BRAINIACS
BRAIN IMAGING AND COMPUTING SCIENCES
2025 Volume 6
Issue 1 Edoc W87F1A123

Attraction and Suppression of Attention: Unravelling the Intricacies of Visual Capture*

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Abstract

The human brain continuously filters sensory information, selectively enhancing relevant inputs while suppressing distractions. Two electrophysiological markers, the N2pc and the distractor positivity (P_D), are central to this process. The N2pc reflects attentional allocation, whereas the P_D is thought to index distractor suppression. Yet, ambiguities remain: electroencephalography (EEG) measures relative voltage differences, making it unclear whether the P_D reflects genuine inhibition or attentional shifts. We introduce a multimodal protocol combining EEG with frequency-domain functional near-infrared spectroscopy (FD-fNIRS) to clarify distractor suppression mechanisms. Participants perform a visual search task requiring enumeration of target occurrences across sequential displays, with distractors presented on half of the trials. Analyses will focus on the N2pc and P_D component as electrophysiological markers of attentional selection and suppression, while FD-fNIRS signals will assess activation in visual, parietal, and frontal regions. Combined analyses of EEG and FD-fNIRS signals will test whether distractors evoke suppression below baseline. We expect the P_D to be reliably elicited and associated with reduced visual cortex activity contralateral to distractors alongside enhanced frontal activation, supporting its interpretation as an inhibitory marker. This approach advances theories of attentional capture and may provide biomarkers for disorders such as ADHD.

Keyphrases

Attentional capture; distractor suppression; EEG; FD-fNIRS, N2pc, P_D component.

Introduction

The human brain continuously filters vast amounts of sensory input, allocating attention to relevant signals while suppressing distractions. Failures in this balance undermine cognitive performance and contribute to neuropsychiatric disorders. Two electrophysiological markers central to understanding attentional dynamics are the N2pc and the distractor positivity (P_D). The N2pc—a posterior contralateral negativity around 200ms—indexes attentional selection during visual search (Luck and Hillyard 1990; Luck and Hillyard 1994). Yet, whether it denotes distractor filtering or target enhancement remains debated (Mazza et al. 2009).

In contrast, the P_D is a contralateral positivity following distractors under certain conditions, often interpreted as active suppression (Mazza et al. 2009; Burra and Kerzel 2013). There's growing support for its role in inhibiting salient distractors (signal suppression hypothesis), although alternative explanations persist (Drisdelle and Eimer 2021; Gaspelin and Luck 2023; Van Moorselaar and Theeuwes 2023).

Understanding the neural substrates of these phenomena requires methods with both temporal precision and spatial specificity. EEG excels at timing but lacks baseline and location clarity. Frequency-domain fNIRS (FD-fNIRS) complements EEG by providing interpretable signal baselines and 2mm spatial resolution (Gratton, Fabiani, et al. 1998; Gratton, Sarno, et al. 2000; Gratton and Fabiani 2001; Gratton and Fabiani 2010). This multimodal setup allows investigation into whether the P_D truly reflects inhibition and where it originates.

Methods

Participants

Participants are healthy adult volunteers (18–40 years) recruited at the Universities of Geneva and Lausanne. They have no history of neuropsychiatric disorders, no major chronic medical conditions, and no use of psychoactive medication. Pregnancy, deafness, or blindness are exclusion criteria.

Experimental paradigm

Participants performed a visual search task in which they detected a predefined target shape among heterogeneous distractors. Each trial comprised four successive search displays (referred to as *frames*). Each frame contained four shapes arranged along the vertical and horizontal midlines, at 3° of visual angle from fixation. The shapes included a circle, diamond, square, and hexagon. The target shape and color were fixed for each participant and counterbalanced across groups.

Figure 1 illustrates the time course of one trial. Trials began with a central fixation cross presented for 500 ms. Following this, the first of the four search displays appeared. Each frame was presented for 150 ms, followed by an inter-frame interval of 500 ms (with a jitter of ±100 ms). Targets could appear in 1 to 4 frames per trial. After the sequence, the fixation cross remained on screen until participants reported the number of target-containing frames (1–4) using the key-

*Report presented 2025-06-05, Neural Coding 2025, 16th International Neural Coding Workshop, Ascona Switzerland.

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board.

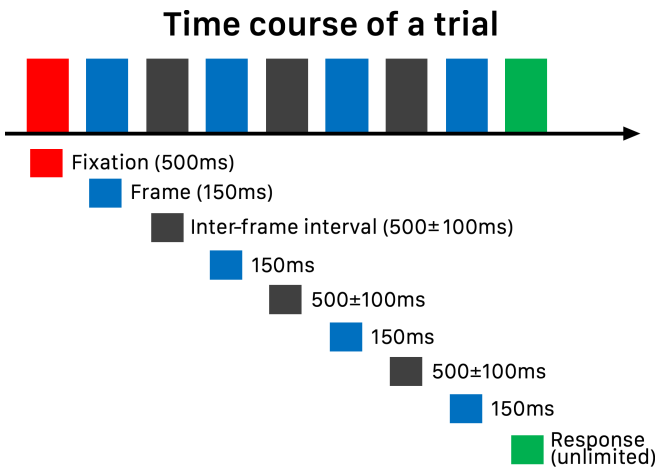

Figure 1: **Time course of a trial of the experimental procedure.**

In target-absent displays, the target shape was replaced by a fifth shape (a rectangle with a demi-circle on top), which appeared alongside three non-target shapes.

A color singleton distractor, differing only in color (red vs. green), appeared in 50% of the frames, regardless of whether the target was present or not. Target and distractor presence were orthogonally manipulated and never appeared on the same axis: when the target appeared on the vertical axis, the distractor appeared on the horizontal axis, and vice versa. Locations were counterbalanced across all conditions (Figure 2).

Overall, the design included 400 trials (16 blocks $\times$ 25 trials), yielding 1600 frames in total. The target was present in 1000 frames and absent in 600. In distractor-present frames, all four possible locations were equally probable. Similarly, target locations were uniformly distributed across conditions.

Event-Related Neuroimaging Protocol

At the University of Geneva, electrophysiological signals are recorded by 32 active Ag/AgCl electrodes (ActiCap Slim) converted by an actiCHamp amplifier at 1,000 Hz (Brain Products, Gilching, Germany).

At the University of Lausanne, event-related potentials (ERPs) are recorded using a 64-channel Biosemi ActiveTwo system (Biosemi, NL). Data are filtered (0.1–100 Hz; notch 50 Hz) with a 1024 Hz sampling rate to capture high-frequency activity and event-related changes. Electrode positions followed the 10-20 system. EOG activity is monitored using additional channels tied to the lateral canthus and mastoid, with minimal electrodes placed over the appropriate hemispheres to account for ocular artifacts.

FD-fNIRS signals are recorded using the Imagent-II system (ISS, Inc., IL) from eight optodes placed over the frontal and occipito-parietal regions of interest, exploiting its sensitivity to fast changes in oxy- and deoxy-hemoglobin. Data are filtered at 5–100 Hz (adjusting for the slow hemodynamic response dynamics; 0.1–100 Hz selected to align with expected EROS peaks), sampled at 125 Hz. A shared event trigger is used to ensure synchronized timing with the EEG (within $\pm$ 1 ms).

To bridge EEG and FD-fNIRS data (Gratton and Fabiani 2010; Jaquerod et al. 2024), we apply artifact identification and rejection independently but systematically; EEG data are preprocessed with ICA (EEGLAB), while fNIRS use artifact detection via built-in algorithms.

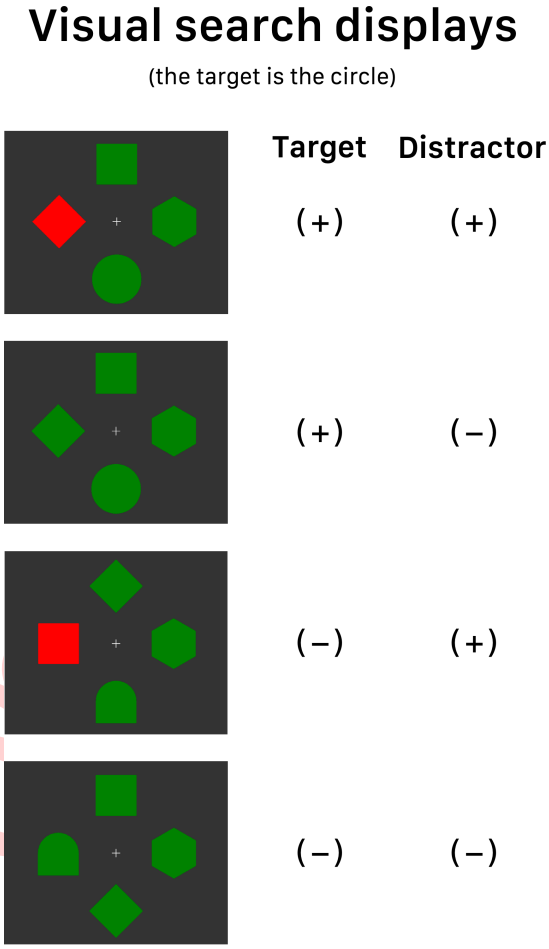

Figure 2: **Examples of the four different types of search displays determined by the combination of the target and of the distractor.** In this figure, the target is the circle. Each panel is characterized by the presence (+) or absence (-) of the target and/or the distractor. The size of the stimuli are not scaled for visualization purposes

Once overlapped in time, ERP components like N2pc are correlated with corresponding changes fast optical signals.

Results

Considerations for Analyses

To isolate the N2pc and P_D, event-related potentials (ERPs) recorded at electrodes PO7/PO8 ipsilateral to the stimulus of interest will be subtracted from those recorded contralaterally. One-sample *t*-tests against zero will be conducted to assess (a) the effect of the target alone (i.e., target-present/distractor-absent frames), (b) the effect of the distractor alone (i.e., target-absent/distractor-present frames), (c) the modulation of the effect of target presence by the distractor (i.e., target-present/distractor-present vs. target-present/distractor-absent frames) and (d) vice-versa (i.e., target-present/distractor-present vs. target-absent/distractor-present frames).

Within-subject repeated-measures ANOVAs will examine the effects of target presence and distractor presence. Effect sizes will be calculated to compare P_D reliability with that observed in standard paradigms where behavioral responses are collected on each trial.

EEG and FD-fNIRS data will be temporally aligned and projected

onto a standard MRI template using photon propagation models (Gratton, Sarno, et al. 2000). Optical signals will be analyzed within regions of interest, including the extrastriate visual cortex, posterior parietal cortex, anterior cingulate cortex (ACC), and prefrontal cortex (PFC). Correlations between ERP amplitudes and FD-fNIRS signals will be used to determine whether distractors evoke suppression below resting levels. Expected outcomes include reduced activation in visual areas contralateral to distractors, coupled with increased frontal activation during suppression.

Finally, exploratory analyses may also be considered. Multivariate pattern analysis (MVPA) could classify experimental conditions based on combined EEG–fNIRS signals. In addition, cross-modal regression models may assess whether frontal fNIRS activation predicts P_D amplitude across participants.

All analyses will include corrections for multiple comparisons (false discovery rate, FDR), estimation of statistical power, and calculation of Bayes factors to evaluate evidence for distractor suppression versus alternative interpretations. This comprehensive approach aims to ensure robust and interpretable results.

Expected Outcomes

We expect that the P_D will be reliably elicited in this paradigm and that its reliability will equal or surpass that observed in paradigms requiring trial-by-trial responses. If the P_D reflects active suppression, we anticipate enhanced activation in frontal inhibitory regions—namely, the anterior cingulate cortex (ACC) and prefrontal cortex (PFC)—and reduced activity in the visual cortex contralateral to distractors, as measured by FD-fNIRS. Such activation patterns would confirm that the P_D is not merely a byproduct of attentional shifts, but reflects an inhibitory mechanism that actively suppresses distractor processing below baseline.

These findings would substantially contribute to theoretical debates in attention research by demonstrating the coexistence of attentional capture (N2pc) and suppression (P_D), while clarifying their underlying neural substrates. Moreover, by providing interpretable baseline measures, multimodal imaging would help overcome the spatial and interpretational limitations inherent to EEG-only approaches.

Discussion

Future Directions

Beyond replication and confirmation, future work could extend these findings by situating them within the framework of predictive coding. According to predictive coding theories, the brain minimizes prediction errors by attenuating responses to expected stimuli and enhancing responses to unexpected ones (Friston 2005; Garrido et al. 2018; Kok et al. 2012; Rao and Ballard 1999). Within this framework, the P_D could be reinterpreted not merely as a suppression signal, but as a marker of the brain's effort to reduce prediction errors generated by distracting events. Specifically, predictable distractors may be more effectively suppressed, while unexpected distractors may disrupt suppression and capture attention more strongly.

A potential way to test this account would be to manipulate distractor predictability by occasionally violating its expected color. If the P_D indeed reflects predictive suppression, we would anticipate stronger P_D amplitudes for expected distractors and weaker or absent P_D for unexpected ones.

Moreover, manipulating attentional priority via selection history has demonstrated modulation of N2pc and P_D amplitudes (Van Moorselaar and Theeuwes 2023). This highlights the importance of incorporating both predictive context and feature stability into future paradigms.

Relevance and Impact

The findings have broader implications for understanding perceptual and clinical phenomena. For instance, attention-deficit/hyperactivity disorder (ADHD) is characterized by impaired distractor suppression (American Psychiatric Association 2013). Studies report attenuated and more variable N2pc in ADHD populations (Deiber et al. 2021; Luo et al. 2019; Marquardt et al. 2018), but the P_D remains understudied. If reliable, P_D metrics could serve as biomarkers for inhibitory control deficits in ADHD. These multimodal electrophysiological signals may bridge the gap between mechanistic understanding and clinical utility.

Conclusion

This study presents a novel EEG–FD-fNIRS multimodal paradigm to resolve long-standing debates about attentional suppression. With high temporal resolution and interpretable baseline signals, this approach seeks to determine whether P_D denotes genuine inhibition and to localize its neural generators. Success would sharpen theories of attentional control, identify biomarkers for clinical disorders, and underscore the value of multimodal neuroimaging in cognitive neuroscience.

Citation

Brainiacs 2025 Volume 6 Issue 1 Edoc W87F1A123
Title: "Attraction and Suppression of Attention: Unravelling the Intricacies of Visual Capture"
Authors: Lou Lescuyer-DeDecker, Alessandro E. P. Villa, Alessandra Lintas, Dirk Kerzel
Dates: created 2025-05-01, presented 2025-06-05, updated 2025-09-07, published 2025-09-08

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NPDS: LINKS/Brainiacs/LescuyerDeDecker2025ASAUIVC
DOI: 10.48085/W87F1A123

Acknowledgments

This study is supported by the Swiss National Science Foundation grant #10.001.386.

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Contributions

All authors contributed equally to the paper.

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