Context homogeneity facilitates both distractor inhibition and target enhancement

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Homogeneous contexts were shown to result in prioritized processing of embedded targets compared to heterogeneous contexts (Duncan & Humphreys, 1989). The present experiment used behavioral and ERP measures to examine whether context homogeneity affects both enhancing relevant information and inhibiting irrelevant in contexts of varying homogeneity. Targets and distractors were presented laterally or on the vertical midline which allowed disentangling target- and distractor-related activity in the lateralized ERP (Hickey, diLollo, & McDonald, 2009). In homogeneous contexts, targets elicited an N_T component from 150 ms on and a P_D component from 200 ms on, showing early attention deployment at target locations and active suppression of distractors. In heterogeneous contexts, an N_T component was also found from 150 ms on and P_D was found from 250 ms on, suggesting delayed suppression of the distractor. Before 250 ms, distractors in heterogeneous contexts elicited a contralateral negativity, indicating attentional capture of the distractor prior to active suppression. In sum the present results suggest that top-down control of attention is more pronounced in homogeneous than in heterogeneous contexts.

Introduction

One of the prime capabilities of the visual system is to filter relevant from irrelevant information in the visual environment within milliseconds. Theories which model *visual search*, i.e., the search for potentially interesting stimuli among other distracting stimuli, often conceptualize this selection to be based upon activation patterns on a "priority map." The priority map is assumed to code information about selection relevance of objects or items in the visual field in a topographical manner (Fecteau & Munoz, 2006; Itti & Koch, 2000; Li, 2002; Wolfe, 1994; Yantis & Jones, 1991). The activation pattern coded on the priority map is a combination of both an item's salience and its relevance in the current task: The priority map receives bottom-up input from a salience map that is activated by physical stimulus features such as contrast or similarity (Itti & Koch, 2000; Li, 2002). The bottom-up input is then weighted by top-down processes such as an observer's current goals (Fecteau & Munoz, 2006; Wolfe, Butcher, Lee, & Hyle, 2003; Wykowska & Schubö, 2011). The activation pattern on the priority map is used to select those objects in the visual field that will receive more elaborated, attentive processing: Based on the activity on the priority map, focal attention is deployed to various locations in the order of decreasing activation (e.g., Wolfe, 1994).

Bottom-up and top-down processes in visual search

There is an ongoing debate on the relative contribution of bottom-up salience and the observer's top-down goals or intentions (Awh, Belopolsky, & Theeuwes, 2012; Bacon & Egeth, 1991; Folk, Remington, & Johnston, 1992; Theeuwes, 1992, 2004, 2010; Wykowska & Schubö, 2011). Support for the view that physical salience can barely be overruled by volitional control comes from experiments in which a salient distractor is presented in addition to a less salient target ("additional singleton paradigm"; Theeuwes, 1992). For example, when observers search for a shape singleton target, a color singleton distractor can slow down response times whereas search for a color singleton is not slowed down by a shape singleton distractor (Theeuwes, 1992). Theeuwes concluded that focal attention is captured by the first feature encoded during the pre-attentive stage (color earlier than form)

Citation: Feldmann-Wüstefeld, T., & Schubö, A. (2013). Context homogeneity facilitates both distractor inhibition and target enhancement. *Journal of Vision, 13*(3):11, 1–12, http://www.journalofvision.org/content/13/3/11, doi:10.1167/13.3.11.

doi: 10.1167/13.3.11 Received December 21, 2012; published May 6, 2013 ISSN 1534-7362

regardless of its importance for the current task. Accordingly, supporters of the attentional capture account demonstrate that intentional control may only take over after some time has passed and the initial phase of salience-based attentional processing is completed (Theeuwes, Atchley, & Kramer, 2000; see also Kim & Cave, 1999; Van Zoest & Donk, 2004).

However, there is also a large proportion of data supporting the view that top-down information is available at the very first sweep of visual processing, meaning that salient but irrelevant objects do only capture an observer's attention when they are contingent on the observer's current task set (Bacon & Egeth, 1991; Folk et al., 1992; Folk, Leber, & Egeth, 2002; Kim & Cave, 1999; Leblanc, Prime, & Jolicoeur, 2008; Wykowska & Schubö, 2010; 2011). Instead, it has been suggested that irrelevant singletons do not capture attention but produce nonspatial filtering costs (Folk, Leber, & Egeth, 2002; Folk & Remington, 2006). Additionally, the interplay of bottom-up and top-down processing seems to strongly depend on several factors such as the attentional demands (Kiss, Grubert, Petersen, & Eimer, 2012) or the value of a stimulus (Anderson, Laurent, & Yantis, 2011).

Context homogeneity determines visual search efficiency

Another factor that may determine how much top-down influence is involved in visual selection is context homogeneity (i.e., how physically distinct the non-singleton distractors are). In fact, the homogeneity of task-irrelevant stimuli can largely affect the efficiency of searching for an embedded task-relevant stimulus. The more similar distractors are, the faster will observers detect an embedded target (Akyürek, Vallines, Lin, & Schubö, 2010; Duncan & Humphreys, 1989; Meinecke & Donk, 2002; Schubö, Wykowska, & Müller, 2007). According to the *Attentional Engagement Theory* (Duncan & Humphreys, 1989) stimuli are grouped according to their shared physical features already in an early parallel stage of visual coding (see also Bacon & Egeth, 1991). The more similar distractors are, the stronger they are linked and grouped to a single structural unit, resulting in fast detection of the target. Perfectly identical distractors may even enhance target processing when they are numerous enough (Schubö et al., 2004; Wolfe, 1994). The present experiment investigated whether a salient distractor singleton that is potentially interfering with target processing (e.g., Theeuwes, 1992) may also benefit from distractor homogeneity; that is, whether a salient distractor singleton is processed preferentially in homogeneous contexts when compared to heterogeneous contexts. Alternatively, one may assume that a salient distractor is suppressed more easily in homogenous contexts than in heterogeneous contexts, because the target is more likely to "pop out" (Wolfe, 1994) and inhibition of the distractor is possible earlier in time.

Neural correlates of target enhancement and distractor inhibition

To examine neural processes associated with target processing and distractor inhibition, we used a technique grounded in work by Hickey and colleagues (Hickey, McDonald, & Theeuwes, 2006; see also Hickey, Di Lollo, & McDonald, 2009; Woodman & Luck, 2003) which investigated the sequence of attention deployment towards targets and towards more salient singleton distractors. The crucial manipulation of the stimuli was their relative position: Target and distractor were presented either both laterally, or one was presented laterally and the other one on the vertical midline (i.e., unlateralized). Since unlateralized stimuli can usually not elicit a lateralized ERP component, target- and distractor-evoked potentials could be analyzed independently. Both target and distractor elicited a contralateral negative deflection in the ERP (i.e., an N2pc) when presented laterally with the other one on the vertical midline. The authors concluded that attention can be deployed to the target but may also be captured by the distractor (Hickey et al., 2006). When target and singleton distractor were presented in opposite hemifields, a negative deflection in the ERP first appeared ipsilateral to the target (reflecting an N2pc elicited by the singleton distractor) and only then contralateral to the target (i.e., a target N2pc). This order of negative deflections argues in favor of attention being deployed first to the most salient item (the distractor), before it is then focused on the target (but see Eimer & Kiss, 2008; Wykowska & Schubö, 2010, 2011 for diverging results). In a more recent study, Hickey et al. (2009) tried to further disentangle target enhancement and distractor inhibition and refined the usage of the N2pc as an indicator of attention deployment. They used a distractor that was less salient than the target and found a positive deflection of the ERP contralateral to the distractor (distractor-positivity, P_D) when the target was presented on the vertical midline. Again, a negative deflection of the ERP contralateral to the target was found (target-negativity N_T), when only the target was presented laterally. Hickey et al. (2009) argued that these components may be considered subcomponents of the N2pc. The results suggest that distinct neural processes are involved in enhancing relevant (N_T) and inhibiting irrelevant information (P_D). A similar technique has been used to dissociate target- and distractor-related processes in fast versus slow attention shifts (Hickey, van Zoest, & Theeuwes, 2010) and in inter-trial priming (Hickey, Olivers, Meeter, & Theeuwes, 2011). As mentioned above, although context homogeneity is known to play a crucial role in how attention is deployed in the visual field, it is still unclear in how far context homogeneity mediates the interplay of these processes.

Rationale of the present experiment

The present experiment investigated whether and how context homogeneity affected enhancing relevant information as reflected in the N_T and inhibiting irrelevant information as reflected in the P_D. Similarly to Hickey et al. (2009), target and salient distractor singleton were either presented both laterally, or one was presented on the vertical midline and the other one laterally. Unlike in previous experiments, target and singleton were always embedded in a large context of 456 vertical and horizontal lines. These were either completely homogeneous (vertical or horizontal lines only) or heterogeneous (horizontal and vertical lines randomly arranged). We were particularly interested in how the varying degree of context homogeneity affected the attention-related N2pc subcomponents P_D and N_T and, more importantly, whether they would be affected in a similar manner. We intended to disentangle prioritized processing of the target (as reflected in the N_T component) and inhibition of a distractor (as reflected in the P_D component) which may be modulated differentially by context homogeneity.

Method

Participants

Twenty-one volunteers naive to paradigm and objective of the experiment participated for payment or course credit. One participant had to be excluded due to excessive eye movements (see below for criteria). The remaining 20 subjects (seven male) were aged 18–32 years ($M = 21.5$, $SD = 3.6$). All were right-handed and had normal or corrected-to-normal vision. The experiment was conducted with the understanding and consent of each participant.

Stimuli and apparatus

Participants were seated in a comfortable chair in a dimly lit, electrically shielded and sound attenuated chamber, with an ergonomic gamepad (Microsoft Sidewinder USB) in their hands. Participants had to use their left and right index finger to press two buttons on the back of the gamepad. Stimulus presentation and response collection were controlled by a *Windows* PC using *E-Prime* routines. All stimuli were presented on a LCD-TN screen (*Samsung Syncmaster 2233*) placed 100 cm away from participants. Search displays with 458 line elements arranged in a matrix of 27 × 17 stimuli were shown on a white background. In the central position, a fixation dot was shown instead of a line element. Single lines had a length of 0.7° of visual angle; the matrix's dimension was 24.2° × 16.2°. The target was a gray oblique line element tilted 45° either to the left or right (equiprobably). The color singleton distractor was a red horizontal or vertical line. The remaining 456 line elements were gray horizontal or vertical lines. In the *homogeneous condition*, all of the remaining 456 line elements (and the color singleton) were either horizontal or vertical (changing randomly from trial to trial, cf. Figure 1A). In the *heterogeneous condition*, 228 of the remaining lines were horizontal and 228 were vertical, randomly assigned to the matrix positions (cf. Figure 1B). In each trial, the target and the color singleton appeared at two out of six equiangular positions on an imaginary circle (cf. Figure 1). Two of the positions were 3.4° above or below fixation on the vertical midline. The other four positions were 2.9° left or right of the vertical midline and 1.7° above or below the horizontal midline. In one third of the trials, the target was presented in one of the vertical midline positions and the singleton was presented in a lateral position. In another third of the trials, location of target and singleton were reversed and in the remaining third of the trials, both were presented in a lateral position, namely in opposite hemifields.

Procedure

A trial started with the presentation of a gray central fixation dot that remained on the screen throughout the entire trial. After 500 ms, the search display was presented for 200 ms and then replaced with a blank display. Participants were asked to press one of the response buttons (labeled "/" or "\") in order to indicate the orientation of the target in the search display, i.e., whether the target was pointing right upwards or right downwards. Button assignment was balanced across participants. Response speed was emphasized, but there was no time limit for the response. After participants' response, the fixation dot disappeared for 1000 ms until a new fixation dot announced the start of a new trial. Participants were told that both the context (the 456 horizontal and vertical lines) and the color singleton were irrelevant to the task and could be ignored.

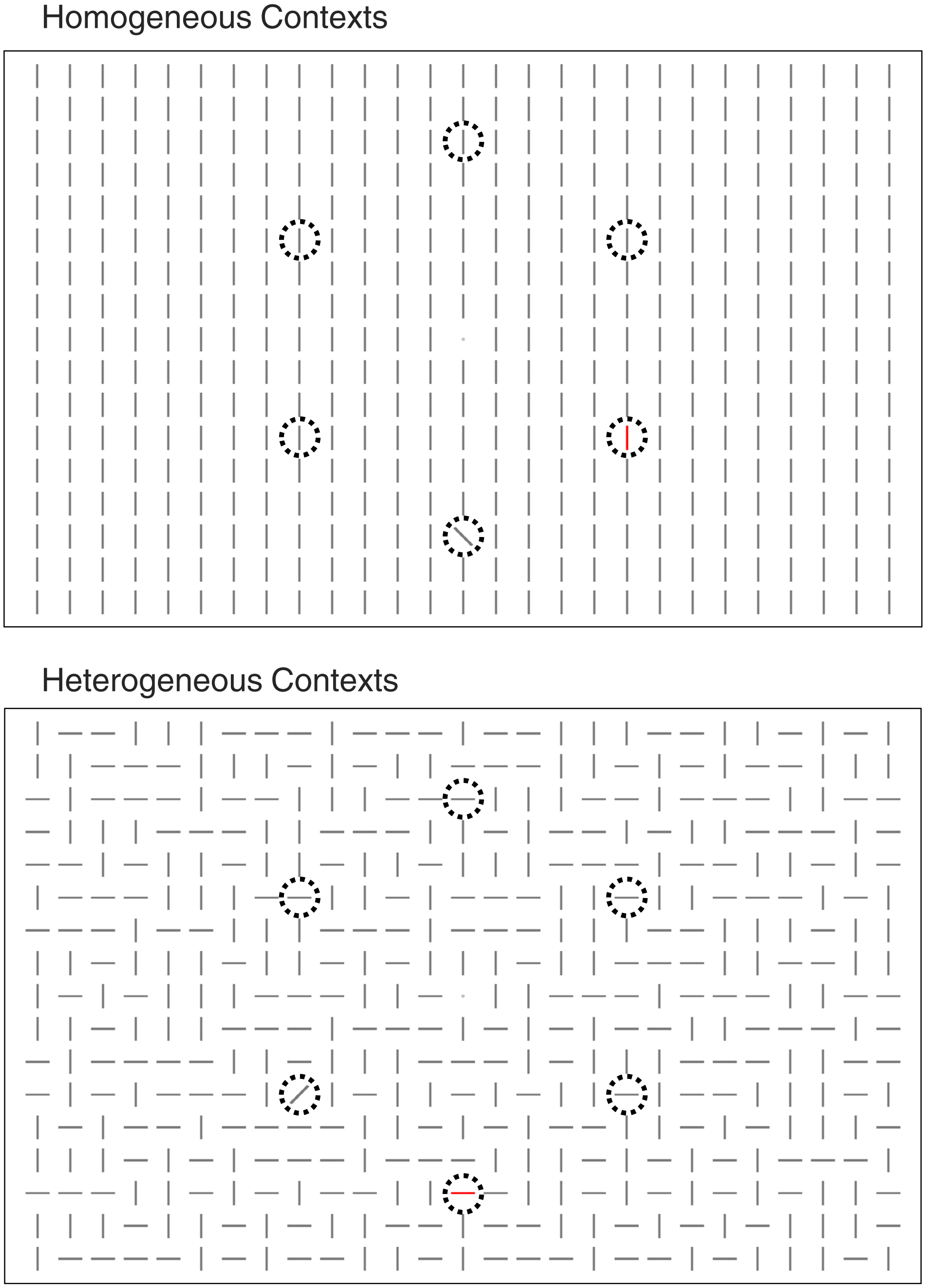

Figure 1. Exemplary search displays. In the upper panel, target (gray oblique line) and singleton distractor (red vertical line) are embedded in a homogeneous context of gray vertical (or horizontal) lines. In the lower panel, target and singleton are embedded in a heterogeneous context of randomly arranged vertical and horizontal lines. Participants were to indicate the orientation of the target (leftward vs. rightward) while ignoring the distractor and the context. Black-dashed circles illustrate the possible target, and singleton locations and were not visible to participants. The target could be presented in a lateral position and the distractor on the vertical midline (lower panel), vice versa (upper panel), or both could be presented in a lateral position (not shown here).

All three position conditions (target lateral, distractor vertical vs. target lateral, distractor lateral vs. target vertical, distractor lateral) were combined with the two context conditions (homogeneous vs. heterogeneous), leading to six experimental conditions. There were 192 trials per condition (1152 in total), randomly mixed across 24 blocks of 48 trials each. Two additional blocks in the beginning of the experiment served as training. After each block, performance feedback (response times and accuracy) was given to participants.

EEG recording

EEG was recorded with Ag–AgCl electrodes from 64 electrodes (according to the International 10–10 System). Horizontal and vertical EOGs were recorded bipolarly from the outer canthi of the eyes and from above and below the observer's left eye, respectively. All electrodes were referenced to Cz and re-referenced off-line to the average of all electrodes. Electrode impedances were kept below 5 kΩ. Sampling rate was 1000 Hz with a high cutoff filter of 250 Hz and a low cutoff filter of 0.1 Hz.

Data analysis

Behavioral data

Mean response times (RT) and accuracy were calculated for each participant, separately for each context type (homogeneous vs. heterogeneous) and each position condition (target lateral, distractor vertical vs. target lateral, distractor lateral vs. target vertical, distractor lateral) and submitted to a 2 × 3 ANOVA. Trials with false responses were removed from the RT analysis. Trials with exceedingly long RT (±2 *SD* from mean RT calculated separately for each participant) were removed from accuracy and RT analyses.

EEG data

EEG was averaged off-line over a 700-ms epoch including a 200-ms prestimulus baseline with epochs time-locked to the search display onset. Only trials with correct responses were analyzed. Furthermore, trials in which EOG electrodes revealed eye movements or blinks (indicated by any absolute voltage difference in a segment exceeding 80 μV or voltage steps between two sampling points exceeding 50 μV) or signal loss (voltage lower than 0.10 μV for a 100-ms interval) were excluded from analysis. Across all participants, 95.2 % of the correct trials showed no contamination with eye movements or blinks (*SD* = 5.8 %). Additionally, segments were excluded from further analysis on an individual-channel basis with the same criteria. One participant was excluded from further data analysis because only 50% of the trials were left after artifact rejection.

For the N2pc analyses, the EEG was averaged for each participant separately for electrode sites contralateral and ipsilateral to the target (or to the distractor in trials with a target on the vertical midline). EEG was further averaged separately for each context type (homogeneous vs. heterogeneous), each position condition (target lateral, distractor vertical vs. target lateral, distractor lateral vs. target vertical, distractor lateral) and three epochs (150–200 ms; 200–250 ms; 250–300 ms). For statistical analyses, the difference of contralateral and ipsilateral ERPs (contra minus ipsi) was calculated for electrodes PO7 and PO8 and forwarded to a two-way repeated measures ANOVA with the factors Context (homogeneous vs. heterogeneous) and Position (target lateral, distractor vertical vs. target lateral, distractor lateral vs. target vertical, distractor lateral). ANOVAs were calculated separately for each of the three epochs.

Results

Behavioral data

Response times (cf. Figure 2A). Response times were generally faster for homogeneous ($M = 470$ ms) than for heterogeneous ($M = 497$ ms) contexts, $F(1, 19) = 39.5$, $p < 0.001$, $\eta^2 = 0.675$. Response times were also modulated by target and distractor location, being shortest for lateral targets and vertical distractors ($M = 479$ ms), followed by lateral targets and lateral distractors ($M = 483$ ms) and vertical targets and lateral distractors ($M = 488$ ms), $F(2, 38) = 12.5$, $p < 0.001$, $\eta^2 = 0.396$. An interaction of context and location showed that the shorter response times for homogenous than for heterogeneous contexts were more pronounced for vertical targets and lateral distractors ($\Delta M = 35$ ms) than for lateral targets and lateral distractors ($\Delta M = 27$ ms) and lateral targets and vertical distractors ($\Delta M = 22$ ms), $F(2, 38) = 9.8$, $p < 0.001$, $\eta^2 = 0.340$.

Accuracy (cf. Figure 2B). A two-way ANOVA with the factors context (homogeneous vs. heterogeneous) and location (target lateral/distractor vertical vs. target lateral/distractor lateral vs. target vertical/distractor lateral) revealed a trend for Location $F(2, 38) = 3.2$, $p = 0.056$, $\eta^2 = 0.141$. Accuracy was highest in trials with a vertical target and lateral distractor (M = 93.5%, followed by trials with a lateral target and vertical distractor (M = 92.3%) and trials with a lateral target and distractor (M = 92.1%). No other effects were significant (all $p > 0.130$).

ERP Data

Event-related brain potential results are shown in Figure 3.

First epoch (150–200 ms)

The lateralized ERP was more positive for distractors with a vertical target ($M = 0.08$ μV; green lines in Figure 3) than for targets both with a lateral distractor

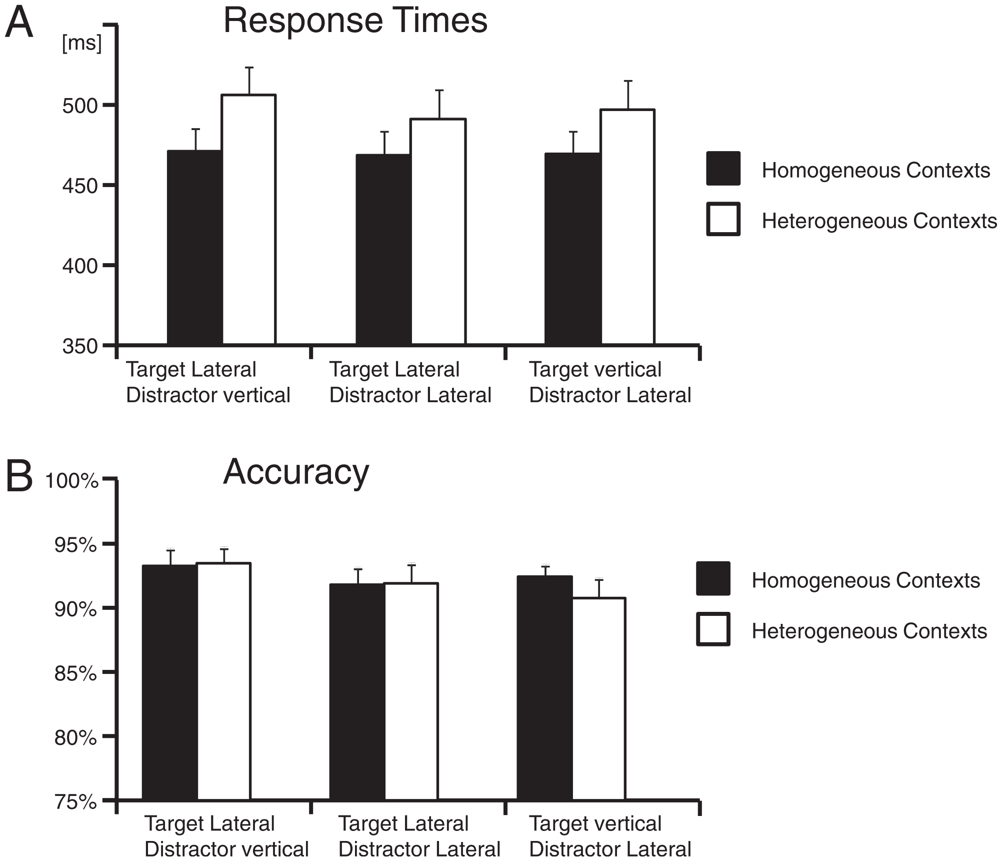

Figure 2. Response times (A) and accuracy (B) for targets in homogeneous contexts (filled bars) and heterogeneous contexts (empty bars). Results are shown separately for trials with lateral target and vertical distractor (left side), trials with lateral target and lateral distractor (middle), and vertical target and lateral distractor (right side). Error bars denote the standard error of the mean.

($M = -1.39$ μV; blue lines) and with a vertical distractor ($M = -1.46$ μV; red lines), main effect of Position, $F(2, 38) = 43.5$, $p < 0.001$, $\eta^2 = 0.696$. Lateralized ERPs were also more negative for targets or distractors in a homogeneous context ($M = -1.23$ μV) than in a heterogeneous context ($M = -0.61$ μV), $F(1, 19) = 18.2$, $p < 0.001$, $\eta^2 = 0.490$. An interaction of Position and Context indicated a differential effect for the two context types, $F(2, 38) = 12.3$, $p = 0.001$, $\eta^2 = 0.392$. Targets in homogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -2.00$ μV; $p < 0.001$; $\varepsilon = 1.86$; red lines) or lateral distractor ($M = -1.89$; μV; $p < 0.001$; $\varepsilon = 1.61$; blue lines). Distractors in homogeneous contexts elicited no reliable lateralized activity ($M = 0.21$ μV; $p = 0.494$; $\varepsilon = 0.60$; green lines). Targets in heterogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -0.92$ μV; $p < 0.001$; $\varepsilon = 1.38$; red lines) or lateral distractor ($M = -0.88$ μV; $p < 0.001$; $\varepsilon = 1.64$; blue lines). Distractors in heterogeneous contexts elicited no reliable lateralized activity ($M = -0.05$ μV; $p = 0.749$; $\varepsilon = 0.10$).

Second epoch (200–250 ms)

The lateralized ERP was more positive for distractors with a vertical target ($M = 0.72$ μV; green lines) than for targets with a lateral distractor ($M = -2.17$ μV; blue lines) or for targets with a vertical distractor ($M = -2.35$ μV; red lines), main effect of Position, $F(2, 38) = 31.7$, $p < 0.001$, $\eta^2 = 0.625$. The lateralized ERP was about the same size in homogeneous ($M = -1.33$ μV) as in heterogeneous contexts ($M = -1.64$ μV), $F(1, 19) = 2.9$, $p = 0.104$, $\eta^2 = 0.133$. An interaction of Position and Context indicated a differential effect for the two context types, $F(2, 38) = 4.4$, $p = 0.019$, $\eta^2 = 0.189$. Targets in homogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -2.22$ μV; $p < 0.001$; $\varepsilon = 1.57$; red lines) or lateral distractor ($M = -2.26$; μV; $p < 0.001$; $\varepsilon = 1.79$; blue lines). Distractors in homogeneous contexts elicited a reliable lateralized positivity ($M = 0.51$ μV; $p = 0.008$; $\varepsilon = 0.95$; green lines). Targets in heterogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -2.49$ μV; $p < 0.001$; $\varepsilon = 2.41$; red lines) or lateral distractor ($M = -2.08$ μV; $p < 0.001$; $\varepsilon =$

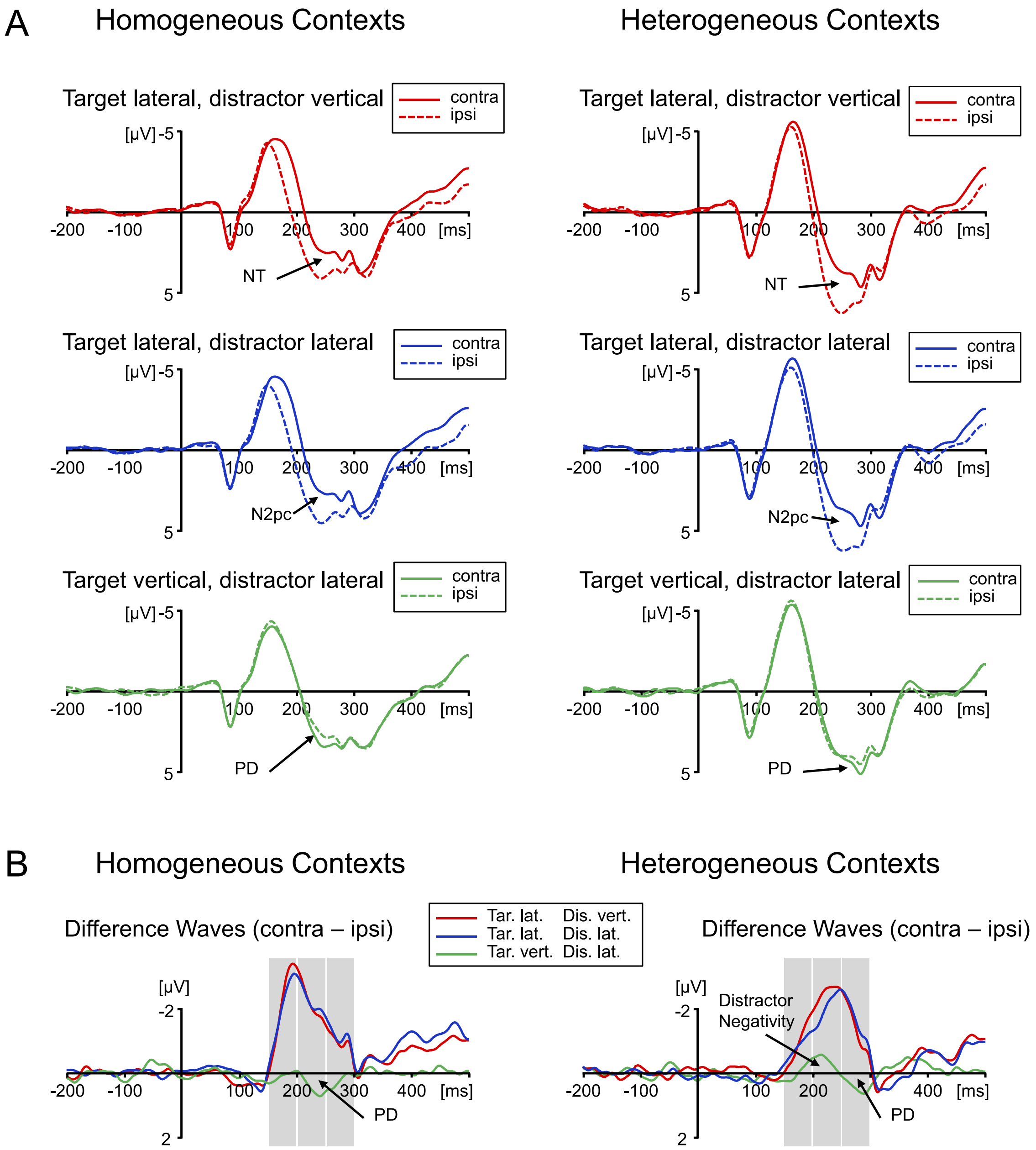

Figure 3. (A) Grand-average ERPs recorded at PO7/PO8, contralateral (solid lines) and ipsilateral (dashed lines) to lateralized stimuli in homogeneous (left panels) and in heterogeneous (right panels) contexts. Results are shown separately for trials with lateral target and vertical distractor (upper row, red lines), for trials with lateral target and lateral distractor (middle row, blue lines; 'contra' denotes contralateral to targets here), and for trials with vertical target and lateral distractor (lower row, green lines; 'contra' denotes contralateral to distractors here). The N2pc is the difference between electrodes contralateral and ipsilateral to target locations when a distractor is presented laterally. The Target-Negativity (NT) denotes this difference when a distractor is presented vertically. The Distractor-Positivity (PD) is the difference between electrodes contralateral and ipsilateral to distractor locations when a target is presented vertically. (B) Shows the same data as (A) but as difference waves (contralateral – ipsilateral). Gray-shaded rectangles depict the time epochs used for statistical analyses. All data are filtered with a 40 Hz low-pass filter for illustration purposes.

1.78; blue lines). Distractors in heterogeneous contexts elicited a reliable lateralized negativity ($M = -0.36$ μV; $p = 0.025$; $\varepsilon = 0.77$; green lines).

Third epoch (250–300 ms)

The lateralized ERP was more positive for distractors with a vertical target ($M = 0.39$ μV; green lines) than for targets with a vertical distractor ($M = -1.19$ μV; red lines) or for targets with a lateral distractor ($M = -1.42$ μV; blue lines), $F(2, 38) = 21.5$, $p < 0.001$, $\eta^2 = 0.530$. The lateralized ERP was more negative for targets or distractors in a heterogeneous ($M = -0.90$ μV) than for targets in a homogeneous context ($M = -0.58$ μV), $F(1, 19) = 6.5$, $p = 0.020$, $\eta^2 = 0.254$. An interaction of Position and Context indicates a differential effect for the two context types, $F(2, 38) = 3.2$, $p = 0.050$, $\eta^2 = 0.146$. Targets in homogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -0.96$ μV; $p = .006$; $\varepsilon = 0.98$; red lines) or lateral distractor ($M = -1.13$; μV; $p = .001$; $\varepsilon = 1.18$; blue lines). Distractors in homogeneous contexts elicited a reliable lateralized positivity ($M = 0.36$ μV; $p = .019$; $\varepsilon = 0.81$; green lines). Targets in heterogeneous contexts elicited a reliable lateralized negativity when presented with a vertical ($M = -1.42$ μV; $p < 0.001$; $\varepsilon = 1.44$; red lines) or lateral distractor ($M = -1.71$ μV; $p < 0.001$; $\varepsilon = 1.41$; blue lines). Distractors in heterogeneous contexts elicited a reliable lateralized positivity ($M = 0.42$ μV; $p = 0.025$; $\varepsilon = 0.78$; green lines).

Latency analyses

In order to assess onset latency differences between homogeneous and heterogeneous contexts for the P_D and the N_T, a jackknife-based procedure was applied (Miller, Patterson, & Ulrich, 1998). The points in time were determined at which the ERP components of 20 grand averages, each excluding one of the 20 participants, reached 50% of the peak amplitude. Subsequently, the jackknife estimate of the standard error of the differences S_D and t values were calculated. The difference in onset latencies between waveforms of different experimental conditions was tested by dividing the latency difference with the estimated S_D. The resulting statistics follow the sampling distribution of Student's t statistic (for a detailed description of the entire method, see Miller et al., 1998). Results showed that the P_D appeared significantly earlier for homogeneous than for random contexts ($D = 42$ ms, $t(19) = -3.57$, $p = .002$). Also N_T appeared significantly earlier for homogeneous than for random contexts ($D = 12$ ms, $t(19) = -4.69$, $p < 0.001$).

General discussion

The present experiment investigated whether background homogeneity affects the extent to which an irrelevant salient distractor captured the observer's attention when presented together with a target. Observers had to search for an oblique line embedded in a homogeneous or heterogeneous context and to ignore a color distractor. We adapted an ERP technique developed by Hickey et al. (2009) which allows separating neural processes underlying prioritized target processing and distractor inhibition. The Distractor-Positivity (P_D) is a positive deflection in the ERP contralateral to a distractor when a target is simultaneously presented unlateralized and reflects suppression of irrelevant information (Hickey et al., 2009). The Target-Negativity (N_T) is a negative deflection in the ERP contralateral to a target when a distractor is simultaneously presented unlateralized and reflects enhancement of relevant information (Hickey et al., 2009). Both components may sum up to the traditional N2pc component which reflects attention deployment in the visual field (e.g., Eimer, 1996; Hopf, Boelmans, Schoenfeld, Luck, & Heinze, 2004; Luck & Hillyard, 1994).

By using neural correlates of target and distractor processing, we wanted to investigate whether the previously found more efficient target processing in homogeneous contexts (Duncan & Humphreys, 1989; Meinecke & Donk, 2002; Schubö et al., 2007) is accompanied by a more efficient inhibition of salient distractors. If so, we expect a pronounced P_D. Conversely, it may be that salient distractors are processed with priority in homogeneous contexts as well, leading to larger filtering costs. In that case, distractors should elicit a less pronounced or even inverted P_D in homogeneous contexts. Finally, it may also be possible that homogeneity does not affect distractor inhibition but only target enhancement. In that case, we would expect a more pronounced N_T in homogeneous contexts but no modulation of the P_D.

As expected, our results showed evidence for efficient target processing in homogeneous contexts: A large negative deflection was observed already in the first epoch (150–200 ms) for targets with distractors in the opposite hemifield (i.e., a classical N2pc) and for targets with distractors on the vertical midline (i.e., an N_T). This suggests that already at an early point, attention was deployed to the target. This was done in a similar way for both targets irrespective of the additional distractor's location. Also in the second (200–250 ms) and third (250–300 ms) epoch, a pronounced N2pc and N_T were found, suggesting persistent attention deployment at target locations. In addition, the lateralized ERP showed a positive deflection for distractors (i.e., a P_D), in the second and third epoch. This suggests active suppression of the distractor in homogeneous contexts from 200 ms onward.

Also in heterogeneous contexts target processing seemed efficient, as both an N2pc and N_T were observed throughout all epochs. Similarly to what was found for homogeneous contexts, these components did not differ with respect to the additional distractor's location. This suggests that also in heterogeneous contexts, attention was deployed to the target rather early in time. Concerning distractor processing, results showed a different picture. A "classical" P_D, i.e., a distractor-related positivity, could only be observed in the third epoch, suggesting relatively late suppression of the distractor. In the second epoch, however, the lateralized ERP elicited by distractors was *negative* (i.e., an N_D). Thus it seemed that rather than showing suppression of the distractor, the distractor seemed to have captured attention in this case. When presented in a heterogeneous context, the distractor seemed to have attracted the observer's attention at least to some degree before it could be inhibited.

The divergent P_D pattern and time course for homogeneous and heterogeneous contexts was well in line with behavioral findings: Response times were faster for targets in homogeneous contexts than for targets in heterogeneous contexts. This result replicates previous studies which have found facilitated search performance in homogeneous compared to heterogeneous contexts (e.g., Akyürek et al., 2010; Duncan & Humphreys, 1989; Schubö et al., 2007). The present findings extend these results by demonstrating that contexts of varying homogeneity do also result in differential attention deployment towards salient distractors. Accordingly, the shorter response times for targets in homogenous contexts may have resulted from both more efficient target processing and less distractor-induced filtering costs.

Time course of target enhancement and distractor suppression in contexts of varying homogeneity

When comparing the attention-related ERP components observed for contexts of varying homogeneity, one may state that the pattern of components reflecting target processing (the N_T and N2pc) seems to be far less divergent than the pattern of the distractor-related P_D. Both N_T and N2pc were slightly more pronounced for homogeneous contexts, a result replicating findings of earlier studies (e.g., Schubö et al., 2007). Besides, attention deployment to targets in homogeneous contexts seemed to happen slightly faster than to targets in heterogeneous contexts: In the first epoch, N_T and N2pc reached a maximum peak for homogenous contexts while they were still ascending in heterogeneous contexts (cf. Figure 3B). This finding suggests that at this early point in time, attention deployment was at its maximum at target locations in homogeneous contexts while attention deployment in heterogeneous contexts was still evolving. This is well in line with the notion that attention deployment towards a target in heterogeneous contexts takes more time to develop (Akyürek et al., 2010; Duncan & Humphreys, 1989; Schubö et al., 2007). More pronounced activation of cortical regions representing attended stimuli has also been found in single cell recordings in animal brains (Roelfsema, Lamme & Spekreijse, 1998; Spitzer, Desimone, & Moran, 1988; Treue & Maunsell, 1999). The present results suggest that such enhanced cortical representation of a target, that may be reflected in the N_T (Hickey et al., 2009), happens at an earlier point in time when the target is presented in a homogeneous context. This enhanced cortical representation may have resulted in faster identification of the target, leading to shorter response times for targets in homogenous than in heterogeneous contexts.

Faster identification of targets in homogeneous contexts may also have been a consequence of more efficient distractor inhibition. The P_D results strongly support this notion: In the first epoch, a P_D could be observed for neither homogeneous nor heterogeneous contexts, suggesting that at this early point in time the salient distractor was not yet suppressed. In the second and third epoch, a reliable P_D for distractors was observed in homogeneous contexts. This observation is in line with earlier findings that P_D is most pronounced between 200 and 300 ms (Hickey et al., 2009) and suggests strong and efficient suppression of salient distractors. The P_D elicited by heterogeneous contexts showed a different picture: A reliable P_D was observed only after 250 ms, suggesting delayed distractor suppression. The distractor-elicited negativity observed between 200 and 250 ms showed that attentional capture preceded distractor suppression. Attentional capture by a salient irrelevant distractor has been reported before (e.g., Hickey et al., 2006; Schubö, 2009). The authors argued that attention is first captured by the irrelevant color singleton before attention can be deployed towards the relevant target in a second step. This effect may have been similar in the present experiment: Attention may have been captured by the salient color distractor before the target could be attended.

In addition to previous findings, our results revealed differential effects of distractor processing as a function of context homogeneity. Distractor-induced attention capture was only found when target and distractor were presented in heterogeneous contexts. In homogeneous contexts, attention deployment seemed more efficient, allowing distractor suppression at an earlier point in time. Apparently, the visual system needed more time to "get rid of" the salient distractor in heterogeneous than in homogenous contexts. Duncan and Humphreys (1989) argued that reducing the heterogeneity of nontarget elements increases search efficiency because similar (or homogeneous) elements are being grouped, and grouping reduces the number of perceptual units that have to be searched in order to find the target (see also Bacon & Egeth, 1991; Schubö, Schröger, & Meinecke, 2004; Schubö et al., 2007). In addition to more efficient grouping, enhanced attention deployment towards targets in homogeneous contexts may be caused by the higher salience of the target in homogeneous contexts. For example, it has been found that a higher local feature contrast causes an increase of salience as revealed by a higher proportion of correct saccadic eye movements (Van Zoest & Donk, 2008) especially for short latency responses (Van Zoest & Donk, 2004; see also Donk & Soesman, 2010). Since in the present experiment, the local feature contrast of target versus surrounding was higher in homogeneous than in heterogeneous contexts (cf. Li, 2002; Schubö, Akyürek, Lin, & Vallines, 2011), the resulting higher salience of the target may have contributed to the larger and earlier N_T component in homogeneous contexts. As the distractor was defined by color, not orientation, its salience was presumably equal in homogenous and heterogeneous contexts.[1] Hence the distractor-elicited N_T and then later P_D in heterogeneous contexts, reflecting less efficient distractor inhibition, maybe due to impaired processing of the less salient target.

The role of homogeneity in top-down and bottom-up processes

There is an ongoing debate to what extent irrelevant salient information attracts an observer's attention and is processed without the observer intending to do so. There has been some support for the view that physical salience can barely be overruled by volitional control (Theeuwes, 1992, 2004; Theeuwes et al., 2000), and a large proportion of studies has shown that volitional control can be very efficient already at an early point in visual processing (Bacon & Egeth, 1991; Folk et al., 1992; Folk, Leber, & Egeth, 2002; Folk & Remington, 2006; Kim & Cave, 1999; Leblanc, Prime, & Jolicoeur, 2008; Wykowska & Schubö, 2011). More recent research has shown that top-down and bottom-up processes may not be a dichotomy but may rather both contribute to visual selection (e.g., Awh et al., 2012; Wykowska & Schubö, 2011) which in turn may depend on several factors such as the attentional demands (Kiss et al., 2012), the value of a stimulus (Anderson, Laurent, & Yantis, 2011; Hickey, Chelazzi, & Theeuwes, 2010), or the complexity of the search process (Töllner, Rangelov, & Müller, 2012).

The present experiment provides evidence that an additional factor may determine the relative contribution of top-down and bottom-up processes, namely the homogeneity of the context in which stimuli are embedded. When contexts were homogeneous, no attentional capture by irrelevant salient distractors was observed. In heterogeneous contexts, however, active suppression of the distractor was delayed, supposedly a consequence of attentional capture by the distractor. This distinction does not necessarily mean that distractor inhibition is not grounded on low-level features, but it suggests that at least top-down processing is less vulnerable to interferences from potentially distracting low-level features in homogeneous contexts whereas attention deployment in heterogeneous contexts is more vulnerable to distraction by salient stimuli.

Keywords: visual search, bottom-up, top-down, homogeneity, N2pc, distractor-positivity, target-negativity

Acknowledgments

This research was supported by the Deutsche Forschungsgemeinschaft (German Research Foundation; SCHU 1330/6-1), by the Graduate School of Systemic Neurosciences, Munich, and by the Studienstiftung des Deutschen Volkes. We would like to thank Clayton Hickey and an anonymous reviewer for helpful comments on a previous version of the manuscript.

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Footnote

[1] The alignment of the color singleton distractors to the respective background suggests identical salience in homogeneous and heterogeneous contexts. Although the iso-orientation surround suppression (e.g., Bair, Cavanaugh, & Movshon, 2003) may be reduced for any given line element in heterogeneous contexts (compared to homogeneous contexts), this supression should be the same for all line elements in heterogeneous contexts (except for the target). Hence there should be no increase in salience for distractors in both context types on the orientation feature map (e.g., Itti & Koch, 2001). However, there should be an identical increase in salience on the color feature map for distractors in both contexts since the color difference for distractor (red) versus context line (black) was identical in both contexts. As a result, distractors should receive more activation than their surroundings on the priority map (see Wolfe, 1994), but this activation should be identical in homogeneous and heterogeneous contexts.

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