. With predictable targets, there was no N2pc to the salient distractor, but a distractor positivity (Pd), suggesting distractor suppression. Also, differences emerged in the topographic segmentation of N2pc and Pd. Further, the amplitude of the N2pc toward the target was larger with predictable than with unpredictable targets.

Descriptors: Visual search, N2pc, EEG, Saliency, Bottom-up, Top-down, Predictability

While the top-down or goal-driven control of attention reflects expectations and intentions of an observer (Bacon & Egeth, 1994; Folk & Remington, 1998; Kim & Cave, 1999; Posner, 1980), bottom-up or stimulus-driven control of attention (Theeuwes, 1991, 2010; Yantis & Jonides, 1990) is modulated by the saliency of a stimulus. While the question of whether one or the other of these processes exclusively controls attention is outdated, their temporal interplay is still a matter of debate. When looking for a target, it is not completely clear whether and when attention is automatically captured by a salient distractor or whether this capture can be attenuated or suppressed by top-down processes. For instance, it has been claimed that selection occurs exclusively in a stimulus-driven fashion in the early stages of perceptual processing, while goal-driven control occurs after the initial saliency-based capture (Theeuwes, 2010).

In contrast, it has been proposed that attentional capture depends on the search mode induced by the experimental situation (Bacon & Egeth, 1994). For instance, while searching for a shape singleton, an irrelevant color singleton may involuntarily attract attention because observers do not search for a particular shape, but for the odd element. Thus, singleton detection mode allows for odd elements defined along irrelevant dimensions to capture attention. However, when observers are forced to search for a particular feature value, for instance, by increasing the variability of

nontarget shapes in the display, attentional capture by irrelevant color distractors is abolished.

Event-Related-Potentials

Allocation of attention in a visual search task has been investigated using the N2pc event-related potential (ERP) component. The N2pc is greatest at posterior sites in the N2 latency range, about 200–300 ms after stimulus onset. It is defined as a negative deflection in electrodes contralateral to the target compared to ipsilateral electrodes (Luck & Hillyard, 1994). Functionally, this component is usually associated with the allocation of attention to task-relevant stimuli (Eimer, 1996; Mazza, Turatto, & Caramazza, 2009) or with the inhibition of distractors (Luck & Hillyard, 1994; Luck, Hillyard, Mouloua, & Hawkins, 1996).

A study of Hickey, McDonald, and Theeuwes (2006) provided compelling evidence for the view that attention is attracted by a salient, but task-irrelevant color singleton. The N2pc component was measured not only in response to a lateral shape target, but also in response to a lateral color distractor. When a lateral distractor was shown with a target above central fixation, an N2pc component was obtained that had the same amplitude as with the lateral target, showing that the salient distractor captured attention. In addition, in a display with a distractor on the opposite side of the target, the N2pc was elicited later in time and was smaller than in the target-only condition, which suggests that attention was captured first by the distractor and then reoriented toward the target.

However, Eimer and Kiss (2008) (see also Lien, Ruthruff, Goodin, & Remington, 2008) challenged the idea of involuntary capture of attention. They did not find an N2pc component for a

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salient cue when the task did not require detection of this feature in the target display. An N2pc to a salient cue was only observed when the subsequent target display required detection of the cued feature (e.g., a color cue and a color target). In contrast to the conclusions of Hickey and colleagues (2006), the N2pc did not show bottom-up capture of attention by salient events, but reflected contingent attentional capture. Further, Wykowska and Schubo (2011) did not observe an N2pc to a salient color distractor in a paradigm that was very similar to Hickey and colleagues.

However, we argue that a shared property of studies that failed to find the N2pc component to salient distractor stimuli (Eimer & Kiss, 2008; Lien et al., 2008; Rodriguez Holguin, Doallo, Vizoso, & Cadaveira, 2009; Schubo, Schroger, Meinecke, & Muller, 2007; Wykowska & Schubo, 2011) was that the target was fixed in a block of trials. For instance, in Eimer and Kiss (2008), observers searched for color or onset targets by block, and in Wykowska and Schubo (2011), observers searched for a circle among bars throughout the experiment. In contrast, participants in Hickey and colleagues' (2006) study searched for a shape singleton that changed from trial to trial. The target could either be a diamond among circles or a circle among diamonds. Consistent with these observations, Pinto, Olivers, and Theeuwes (2006) already noted that effects of the additional color singleton on reaction times (RTs) were larger with unpredictable targets than with predictable targets.

Purpose of Our Experiment

In the present task, we investigated effects of target predictability on attentional capture by color singletons. Our experiment was modeled on the study by Hickey and colleagues (2006), but the within-subject factor target predictability was added. Observers searched for a form singleton and indicated the line orientation inside the form singleton by speeded key press.

We predict that attentional capture by the distractor, as indicated by an N2pc to the distractor, is attenuated when targets are predictable compared to when the target is unpredictable. With unpredictable targets, the target was randomly a diamond among circles or a circle among diamonds. Unpredictable targets made it impossible to search for a particular shape. Rather, the odd element had to be detected on each trial, which forced observers into singleton detection mode. With predictable targets, it was possible to search for a particular shape, because the target shape remained the same in a block of trials. Observers could therefore access feature search mode. On the basis of work by Bacon and Egeth (1994), we expect less attentional capture in feature search mode than in singleton detection mode. Thus, an N2pc to the distractor should be absent with predictable targets that result in feature search while it should be present with unpredictable targets that result in singleton detection.

Note that the salient color distractor was always task irrelevant and any distractor-related N2pc would therefore provide evidence for bottom-up capture of attention. It is known that temporarily making a distractor task relevant increases its chances of attracting attention (Rodriguez Holguin et al., 2009). Further, a distractor positivity (Pd), which occurs slightly later than the N2pc (Hickey, Di Lollo, & McDonald, 2009; Hilimire, Mounts, Parks, & Corballis, 2011; Sawaki & Luck, 2010), would reveal the presence of the active inhibition of the distractor.

Additionally, we will compare the N2pc with two different trial transitions in the unpredictable target shape condition. When the target feature (circle or diamond) remains the same in trials n and $n + 1$, priming of pop-out (Maljkovic & Nakayama, 1994) is pos-

sible. Priming of pop-out is considered a rather passive bottom-up process unrelated to search strategies. Possibly, intertrial priming increases the N2pc in trials in which the target shape is repeated compared to trials in which the target shape changes from one trial to the next. If intertrial priming affects the magnitude of the N2pc with unpredictable targets, it may be that intertrial priming underlies differences between predictable and unpredictable targets: With predictable targets, there is priming of pop-out on every trial because the target is repeated. With unpredictable targets, priming of pop-out occurs on only half of the trials.

Beyond ERPs

ERP investigations are often focused on a discrete number of electrodes (the scalp distribution of the N2pc is discussed by Praamstra & Kourtis, 2010). Some authors use the maximal peak of a single site of electrode (e.g., PO7/8, P7/8, O1/2, etc.), others use 2 or 3 electrode sites (e.g., PO7/8 and P7/8) or by pooling waveforms from 3 to 6 electrodes. In contrast, the topographical analysis allows for the classification of the brain's electrical topography over the entire scalp and for the comparison of the distribution of electrical signal across different conditions in time. So far, the scalp topography has never been used as an index of the occurrence of the N2pc or Pd.

Materials and Method

Participants

Fifteen right-handed students of the University of Geneva without any neurological or psychiatric indications participated in this experiment for course credit. Participants were naive as to the purpose of the experiment. The local ethics committee had approved the study, and informed consent was obtained from participants prior to the experiment. Data from three subjects were discarded due to the large numbers of choice errors (two participants with less than 70% correct response) and excessive eye movements (one participant).

Stimuli

We used the Cogent toolbox (www.vislab.ucl.ac.uk/cogent.php) for MATLAB to display the stimuli. Ten shapes were presented at 6° of eccentricity on a black background. Diamonds (1.67° diameter) and circles (1.5° diameter) were drawn in red or green one-pixel (0.022°) lines. The diameters were chosen to equal the total line length between diamonds and circles. Thus, the overall luminance of diamonds and circles was equal. Inside every shape, a vertical or horizontal line (1.2° length) was drawn in gray. The luminance was ~11.6 cd/m² for red, green, and gray. In the unpredictable condition, the target shape varied randomly from trial to trial. Consequently, the shape of the nine distractor stimuli also changed randomly. In the predictable condition, the target shape was fixed during a block of trials. In both cases, the color varied randomly between red and green. As in Hickey and colleagues' (2006) study, 392 of the trials (1/3) were without color singleton (control condition, CC). In the remaining trials, a nontarget element had a color different from the nine remaining elements. Trials with color singleton were divided into four conditions of 196 trials (1/6) according to the position of color and shape singletons. The two positions directly above and below the fixation mark are referred to as vertical positions. The four positions on each side from fixation are

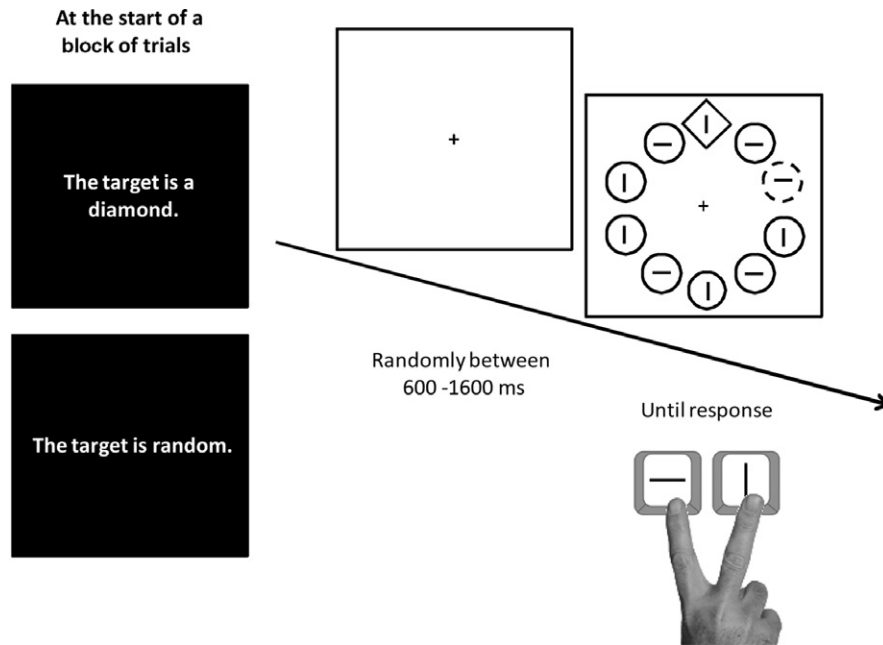


Figure 1. Illustration of experimental trial. Observers indicated the orientation of the line in the shape singleton. The shape singleton was predictable or unpredictable.

referred to as horizontal positions. When the target was at a vertical position and the color singleton at a horizontal position (TvDh), we expect an N2pc to the horizontal distractor if bottom-up capture of attention occurred. An N2pc to the target is expected when the target is horizontal and the distractor is vertical (ThDv) or when the distractor is on the same side as the target (ThDh ipsi). Finally, it is not clear whether an N2pc will occur if both target and distractor are horizontal but on opposite sides (ThDh contra).

Procedure

Subjects were seated in a sound-attenuated room at 85 cm from a 17" LCD screen refreshed at 60 Hz. The order of conditions was randomized within each block, and predictable and unpredictable target conditions alternated in blocks of 48 trials that took about 1.5 min to complete. As shown in Figure 1, each trial began with a gray fixation cross on a black background for a random interval between 600 and 1,600 ms. The stimulus remained on the screen until a response was given. It has been shown previously that the N2pc to the distractor vanishes with short presentation times (Kiss, Grubert, Petersen, & Eimer, 2012). The participants were instructed to report the orientation of a line inside the form singleton as quickly as possible while maintaining accuracy better than 90%. Responses were given using two keys of a standard keyboard with one hand (counterbalanced across subjects). Incorrect responses were indicated by a message displayed at the center of the screen. Before the experiment, participants completed 48 trials in which they were trained to avoid moving their eyes in the direction of the target. Participants performed two sessions of 24 blocks of 48 experimental trials each for a total of 2,304 trials.

Electroencephalogram (EEG) Recording and Analysis

A BioSemi (Amsterdam, The Netherlands) ActiveTwo amplifier system AD-Box with 64 active Ag/AgCl electrodes sampled at 1024 Hz was used. Moreover, we used the voltage difference of

two horizontal electrooculogram (HEOG) electrodes, fixed at outer canthi side of both eyes, to detect horizontal eye movements. The two earlobes were used as online and offline references.

Using BrainVision Analyzer 2.1 (Brain Products, Gilching Germany), trials corresponding to incorrect behavioral performance were eliminated from the analysis, as were trials with RTs smaller than 200 ms and larger than 2,000 ms. Then, baseline correction (-100 ms to stimulus onset) was performed before artifact exclusion. We excluded blinks and vertical eye movements ($Fpz \pm 60 \mu V$), horizontal eye movements ($HEOG \pm 40 \mu V$), and all different artifacts (all electrodes $\pm 100 \mu V$). When the electric signal of an electrode was too noisy during the entire recording, it was spline interpolated (order 4, degree 10). No interpolation was used for the electrode PO7/PO8. Typically, 3% of the total electrodes were corrected. When we had doubts about the signal quality, epochs were checked manually. We computed the average for left and right targets separately and rejected one subject whose HEOG from 0 to 350 ms was larger than $\pm 3 \mu V$ (Luck, 2005). On average, 7% of the trials were removed for each condition due to incorrect responses and 22% of the data were removed because of artifacts.

EEG epochs lasted from 100 ms before to 500 ms after the onset of the display. All analyses of ERP amplitude were conducted on unfiltered data. In the following statistical analysis, we corrected for nonsphericity by Greenhouse-Geisser correction of the degrees of freedom.

Topographic Analysis

The topographic microstate segmentation (Michel, Seeck, & Landis, 1999; Pascual-Marqui, Michel, & Lehmann, 1995) was done using Cartool (Denis Brunet, Functional Brain Mapping Lab, University of Geneva). The grand average differences between contralateral minus ipsilateral were calculated, low-pass filtered at 20 Hz, and submitted to analysis by Cartool.

To detect microstates, voltage maps corresponding to each time frame of the grand average ERP were subjected to a Topographic Atomize & Agglomerate Hierarchical Clustering analysis, which segments the data into periods of stable topographical patterns, varying only in intensity over time (for a tutorial, see Murray, Brunet, & Michel, 2008). The optimal number of clusters (6 for our data) was determined objectively using the clusters with both minimal cross-validation (Pascual-Marqui et al., 1995) and maximal Krzanowski-Lai (Tibshirani & Walther, 2005). Next, we fitted the different maps to the individual averages in order to determine how long (in milliseconds) each map was present at the single subject level. The resulting durations were submitted to analysis of variance (ANOVA). The analyses were run on the same time window as the analyses of ERP mean amplitude.

Comparing the topography of the difference wave allows us to describe the presence of specific N2pc-related and Pd-related maps and to explore the dynamics of these maps in our experimental conditions. While the distribution of electrical activity observed at the scalp may be the result of a virtually unlimited number and combination of neural sources, differences in topography indicate differences in neural sources.

Results

Behavioral Performance

Reaction time and error rate are shown in Table 1. A repeated measures analysis of variance (rANOVA) with target predictability (predictable, unpredictable) and presence of color singleton (absent, present) as factors was conducted. RTs were shorter without than with color singleton (768 vs. 814 ms), $F(1,11) = 18.45$, $p = .01$. RTs to predictable targets were faster than RTs to unpredictable targets (689 vs. 833 ms), $F(1,11) = 73.04$, $p = .001$. The effect of distractor presence was larger with unpredictable (858 vs. 925 ms) than with predictable targets (679 vs. 698 ms), $F(1,11) = 9.81$, $p = .01$. Accuracy was better with predictable than with unpredictable targets (.98 vs. .95), $F(1,11) = 22.96$, $p = .001$, and better without than with a color singleton (.97 vs. .96), $F(1,11) = 11.51$, $p = .006$. An interaction effect was confirmed, $F(1,11) = 4.954$, $p = .048$, explained by a small, but significant effect of distractor presence with unpredictable targets (.96 vs. .95), $t(11) = 3.40$, $p = .006$, which was not observed with predictable targets (.98 vs. .98). The pattern of behavioral results is a close replication of Pinto and colleagues' (2006) study.

Table 1. Mean Response Time (RT) and Accuracy for Predictable and Unpredictable Target Conditions

Distractor position	Unpredictable targets		Predictable targets	
	RT	Accuracy	RT	Accuracy
Control	858 (29)	.96 (0.007)	679 (13)	.98 (0.004)
TvDh	915 (41)	.95 (0.008)	700 (17)	.98 (0.004)
ThDv	942 (47)	.95 (0.008)	697 (14)	.98 (0.003)
ThDh contra	882 (42)	.95 (0.007)	685 (14)	.97 (0.005)
ThDh ipsi	971 (46)	.93 (0.011)	718 (20)	.97 (0.006)

Notes. Means and standard error are given in the format M (SE).

TvDh = target vertical, distractor horizontal; ThDv = target horizontal, distractor vertical; ThDh contra = target horizontal, distractor horizontal and contralateral to target; ThDh ipsi = target horizontal, distractor horizontal and ipsilateral to target.

ERP Data

N2pc mean amplitude. Waveforms were computed separately for left and right singletons and experimental condition. The N2pc is the difference between the contralateral and the ipsilateral signal on electrodes PO7/8. The mean contra- and ipsilateral amplitudes and the difference waves are shown in Figures 2 and 3, respectively. The voltage differences were subjected to a rANOVA with target predictability (predictable, unpredictable) and singleton position (CC, TvDh, ThDv, ThDh ipsi, ThDh contra) as within-subject factors. A rANOVA on the typical time interval of the N2pc (200–280 ms) showed a larger N2pc with predictable than unpredictable targets (-1.53 vs. -0.83 μ V), $F(1,11) = 27.7$, $p = .001$. The effect of singleton position, $F(1.99,18.32) = 4.59$, $p = .029$, showed a smaller N2pc to horizontal distractors in the TvDh condition (-0.41 μ V) than in the remaining singleton conditions (more negative than -1.12 μ V). The interaction between target repetition and singleton position, $F(2.52,27.72) = 8.4$, $p = .001$, showed that the reduction of the N2pc to horizontal distractors in the TvDh condition occurred only with predictable, $F(4,44) = 11.09$, $p = .001$, but not with unpredictable targets, $F(4,44) = 0.15$, $p = .96$. To confirm this conclusion, we carried out planned t tests against zero on the N2pc for each combination of target repetition and singleton position. The N2pc was significant for all singleton positions with unpredictable targets, $t(11) > 3.34$, $ps < .05$. With predictable targets, the N2pc was significant for all singleton positions, $t(11) > 2.45$, $ps < .033$, except with horizontal distractor and vertical target in the TvDh condition, $t(11) = 0.19$, $p = .851$.

Intertrial priming. In order to investigate intertrial priming in the mixed condition, we divided trials according to whether the target shape was the same as in the preceding trial or different. We ran a rANOVA with target repetition (repeated, changed) and singleton position (CC, TvDh, ThDv, ThDh ipsi, ThDh contra) as within-subject factors. There were no main effects or interactions, $ps > .89$. The fact that the N2pc was not larger in trials with repeated target shape than in trials with changed target shape suggests that intertrial priming did not cause the difference between unpredictable and predictable target conditions.

Distractor positivity analysis. The mean voltage difference (contra-ipsi, as for the N2pc) during the 280–340 ms time window was calculated. We performed a rANOVA, with the same factors as in the N2pc analysis. No effect of target repetition was observed, $p = .296$, but an effect of singleton position emerged, $F(2.34,25.73) = 10.13$, $p = .001$, indicating a larger Pd to horizontal distractors in the TvDh condition (0.25 μ V) than the target-related components in the control, ThDv, ThDh contra, and ThDh ipsi conditions (-0.62 , -0.61 , -1.19 , and -0.47 μ V, respectively). The Pd to the horizontal distractor in the TvDh condition was significantly different from zero with predictable targets (0.4 μ V), $t(11) = 2.55$, $p = .027$, but not with unpredictable targets (0 μ V), $p = .667$.

Topographic Maps of Difference Waves

As shown in Figure 4, an N2pc map was extracted by clustering, with a maximum at the PO7/8 electrode corresponding in shape to past reports (Brisson & Jolicœur, 2008; Eimer & Kiss, 2008; Eimer, Kiss, Press, & Sauter, 2009; Gamble & Luck, 2011; Hickey, van Zoest, & Theeuwes, 2010; Kiss, Driver, & Eimer, 2009; Kiss, Van Velzen, & Eimer, 2008). The N2pc map to the horizontal

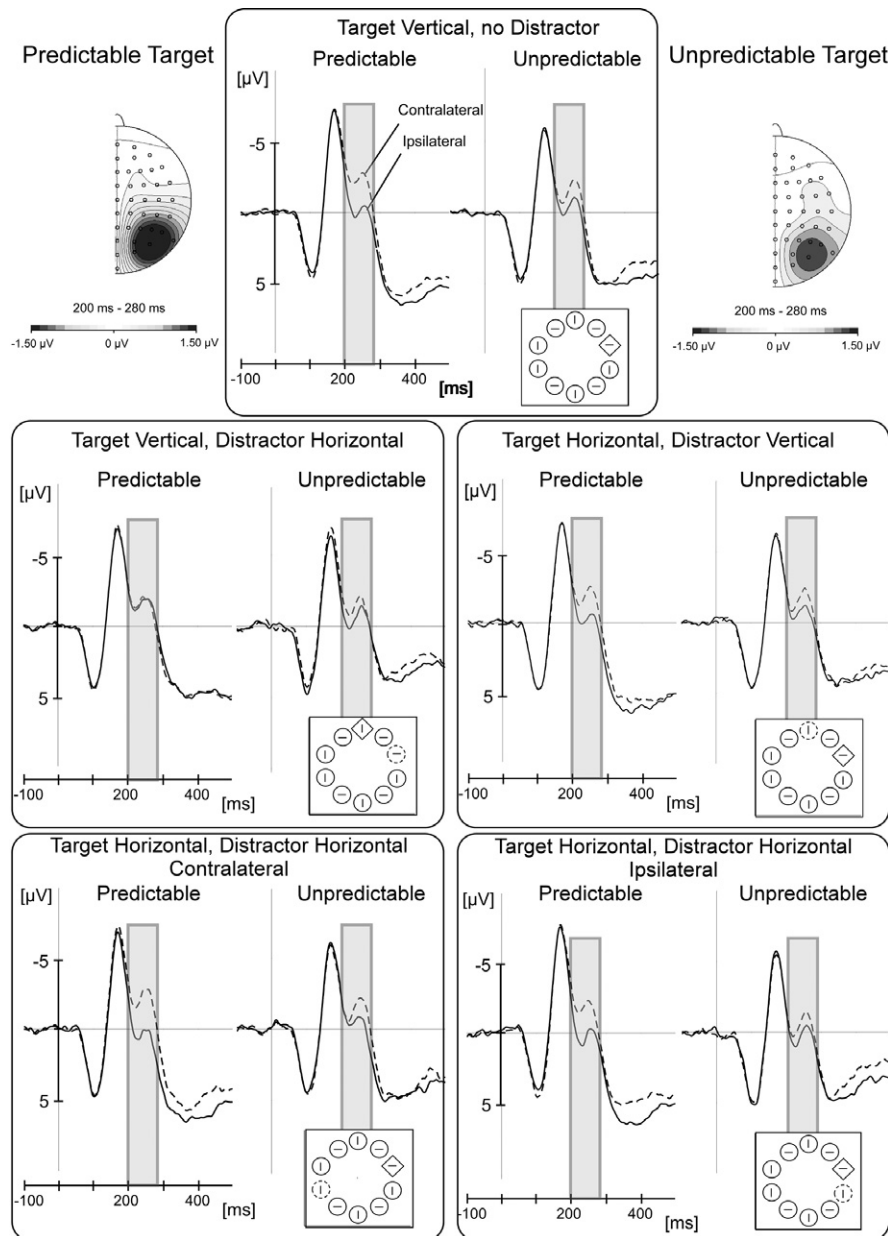


Figure 2. Contralateral and ipsilateral ERPs. The topography of the N2pc component is shown for the control condition. The maximum amplitude is located on electrode PO7/PO8, during the 200–280 ms time range (in gray). Traces in the graph were low-pass filtered with a Butterworth zero phase shift filter (40 Hz with 24 db/octave) for clarity.

distractor in the TvDh condition only occurred when the target was predictable, but not when it was unpredictable. We also noticed a Pd map with a maximum at O1/O2 electrodes, which occurred to horizontal distractors in the TvDh condition with both predictable and unpredictable targets.

Next, we fitted maps that appeared in our two time windows of interest to the topography of individual participants and determined the time each map of interest (N2pc or Pd) was present. We used the same interval as in the ERP experiment; that is, 200–280 ms for the N2pc and 280–340 ms for the Pd. In order to fit the data as well as possible, we added two maps co-occurring with the N2pc and Pd to the analysis. These maps represent “noise maps” because no further assumptions are made about their functional significance. The mean proportions of map durations are shown in Figures 5 and 6.

Then, a rANOVA (2 Target Repetitions \times 5 Singleton Positions) was run on the duration of the N2pc and Pd maps. In the early interval (200–280 ms), an interaction of target repetition and singleton position was observed, $F(4,44) = 3.05$, $p = .027$, showing that the duration of the N2pc map to horizontal distractors in the TvDh condition was shorter with predictable than with unpredictable targets (24 vs. 49 ms, see Figure 5).

In the late interval (280–340 ms), no significant interaction effect was found, $p = .29$. Only an effect of distractor position emerged, $F(2.20,24.22) = 7.68$, $p = .002$, corroborating that the Pd map lasted longer with horizontal distractors in the TvDh condition (41 ms) than in the other conditions (19, 20, 14, 23 ms for control, ThDv, ThDh contra, and ThDh ipsi, respectively). Please note that the Pd map to horizontal distractors in the TvDh condition lasted longer independently of target repetition, while the mean Pd

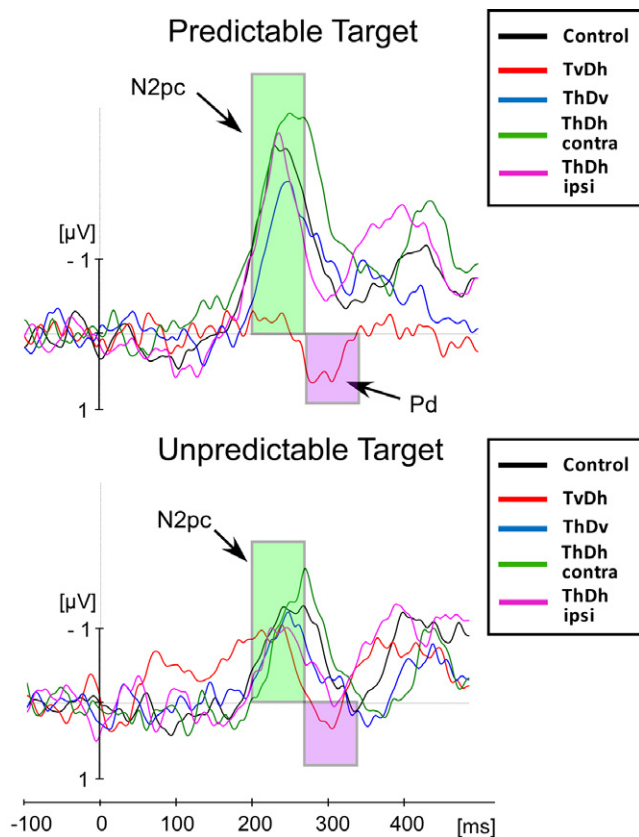


Figure 3. Difference between ipsi- and contralateral electrodes. The N2pc/Pd occurred to the lateral target in the control, ThDv, ThDh contra, and ThDh ipsi conditions. The N2pc/Pd occurred to the lateral distractor in the TvDh condition. Note the presence of a Pd in the predictable target condition. Traces in the graph were low-pass filtered with a Butterworth zero phase-shift filter (40 Hz with 24 dB/octave) for clarity.

amplitude (see above) was only significantly different from zero with predictable, but not with unpredictable targets.

Distractor positivity reanalysis. We conducted an additional ERP analysis using the O1/O2 sites as suggested by the maximum amplitude at these electrodes in the Pd map. A rANOVA (2 Target Repetitions \times 5 Singleton Positions) showed no effect of target repetition, $p = .705$. However, an effect of singleton position emerged, $F(2.07, 22.82) = 6.63$, $p = .004$, with a larger Pd to the horizontal distractor in the TvDh condition ($0.53 \mu\text{V}$) compared to the control, ThDv, ThDh contra, and ThDh ipsi conditions (-0.3 , -0.38 , -0.74 , and $-0.07 \mu\text{V}$, respectively). This time, the Pd to horizontal distractors in the TvDh condition was significant with predictable targets ($0.61 \mu\text{V}$), $t(11) = 3.59$, $p = .004$, and with unpredictable targets ($0.47 \mu\text{V}$), $t(11) = 3.42$, $p = .006$.

Discussion

In the present study, we assessed how effects of salient stimuli on attentional selection are modulated by task requirements. In general, attentional selection of task-relevant, lateralized stimuli can be measured using the N2pc component. It has been hotly debated whether attentional capture and the N2pc occur involuntarily in response to task-irrelevant, salient stimuli (e.g., Hickey et al., 2006; Wykowska & Schubö, 2011). Independent evidence

from the contingent attentional capture paradigm has favored the role of top-down intentions over bottom-up saliency (Eimer & Kiss, 2008; Kiss, Jolicœur, Dell'acqua, & Eimer, 2008; Lien et al., 2008). Using the additional singleton paradigm, we compared whether attentional selection of a salient distractor occurs with and without foreknowledge about the upcoming target.

First, we demonstrate that target predictability modulates the amplitude of the N2pc. We obtained a larger N2pc when the target feature was predictable during a block of trials. Previously, the N2pc was related to attentional filtering (Luck & Hillyard, 1994) because the N2pc was larger in difficult searches with targets that resembled the distractors compared to easy searches with pop-out targets. In the present experiment, target-distractor similarity was the same in all experimental conditions such that the cause for the difference in the magnitude of the N2pc has to be sought elsewhere. Our results are more in line with the notion that the N2pc reflects the allocation of attentional resources toward task-relevant stimuli (Ansorge, Kiss, Worschech, & Eimer, 2011; Eimer, 1996; Kiss & Eimer, 2011; Kiss, Jolicœur et al., 2008; Mazza et al., 2009). Our results suggest that more efficient allocation of attention, as with predictable targets, leads to a larger magnitude of the N2pc

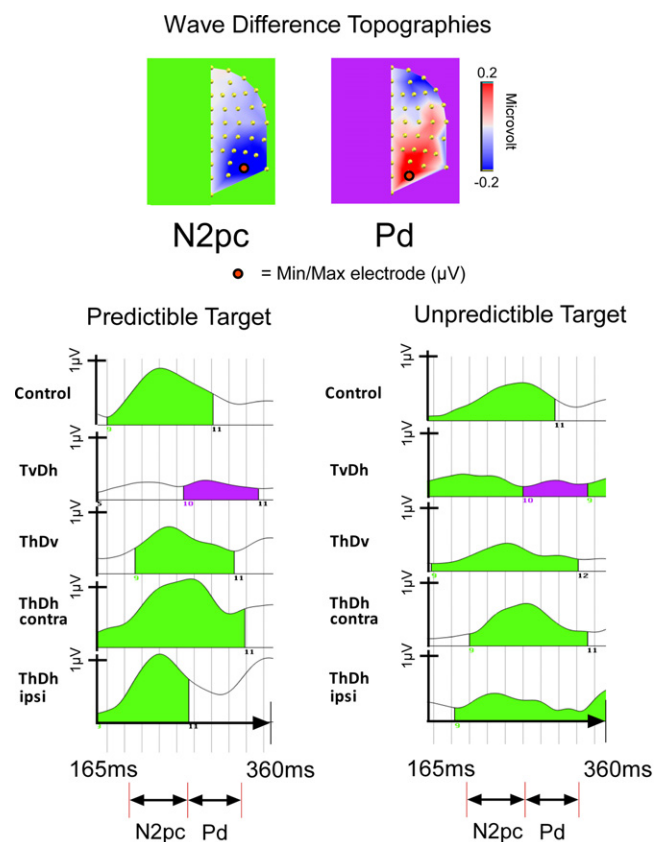


Figure 4. The top panel shows the two maps and the site of minimal and maximal amplitude (note that the midline electrodes have been set to zero). Because difference wave topographies were calculated, only one half of the electrodes are displayed. We chose the right set of electrodes, but this choice was random. The maps correspond to the N2pc (in green, min/max at PO7/PO8) and Pd (in purple, min/max at O1/O2). The bottom panel shows that the N2pc map was present for each condition except TvDh with predictable targets. In the time interval of the Pd, a corresponding map is observed both with predictable and unpredictable targets, even if no clear Pd is found in the typical ERP analysis for TvDh with unpredictable target.

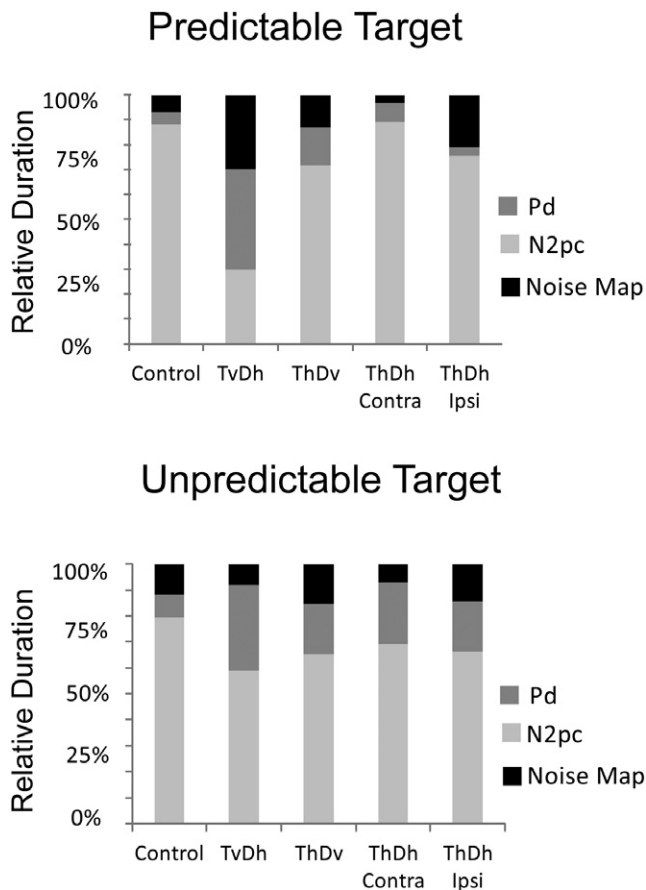


Figure 5. Mean proportions of map durations for the N2pc, Pd, and noise maps after individual fitting in the early segment of analysis (200–280 ms). The N2pc map is strongly reduced in the TvDh condition with predictable targets (top panel).

component. Selection was more efficient with predictable targets than with unpredictable targets because RTs were faster and the distracting effect of the color singleton was smaller. The efficiency of attentional selection, in turn, may be determined rather passively by priming of pop-out (Kristjansson & Campana, 2010; Maljkovic & Nakayama, 1994) or more actively by contributions of working memory to attentional selection (for reviews, see Olivers, Peters, Houtkamp, & Roelfsema, 2011; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). The finding that the N2pc was about as large after repetition of a target shape compared to a change of target shape from one trial to the next (see intertrial analysis above) is more in line with contributions from working memory. Priming of pop-out would have predicted a larger N2pc when the target shape was repeated.

Second, we observed an N2pc to a lateral color distractor only with unpredictable, but not with predictable targets, which partially explains the conflicting results in previous studies. Therefore, reports of an N2pc to a salient lateral distractor with unpredictable targets (Hickey et al., 2006) and reports of its absence with predictable targets (Eimer & Kiss, 2008; Wykowska & Schubo, 2011) may be caused by different search modes. With predictable targets, observers were able to use feature search. They could store the target's shape in working memory and look for a particular object. With unpredictable targets, observers had to use singleton detection mode because the target feature changed randomly from trial to

trial. Our results support Bacon and Egeth's (1994) idea that only singleton detection mode leaves room for attentional capture to occur.

Further, as suggested by Woodman, Arita, and Luck (2009), observers may anticipate an attention shift to a particular object, and not to a particular location, in the predictable target condition, which could explain how knowledge of the shape at the beginning of each block increased the N2pc to the target and reduced the N2pc to the distractor. Yet another view is offered by the dimensional weighting theory of attention (Muller, Heller, & Ziegler, 1995; Muller, Reimann, & Krummenacher, 2003), which claims that there is top-down adjustment of feature selection before trial onset. This adjustment allows for rapid selection of the expected feature, an effect which is confirmed by our data. Our current results suggest that better guidance of attention towards the location of the target (cf. larger N2pc to the target in control condition) also prevents it from going astray (cf. no N2pc to the distractor in the TvDh condition).

Further, we noticed that with lateral distractors in the TvDh condition, a positive deflection occurred with predictable targets, but was not significant at PO7/PO8 with unpredictable targets. Hickey et al. (2009) identified this positive component and labeled it Pd. They associated it with distractor suppression, and this account has been corroborated in subsequent work (Hilimire, Hickey, & Corballis, 2012; Hilimire et al., 2011; Sawaki, Geng, & Luck, 2012; Sawaki & Luck, 2010, 2011). In our experiments, the Pd shows that a salient lateral distractor was suppressed when the target was presented above or below the fixation cross. Also, it is surprising to note that with predictable targets, the salient lateral distractor was suppressed (presence of Pd) although it had not been attended before (absence of N2pc). Thus, suppression of irrelevant but salient stimuli may occur without prior attentional engagement (cf. the "attend-to-me" signal, Sawaki & Luck, 2010), arguing for an independent cognitive process that is not yoked to attentional selection. In contrast, most theories state that suppression occurs after prior attentional capture. For instance, Belopolsky, Schreij, and Theeuwes (2010) claimed that suppression must occur after attention has been allocated in the direction of the distractor (or the target), but that the strength of the top-down set can lead to a suppression of attentional capture (Hickey, Olivers, Meeter, & Theeuwes, 2011; Moher & Egeth, 2012).

In the ThDh contra condition, the N2pc to the target and the Pd to the distractor may be confounded, as suggested by Hickey et al.

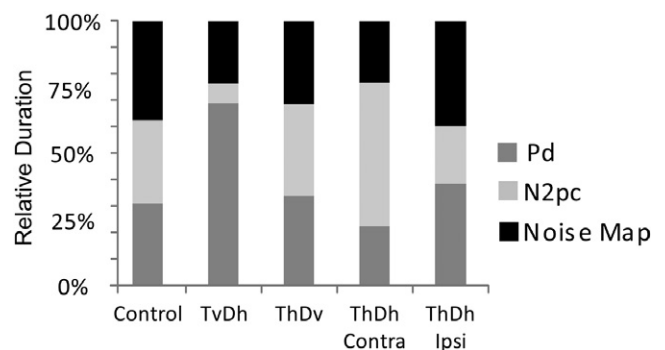


Figure 6. Mean proportions of map durations for the N2pc, Pd, and noise map after individual fitting in the late segment of analysis (280–340 ms). Results were collapsed across unpredictable and predictable targets because there was no interaction in the ANOVA.

(2009). Our data is informally consistent with this idea: The N2pc to the target in the ThDh contra condition is numerically larger, as if the Pd to the contralateral distractor had increased its amplitude (see Figure 3, top panel). However, *t* tests did not confirm a significant difference between the control and the ThDh contra condition, and the analysis of microstates revealed that the N2pc map was dominant in this time interval (Figure 5, top panel).

Finally, in our topographic analysis, we addressed a common concern in ERP research, the selection of the electrode of interest. To remedy these problems, we calculated maps by clustering techniques and determined the duration of their presence in each individual participant. The topographic analysis confirmed that target repetition increases the presence of a map that is related to target selection. Enhancement of this map also goes with less attentional capture by a distractor. Further, we did not notice a significant difference in the presence of the map related to distractor suppression between predictable and unpredictable target conditions. In contrast, the traditional analysis of ERP components had only shown a significant Pd with predictable, but not with unpredictable targets. Because the occurrence of a positivity depends on the baseline prior to the occurrence of the deflection, the topographic analysis may be more sensitive. It may reveal states that correspond to suppression even in the decreasing part of the N2pc that is nominally still negative. The map related to the Pd may functionally correspond to the later part of the N2pc as described earlier (Hickey et al., 2009). Also, the topographic analysis led to a rean-

alysis of the Pd at a different site, O1/O2, where a significant Pd to the lateral distractor occurred both for predictable and unpredictable targets, suggesting that focusing on the PO7/PO8 electrodes leads to a loss of information regarding this component in our data set.

Further, in a supplementary analysis of N2pc onset latencies (not reported), we did not find longer latencies in trials with a salient color opposite the target (but see Tollner, Zehetleitner, Gramann, & Muller, 2011; Wykowska & Schubo, 2011). The reasons for this difference remain unclear.

In sum, we show that a predictable target shape abolishes the N2pc to salient color distractors, suggesting that trial context and the resulting search mode modulate the effect of salient stimuli on attentional capture. We suggest that predictable targets induced feature search, which decreased RTs, increased the amplitude of the N2pc to the target, and abolished the N2pc to salient distractors. With predictable target presentation, there was also distractor suppression as indexed by the Pd. However, our topographic analysis showed that distractor suppression may be present with unpredictable targets as well. With unpredictable target shapes, observers adopt singleton detection mode because target features vary randomly, allowing for attentional capture by salient distractors to occur. Taken together, our data support the idea that attentional capture only occurs in singleton detection mode, but not with feature search, which is highly consistent with a classical paper on this issue (Bacon & Egeth, 1994).

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