



## Research article

## Where to display vital information? ERP evidence for background changes

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## ARTICLE INFO

## Keywords:

Target-distractor discrimination tasks  
 Attentional capture  
 Distractor suppression hypothesis  
 Event-related potentials (ERP)  
 Distractor positivity (PD)

## ABSTRACT

Critical decision systems require expeditious and accurate responses to the displayed information. In addition to content, location and background are equally important. Several visual search studies have pointed out the differences and compared modes of top-down attention allocation: distractor suppression and attentional capture. Previous studies have used color (mainly) and shape as a feature but have overlooked luminance as a feature for studying underlying attention mechanisms. The present study attempts to bridge this gap. In this study, participants performed a target-distractor discrimination task by identifying a randomly appearing target from the pool of distractors based on defined luminance levels. Background change was noticed by manipulating the task such as making visible quadrant boundaries over the screen. The preliminary evidence suggested that displaying information at the top-left of the screen had higher percentage accuracy; whereas, response time (RT) remained unaffected. Improvement in RT and percentage accuracy was observed with task manipulation. Event-related potential (ERP) analysis revealed elicited Distractor Positivity (PD), providing evidence for the distractor suppression hypothesis. Further, differences emerged in the topographic plot of N2pc and PD. In sum, the result contributes to classic debate of capture vs. suppression and provides a crucial connection between display design and electrophysiological indices, emphasizing locations and background as equally important factors.

## 1. Introduction

Mission-critical display requires pertinent locations to exhibit crucial information for operational safety and efficient performance. However, low-level visual features such as luminance could affect the user interaction in labelling and attention management. For instance, lowering the luminance contrast of less significant information is a common approach to reduce clutter without fully removing context information. Sometimes displaying information in a similar mode could cause a delay in response resulting in mission failure. Thus, efficient attention allocation is required by an operator to discriminate between the target (critical information) and distractor (contextual information) that accelerates feature analysis and assists decision making. Goal-directed or top-down mechanisms guide attention either to attend relevant information (target facilitation) or ignore irrelevant distractors (distractor inhibition). While there have been arguments between two mechanisms for a classical visual search paradigm or a target-distractor discrimination task ([1, 2, 3, 4, 5, 6], their temporal interplay is still a matter of debate. In this study, we provide evidence that rather than target facilitation, distractor inhibition occurs when target and distractor are discriminated only at the level of

brightness (perceived luminance). In addition, the importance of location and background of display is also highlighted.

## 1.1. The attention capture debate

A classic debate for attention capture boils down to two competing theories of attention mechanism: Stimulus-driven or Bottom-up; and Goal-directed or Top-down. According to stimulus-driven theories, physically salient objects will capture attention, regardless of the intentions of the observer [7]. On the contrary, goal-driven theories state that only stimuli that match the features of the search target will capture attention [3]. Goal-directed attention mechanisms can be bifurcated into two distinct cognitive processes: target facilitation and distractor suppression [8]. Both processes work with the underlying mechanism for matching an observer's attentional set rather than automatically capturing attention. Target facilitation guides attention capture by target rather than a distractor, whereas, the distractor suppression mechanism selectively inhibits task-irrelevant stimuli. Recent findings have shown [9] faster response time on distractor present trials as compared to distractor absent trials due to the suppression process. The suppression

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mechanism resolves the competition for attention during visual search, even when the target and distractor reside in the same feature dimension [10]. Therefore, we refer to faster response time as an indicator of the distractor suppression mechanism. Moreover, goal-directed theories demonstrate the effect of a singleton on attention capture in the attentional set of the observer. When the target is a singleton and is defined by a known feature, two search strategies i.e. feature-search mode & singleton-detection mode are available to the participants [11]. In a feature-search mode, participants delineate the outputs of the feature map where the saliency of distractors can be overridden [12]. By contrast, in singleton-detection mode, participants adopt the strategy of searching for a discontinuity. Here, we propose that both the search strategies will be available to the participants, but they prefer the feature-search mode. The reason might be that participants are discouraged from using the singleton-detection strategy in case of less salient features (such as luminance instead of color or shape) [12]. It is noteworthy that luminance is also considered a salient feature [13]. However, saliency is mitigated by a suppressive mechanism that reduces the salience of potentially distracting visual objects following the salient signal suppression hypothesis. According to the hypothesis, the observer suppresses signals arising from salient-but-irrelevant items when searching for a known target [10]. To summarise, we could say that discrimination based on luminance would be facilitated by distractor suppression with feature search mode strategy.

### 1.2. ERP studies of attention capture

ERP studies of attention capture have focused on an ERP component known to reflect the selection of items in visual search. This component—known as the posterior contralateral N2 (N2pc)—is apparent in the ERPs recorded over the lateral occipital scalp, 175–300 ms after the onset of a search display containing a task-relevant singleton. This is an ERP component that is a negative-valued deflection in electrodes over the visual cortex contralateral to the to-be-attended region of space. It is often considered to be an index of attentional allocation. 'N2' signifies part of the second major negative ERP response, and 'pc' indicates posterior and contralateral response [3]. An earlier study suggested that N2pc is an index of target enhancement [14]. That is, it is involved in identifying and localizing relevant stimuli in the scene by enhancing relevant features rather than suppressing distractors [15].

Another distinct neural marker for the target-distractor discrimination task is Distractor Positivity (PD). The PD is a positivity, contralateral to the distractor between 200 and 300 ms at posterior electrode sites PO7/8 [16]. It is a positive-valued deflection observed at electrodes over the visual cortex contralateral to an object to be ignored. This ERP component is a putative index of suppression [3]. Kerzel & Burra (2020) [5] showed larger PD to the distractor in trials with fast responses. Results suggested that attentional suppression of salient distractors contributed to top-down control by biasing attention away from the distractor. PD component is used to assess the timing and neural substrates of the behaviorally observed suppression. Gaspelin & Luck (2018) [7] have directly linked the PD component with the behavioral index of covert attention suppression. Another shred of evidence comes from a study revealing that salient distractors failed to elicit ERP activity associated with attentional selection when participants searched repeatedly for the same target [14].

### 1.3. The current study

In the present study, we investigated the underlying attentional mechanism when a target was discriminated against a distractor based on luminance. In addition, we explored the effect of target location and the background changes on the behavioral response and neural mechanisms. To our knowledge, no clear evidence exists of attention mechanisms when low-level visual features are compared based on luminance only.

Previous studies have observed various combinations of luminance with both orientation and movement [13, 17] or have investigated the effects of target and distractor heterogeneity varied in luminance rather than chromaticity [6]. For inconspicuous targets, as in our case, systematic scanning is promoted, resulting in N2pc and PD components. A recent study has reported changes in the N2pc to the target, suggesting that target enhancement prevents attention capture by salient distractors [7]. On the contrary, distractor suppression prevents attentional capture by salient elements (distractor suppression hypothesis) [3]. The salient ERP marker, PD, is typically found in color-based feature search, supporting the distractor suppression hypothesis. While for shape-based feature search, PD was followed by N2pc for distractor promoting either way of attentional guidance (i.e., attentional capture or distractor suppression).

Furthermore, we have used topographical analysis, which allows us to classify the electrical topography of the brain throughout the entire scalp and compare the distribution of electrical signals across different periods. Burra & Kerzel (2013) [18] revealed significant PD at O1/O2 electrode sites compared to previously established PO7/PO8 electrode sites [3, 5]. They reported a reduction in N2pc as an indicator of distractor suppression.

To summarise, the present study investigated electrophysiological correlates and topographic visualization of target and distractor processing in luminance-based feature search with large set sizes in a homogenous display.

## 2. Materials and methods

### 2.1. Participants

Thirty-two subjects participated after giving informed consent. Subjects did not have any known history of neurological or psychiatric disorders. All subjects were right-handed. The mean age was 18.75 years with SD 0.52 years, and 13 participants were females. All subjects reported normal or corrected-to-normal visual acuity and were tested for typical color vision, using Ishihara color test plates [19]. The experiment has been carried out in accordance with American Psychological Association Code of Ethics, and all measurements were approved by the Institute of Nuclear Medicine and Allied Sciences (INMAS) institutional ethical committee (Number: ECR/824/Inst/DL/2016).

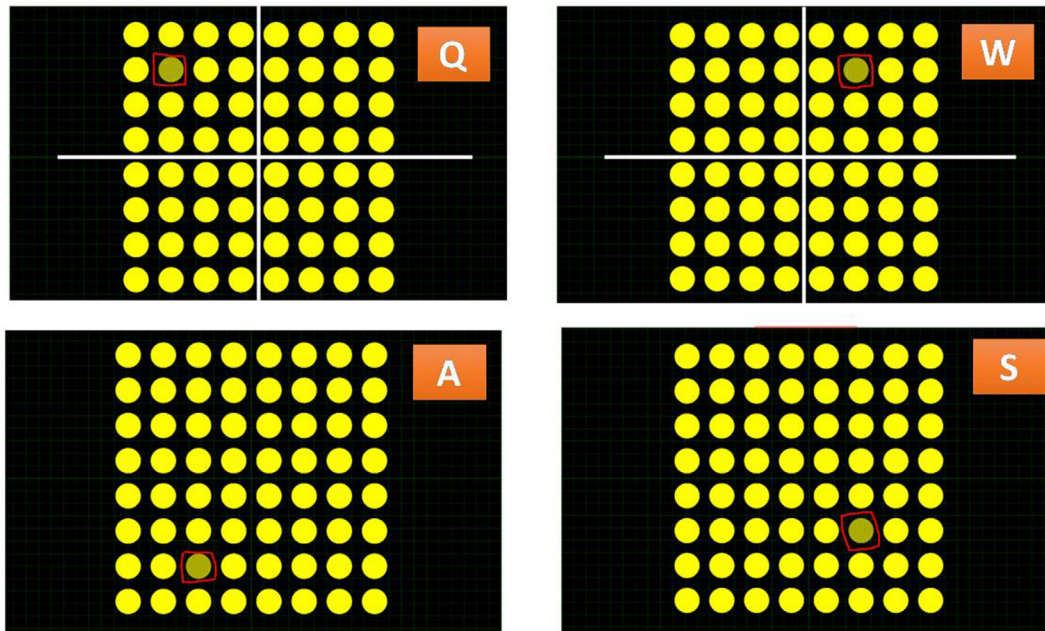
### 2.2. Stimuli

The experimental tasks were created using OpenSesame software. The tasks were shown on a 24-inch LCD monitor viewed from a distance of 20 inches. Visual search arrays comprised 64 filled circles presented equidistant in a square pattern. Each circle was 20 fonts (i.e., 1.4 cm) in diameter. Sixty-three of the circles were uniformly colored (yellow) distractors, and one was a target with slightly lower luminance. The color yellow appears to have a higher probability of fixation compared to RGB [20]. In task 1, no evident screen segmentation was present; whereas, in task 2, a white cross was present in the background, reflecting evident screen segmentation into four quadrants. Two tasks were counter-balanced among participants.

In each task, the display contained one target which was randomly positioned along with 63 distractors in every trial. Target locations were varied to produce the following display configurations: Top-Right position (Quadrant I); Bottom -Right position (Quadrant IV); Top -Left position (Quadrant II); Bottom -Left position (Quadrant III) (Figure 1). The order of these display configurations was determined pseudo-randomly within each block of trials [21].

### 2.3. Procedure

At the beginning of each trial, a fixation point appeared at the center of the screen for 500 ms. The search array remained visible for



**Figure 1.** Stimuli used in the experiment. Note. Top figures represent stimuli for task 1, whereas bottom figures represent stimuli for task 2. "Q" represents quadrant II, "W" represents quadrant I, "S" represents quadrant IV, "A" represents quadrant III.

2500 ms or until the response was made. Participants were instructed to identify the target and indicate its position by pressing one of four keys on a response pad (i.e., key "W" for Quadrant I, key "Q" for Quadrant II, key "A" for Quadrant III, and key "S" for Quadrant IV). The end of the trial was marked by an interstimulus blank screen displayed for 500 ms.

Each task consisted of 300 trials. A one-minute break was given to participants between each task. Each participant performed eight practice trials and 600 experimental trials.

#### 2.4. Electrophysiological recording and analysis

The EEG recording consisted of an eego mylab 256 ES-302 system (ANT Neuro) with two cascaded 128-channel eego™ amplifiers, having a maximum sampling frequency of 16 kHz with active Ag/AgCl electrodes. We deactivated cut-offs and the notch filter in the filter settings of the eego™ recording software. Data consisted of a sampling frequency of 2048 Hz and was collected from 125 standard sites and three nonstandard sites inferior to the standard occipital locations. Horizontal EOGs were recorded using two electrodes positioned 1 cm lateral to the external canthi. Vertical EOGs were recorded using two electrodes positioned above and below the right eye. FPz was the ground electrode and CPz was the reference electrode. Impedances for active electrodes were kept below 20 kΩ. One-minute baseline was recorded using eye close. The timestamps (triggers) were sent through parallel ports from OpenSesame using the python-based extension "PyPI". Pre-processing artifacts were removed using ASA-Pro, software available with ANT neuro EEGO sports system. Data processing and averaging were performed using MATLAB software (MATLAB 2014b). These signals were then filtered offline using a non-causal Butterworth band-pass filter (cut-off: 0.5–45 Hz, slope: 12dB/octave). Processed data were averaged offline over a 850 ms epoch including a 200 ms pre-stimulus baseline with epochs time-locked to target identification display onset. Trials with incorrect responses and blinks or saccades between 0 ms and 600 ms were excluded from the analysis (Invalid trials exceeding 10% of total) [22]. Blinks were defined by absolute amplitude of the vertical EOG exceeding 60 μV. Segments having absolute voltage exceeded 60 μV were excluded from the analysis. The primary analysis focused on ERPs

elicited by the following display configurations: quadrants\*background changes (4\*2).

#### 2.5. Statistical analysis

##### 2.5.1. Behavioural analysis

Two-way multivariate analysis of variance (MANOVA) was applied on behavioral variables, i.e., RT and percentage accuracy (ACC). Quadrants ("Q", "W", "A", "S") and tasks (with and without white cross) were taken as independent variables; whereas, RT and percentage accuracy were taken as dependent variables. The significance levels were adjusted with Bonferroni correction for multiple comparisons.

##### 2.5.2. Electrophysiological analysis

Trials with behavioral errors and RTs slower than 2s were excluded from analysis for both behavioral and ERP analysis. Furthermore, individual trials in the ERP analysis were rejected when blinks and eye movements (exceeding ± 50 μV), and muscular or other artifacts (any electrode exceeding ± 80 μV) occurred between 100 ms before and 600 ms after stimulus onset. Conventional Trial Rejection (CTR) method was used to remove high-amplitude artifacts from individual trials [23]. Two subjects were excluded because more than 30% of the trials were rejected as a result of excessive ERP artifacts (rejection criterion set in advance).

Then epochs of EEG data began 250 ms before the stimulus onset and ended 600 ms after the onset.

$$X(t, i) = x(t) * [u(t - T + 0.250) - u(t - T - 0.6)] \quad (1)$$

Where T is the onset of the  $i^{\text{th}}$  stimulus and  $x(t)$  is the out filtered EEG signal and  $u(t)$  is the step signal.

Then the average of the Epochs was used to create the ERPs for each subject.

$$ERP(i) = \frac{1}{N} \sum_{j=1}^N X(j) \quad (2)$$

where ERP(i) is the ERP for the subject number i and N is the total number of epochs

Then the ERPs of each subject were averaged over the subjects to get the grand ERP.

$$\text{GrandERP}(i) = \frac{1}{M} \sum_{j=1}^M \text{ERP}(j) \quad (3)$$

Where, M is the total number of subjects.

### 3. Results

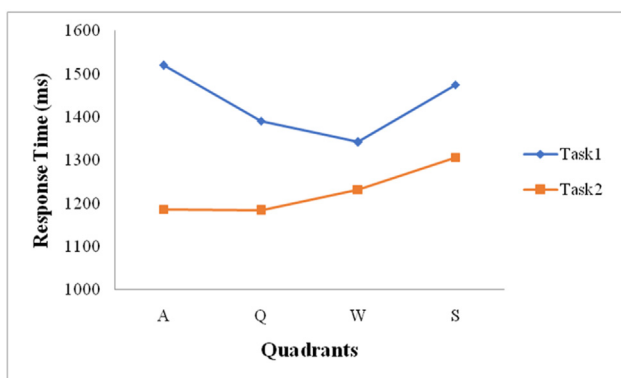
#### 3.1. Behavioral results

Only data from thirty participants (13 females) were further analysed. Trials with RTs slower than 2s and more than 2.5 SDs above the respective condition mean were excluded (less than 1%). The location of the target on any side of quadrants did not affect the response time of the participant ( $F(3,240) = 6.22, p < .001, \eta^2 = .066$ ). However, the location of target on any side of quadrants did affect the percentage accuracy of the participant ( $F(3,240) = 1.40, p = .244, \eta^2 = .016$ ). Whereas, the presence or absence of white cross did affect the response time ( $F(1,240) = 22.08, p < .001, \eta^2 = .084$ ) and percentage accuracy of the participant ( $F(1,240) = 26.51, p < .001, \eta^2 = .099$ ). There was no significant interaction between these two factors for RT ( $F(3,240) = 1.17, p = .320, \eta^2 = .013$ ) and percentage accuracy ( $F(3,240) = 0.83, p = .479, \eta^2 = .008$ ). Tukey post hoc comparisons showed significant differences between quadrant II, 'Q', and quadrant I, "W", ( $p < .05$ ), quadrant II, 'Q', and quadrant III, "A", ( $p < .05$ ), and quadrant II, 'Q', and quadrant IV, "S", ( $p < .001$ ).

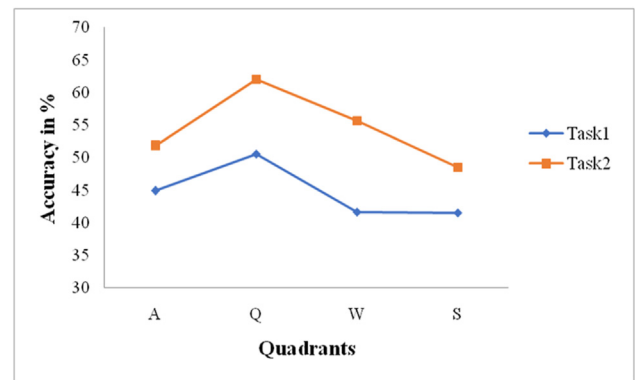
RTs on segmentation-present trials were 204 ms shorter than on segmentation-absent trials (1228 vs. 1432 ms). Similarly, percentage accuracy on segmentation-present trials was 9.85% higher than on segmentation-absent trials (54.53% vs. 44.68%).

Figures 2 and 3 summarise RT and percentage accuracy for quadrants and background respectively.

Agglomerative results showed that for any viable and important information, displaying information at top-left or quadrant II would be more optimal. In addition, the location of the target affects the accuracy of the task but not the response time, whereas evident screen segmentation affects both accuracy and response time. Improving visibility of the background can enhance task performance, i.e., a 22% gain in accuracy and a 14% faster RT.



**Figure 2.** Changes in RT with respect to quadrants for each task. Note. This figure demonstrates variation in RT for each quadrant and task 1 and task 2. A = Quadrant III [bottom-left position], Q = Quadrant II [Top-left position], W = Quadrant I [top-right position], S = Quadrant IV [bottom-right position]. Task 1 = no screen segmentation and Task 2 = evident screen segmentation in four quadrants. Here, faster RT is observed for quadrant I (i.e. W) and quadrant II (i.e. Q) for task 1 and task 2 respectively.



**Figure 3.** Changes in percentage accuracy with respect to quadrants for each task. Note. This figure demonstrates variation in percentage accuracy for each quadrant and task 1 and task 2. A = Quadrant III [bottom-left position], Q = Quadrant II [Top-left position], W = Quadrant I [top-right position], S = Quadrant IV [bottom-right position]. Task 1 = no screen segmentation and Task 2 = evident screen segmentation in four quadrants. Here, percentage accuracy is highest for quadrant II (i.e. Q) for both tasks.

#### 3.2. Electrophysiological results

Twenty-eight subjects' data (11 females) were analyzed after removing two subjects' data (>30 % artifact). The mean number of trials per condition and participant was 300 trials for task 1 (75 trials for each quadrant) and 300 trials for task 2 (75 trials for each quadrant). Total 58 electrodes were analyzed further: Frontal (FP1, FP2, FPz, F7, F3, F4, F8, Fz, FC1, FC2, FC5, FC6, F1, F2, F5, F6, FC3,FC4,FCz, AF3,AF4,AF7,AF8, FT7, and FT8), central (C3,C4,Cz, CP1,CP2, CP5, CP6, C1, C2, C5, C6, CP3,CP4), temporal (T7, T8, TP7, and TP8), parietal (P3, P4, P7, P8, Pz,POz,P1,P2,P5,P6,PO3,PO4,PO7, and PO8), and occipital (O1 and O2). The differential voltages were analyzed from 100 to 250 ms for task 1 and task 2 at electrodes P3/P4 in the PD. Figure 4 shows ERP waveforms elicited by the four search display configurations of interest for both tasks. We tested whether average voltage differences in the 50 ms interval centered on 250 ms were significantly different from zero. By one-sample *t*-test, the positivity to targets was significant ( $0.85 \mu\text{V}$ ),  $t(27) = 8.02, p < .005$ , Cohen's  $d_z = 1.08$ , consistent with the occurrence of a PD.

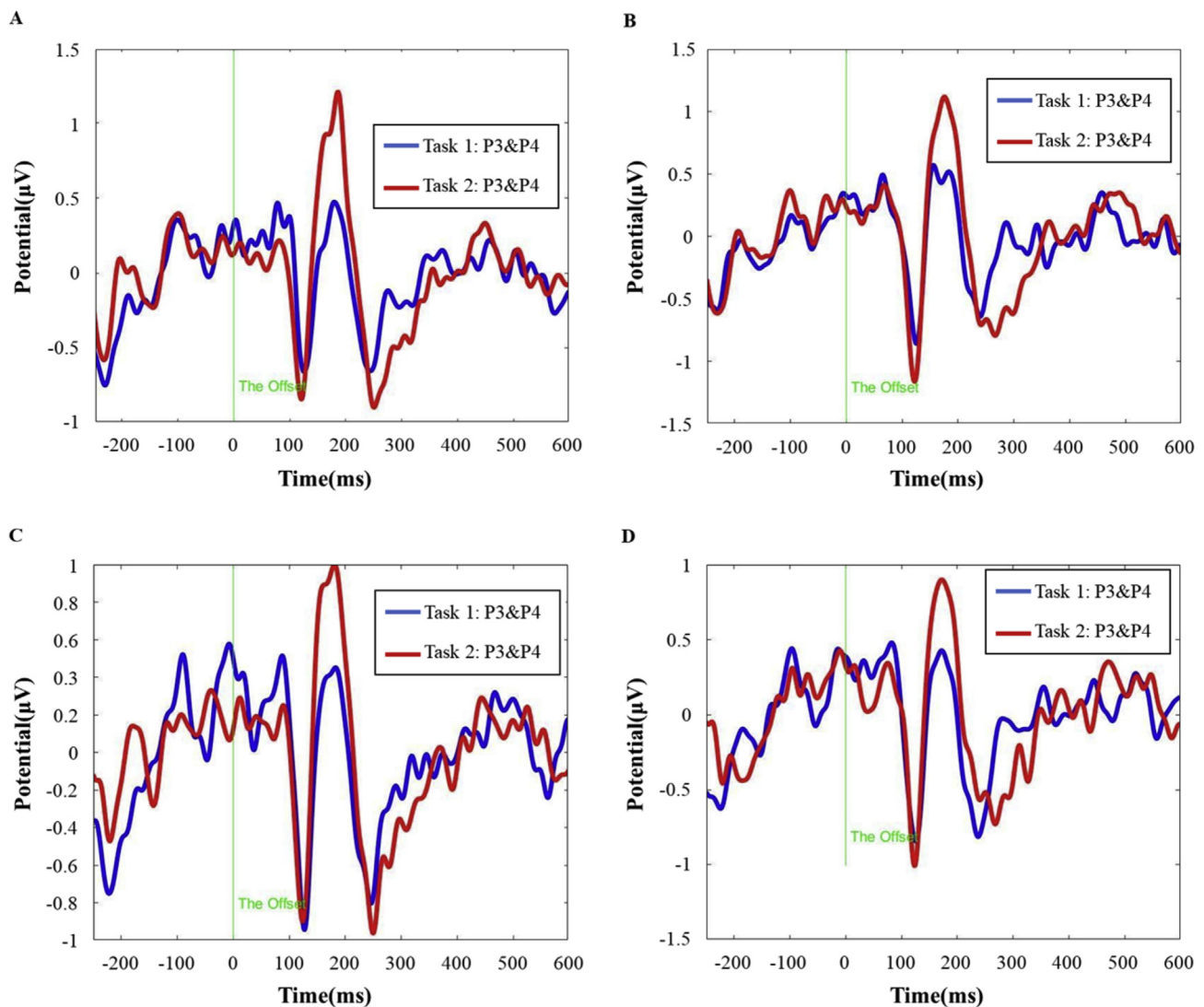
Grand average ERP waveforms for all four quadrants were compared between task 1 and task 2 for each electrode from 100 to 250 ms ( $4 \times 28$ ). The significant electrodes were P1 ( $t(111) = 2.630, p < .05$ ), P2 ( $t(111) = 2.664, p < .05$ ), P3 ( $t(111) = 2.375, p < .05$ ), P4 ( $t(111) = 2.162, p < .05$ ), P6 ( $t(111) = 3.254, p < .05$ ), P8 ( $t(111) = 2.080, p < .05$ ), PO4( $t(111) = 2.034, p < .05$ ), FP2( $t(111) = 8.477, p < .05$ ), F8 ( $t(111) = 2.668, p < .05$ ), FT8 ( $t(111) = 3.033, p < .05$ ) T8 ( $t(111) = 2.023, p < .05$ ), AF8 ( $t(111) = 2.173, p < .05$ ), CP4( $t(111) = 2.842, p < .05$ ).

However, N2pc differences were non-significant between task 1 and task 2. The grand-averaged PD waveforms and amplitude topographies for 4 quadrants and the comparison between task 1 and task 2 are illustrated in Figure 5.

The results showed that distractors were suppressed but not attended, reflecting top-down attention allocation or goal-directed search. A larger PD was elicited for task 2 and left quadrants (i.e. "Q" and "A"). It would also be consistent with the finding that larger PD corresponds to faster responses [24, 25]. Put another way, larger PD indicates that when active suppression of irrelevant information occurs, voluntary attention capture takes place, improving search performance [10]. Analogously, distractors in a homogenous context allow parallel, efficient visual search, eliciting an early PD and no distractor-N2pc [26]. In line with this notion, higher activation in the parieto-occipital region covering PD, but not N2pc was revealed in the topographic plot (Figure 5).

In sum, these results suggest that the PD component is crucial to preventing initial attentional capture by irrelevant items and may also help to terminate the deployment of attention to relevant items [24].





**Figure 4.** Grand-average ERP waveforms for display configurations of interest. *Note.* Grand average Event-related potential (ERP) waveforms for all four quadrants compared between task 1 and task 2 for electrode P3–P4. ERP waveforms for task 1 and task 2 are represented in blue color and red color respectively. Panel A: ERP waveform for “Q” = Quadrant II [Top-left position]. Panel B: ERP waveform for “W” = Quadrant I [top-right position]. Panel C: ERP waveform for “A” = Quadrant III [bottom-left position]. Panel D: ERP waveform for “S” = Quadrant IV [bottom-right position]. Task 1 = no screen segmentation and Task 2 = evident screen segmentation in four quadrants.

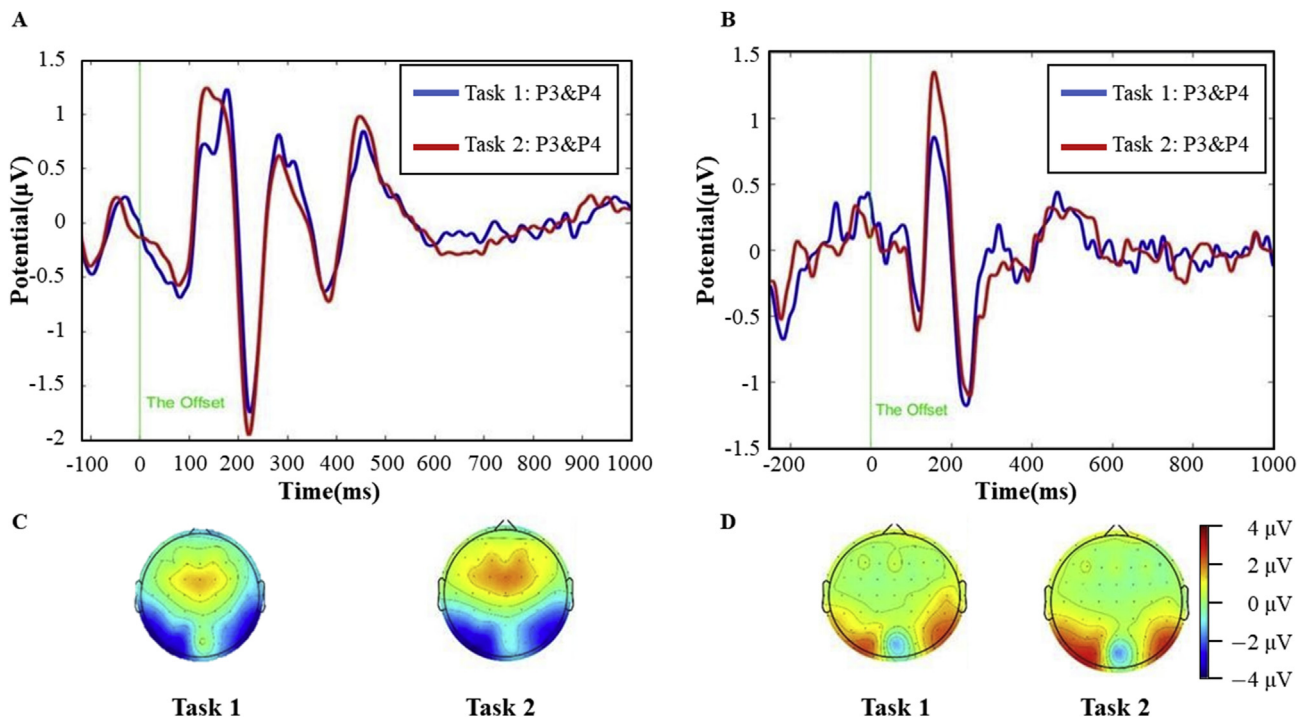
Top-down tuning of attention to a particular feature (e.g., contrast) can eliminate bottom-up saliency effects and neutralize the attention-driving capacity of irrelevant salient distractors (for example, visible screen segmentation), provided that the conditions allow an effective top-down tuning of attention, i.e., when the target and feature remain constant [27].

#### 4. Discussion

The present study observed distractor suppression for target-distractor discrimination tasks based on the low-level visual feature (luminance). In addition, the effect of the location of target and background of display were observed on performance. Behavioral results showed that target location influenced only percentage accuracy, not RT. Whereas, background changes such as introducing a white cross influenced both RT and percentage accuracy. Neurophysiological results revealed significant PD for parieto-occipital electrodes, supporting the distractor suppression hypothesis. Our results thus suggest that, in addition to the common notion that efficient target selection depends on

prioritization of relevant items, early active suppression of irrelevant items also contributes to top-down attention mechanisms. We found that the PD increased with the evident screen segmentation, reflecting active suppression that contributes to efficient selective attention.

Behavioral results indicated that displaying a target at a particular location influences the successful identification of the target but not the search time for target recognition. For instance, the top-left position (quadrant II or “Q”) was the appropriate location for higher accurate detection of the target irrespective of the background. On the other hand, the bottom-right position (quadrant IV or “S”) was the least favored location to display the target. However, background changes such as visible boundaries for quadrants improved the visibility of the target in the large search set. This in turn improved the performance in terms of RT (14% faster) and ACC (22% increased). It is noteworthy that improved visibility via background did affect the search time and success rate. In this context, we could find answers in the Gestalt law of perceptual organization, especially the law of proximity, the law of symmetry, and the law of common region. As emphasized by the previous finding that, besides the properties of the target and distractors,



**Figure 5.** Grand-average ERP waveforms and topographic maps for display configurations of interest. *Note.* Electrophysiological and topographic results for tasks at P3–P4. Panel A: ERP waveforms for N2pc (non-significant) in task 1 and task 2. Panel B: ERP waveforms for PD (significant) in task 1 and task 2. Panel C: Topographic plot signifying decreased amplitude for N2pc during 100–250 ms. Panel D: Topographic plot signifying increased amplitude for N2pc during 100–250 ms.

properties of the background were equally important in visual search [28]. Thus, in task 2, rather than searching for a target in a whole search set guided by serial scanning, participants searched in four chunks (four quadrants), reducing the number of items to be searched. Subsequently, the cost of filtering in working memory was reduced, resulting in improved performance [2]. Earlier findings also suggested that high target-distractor similarity resulted in high filtering demands, leading to the distractors being processed up to the individual level [29]. However, such processing could also be influenced by the search set and the number of distractors that emphasize the location of the target as the utmost priority for mission effectiveness. In line with this notion, it was found that distractors in a homogenous context that allowed parallel and efficient visual search, elicited an early PD and no distractor-N2pc [30]. In our case, N2pc was not significant, indicating a failure in attentional capture [16, 31]. On the other hand, PD was significant when trials for different target positions were presented. Even for task 2, where the screen was properly segmented, enhanced PD was observed. The result supported the distractor suppression hypothesis [9, 24]. According to the hypothesis, distractor suppression serves to prevent attentional capture by salient elements. However, for large homogenous display, having a higher distractor numerosity elicits N2pc, reflecting the degree of enhancement of the target features rather than suppression of the non-target features [15]. On the contrary, we found significant PD as compared to non-significant N2pc because target position was random in each trial rather than a higher number of distractors. Similar results were reported in an earlier study where PD was associated with fast-response trials [10]. The authors found that the PD reflected the operation of a suppressive mechanism that minimized the impact of the salient distractor on subsequent stages of processing associated with working memory. However, PD indicated the guided top-down attention mechanism, which improved further when the screen was segmented into four quadrants or visible boundaries were available. As there were 63 distractors to one target, this encouraged a parallel search method in addition to distractor suppression for target identification.

Furthermore, the non-significant N2pc supported the evidence for the distractor suppression hypothesis. Many studies have corroborated this basic pattern of results: under conditions where singletons elicit a PD component, it is typically not followed by an N2pc component [3, 7]. For example, Gasper & McDonald (2014) [10] showed that the amplitude of the target N2pc did not appear to vary, perhaps because the set size was held constant. Similar to our case, where the set size was constant ( $n = 64$ ), but the location of the target was randomized between different quadrants. It has been reported by an earlier study that when the target and features remain constant, there would be an effective top-down tuning of attention that would facilitate the feature search mode [27]. Subsequently, distractor suppression would replace the attention-driving capacity of an irrelevant salient distractor [11]. However, the distractor had produced unspecific interference or filtering costs that were reflected in the search time. The cost can be reduced by adding visibility to stimuli set by enhancing figure-ground segregation or displaying the target at the top-left position of the display. In sum, there is clear evidence that distractor suppression is favored by feature mode search strategy, and filtering costs can be reduced by introducing appropriate screen segmentation or enhancing boundaries between stimuli and background.

Electrodes-wise analysis revealed significant activity in the right hemisphere, particularly in parietal (P2, P4, P6, P8, PO4, CP4), frontal (FP2, F8, FT8, AF8), and temporal (T8) regions. Activation of the right hemisphere showed engagement of low-resolution attentional analysis and parallel search strategy [32] as reflected in task 2. In addition, an advantage from the right hemisphere is obtained when the target stimulus is very distinct and globally distributed. According to previous research, the right parietal lobe has a prominent role in visual search behaviour [33]. Wöstmann & colleagues (2019) [34] showed that distractor suppression induced relatively stronger alpha modulation in distributed regions including parietal, posterior temporal, and frontal. Our study highlighted the role of background changes in hemispheric lateralization and parietal cortex involvement in this context.

Finally, in our topographic analysis, we found a significant difference between N2pc and PD for task 1 and task 2. The topographic plot

revealed higher activity in task 2 for N2pc and PD. Also, both ERP markers supported the distractor suppression hypothesis. We observed enhancement in PD (orange color at parieto-occipital regions) and diminution in N2pc (blue color at parieto-occipital regions). The previous study also reported that even decreasing part of N2pc, which is nominally still negative, corresponded to suppression, besides increasing part of PD [18]. Our findings support the notion that distractor suppression occurs during feature search when discrimination between target and distractor is performed with a single target based on luminance.

## 5. Conclusion

The current findings emphasize that, besides the content of information, location and background are equally important for mission critical display. Top-left (or Quadrant II) is the optimum location for accurate detection. Change in the background that leads to improved figure-ground segregation has shown increased percentage accuracy and faster response time. Finally, it is also conceivable that PD does support the distractor suppression hypothesis, explaining flexible top-down inhibitory mechanisms.

Although the limitations of the study could be sample size (such as different participants in each task), experimental paradigm (such as small search set or black cross on white background), and ERP waveforms (such as use of P170 and contralateral delay activity), this study begins to shed some light on the long-lasting debate regarding the enhancement versus suppression. Though the study stands out in considering luminance as a feature, a future study could permute various stimulus dimensions to replicate the findings. Furthermore, the effect of handedness (left-handed vs. ambidextrous) on the performance, including target position, could be explored. Besides, varying the number of targets along with hemispheric lateralization could be examined with respect to distractor suppression hypothesis. The results can be further validated using Eye tracking and functional near-infrared spectroscopy (fNIRS). Preliminary observation shows the potential for future research to evaluate the impact of human factors on performance, such as individual differences or cognitive limitations. Future outcomes could have applications in military surveillance, night vision, and camouflage detection.

## Declarations

### Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

### Funding statement

This work was supported by grants from the sanctioned project ST-14/DIPR-734.

### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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