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Distilling the distinct contralateral and ipsilateral attentional responses to lateral stimuli and the bilateral response to midline stimuli for upper and lower visual hemifield locations

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Abstract

A contralateral posterior negativity elicited by lateral oddballs (N2pc) and a bilateral posterior negativity elicited by vertical midline oddballs (bilateral N2) are ERP components reflecting attentional deployment that have been rarely compared. In different tasks, we explored to what extent they reflect similar underlying mechanisms of attention. We used a multiple-frame procedure to present pop-out color oddballs among distractors. A homogeneous condition contained only distractors (0 oddballs) and served as a control condition that was subtracted from oddball-present conditions to isolate attention effects. The number of oddballs and the vertical hemifield containing them (upper vs. lower) were two critical factors. For the lower hemifield, the signal amplitude increased with the number of oddballs, otherwise had similar effects and scalp distributions, suggesting the bilateral N2 acted as a bilateral N2pc and likely reflected similar underlying generators. For the upper hemifield, component amplitude also increased with the number of oddballs, but the scalp distributions were positive and more centered, suggesting inverted generators across the two vertical hemifields. An ipsilateral positivity occurred about 50 ms after a contralateral positivity, similar in magnitude, producing a biphasic contra-minus-ipsi difference wave. Previously reported smaller negative N2pc components for upper hemifield oddballs likely reflected a negative lobe artificially created by the subtraction of a lagged positive ipsilateral response. The results compel us to argue for a systematic separation of data for upper versus lower hemifields in studies of visuo-spatial attention, and the use of an experimental design permitting the separate estimation of contralateral and ipsilateral responses.

KEYWORDS

ERP, N2pb, N2pc, posterior N2, posterior P2, vertical hemifields, visual spatial attention

1 | INTRODUCTION

In contrast to early visual processing, later phases of visual processing have limited capacity that restrict the amount of information from the retina that can be processed in detail at the same time Pinker (1984). Complex neural mechanisms are required to distinguish, analyze, select, and send information to visual short-term memory for further processing,

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depending on our intentions. Visuo-spatial attention allows us to filter certain information presented in our visual field, presumably to enhance relevant stimuli relative to distractors (Hillyard, Vogel, & Luck, 1998).

A well-known electroencephalographic event-related potential (ERP) has been associated with the lateral (left or right) deployment of visuo-spatial attention. This component is characterized by a negative deflection measured at posterior electrodes contralateral to the attended lateral hemifield relative to ipsilateral electrodes (N2pc). The N2pc is typically observed between approximately 180 and 300 ms post-stimulus onset and is suggested to reflect neural activity involved in distractor suppression (Luck & Hillyard, 1994a, 1994b), and/or target processing (Eimer, 1996).

Whereas the N2pc reflects the deployment of attention toward lateral stimuli, a small bilateral N2 called N2pb[1] has also been isolated in the ipsilateral hemisphere by subtracting a homogeneous array containing only distractors from an array containing a lateral oddball (Luck & Hillyard, 1994b). Luck and Hillyard described the N2pb as a bilateral negativity that occurs for targets presented laterally, superposed with the N2pc component as they are additive subcomponents but occurring slightly after N2pc. They proposed to isolate the N2pb amplitude at ipsilateral electrodes, and measured larger N2pb for color than other feature pop-outs, and larger as target probability decreased, contrary to N2pc amplitude, whose amplitude was independent of probability and feature dimensions (Luck & Hillyard, 1994a). The authors suggested that two posterior subcomponents could explain the asymmetric posterior N2 activity for lateral targets: a primarily bilateral subcomponent (N2pb), responsive to probability manipulation, superposed on a distinct contralateral subcomponent. Since then, their suggestions and the interpretation of the N2pb, measurable at ipsilateral side, has not been debated. Much research on the N2pc has been done since then, however, focusing on the underlying mechanisms of this contralateral component occurring with lateral stimuli (often with pop-out oddballs; Hilimire, Mounts, Parks, & Corballis, 2011; Kiss, Van Velzen, & Eimer, 2008; Mazza, Pagano, & Caramazza, 2013).

In their recent article, Doro, Bellini, Brigadoi, Eimer, and Dell'Acqua (2020) also explored the comparison of N2pc and N2pb, and for clarity, named the difference wave created by subtracting the ipsilateral signal elicited by a lateral target from the averaged bilateral signal elicited by vertical midline oddballs "N2pcb," thus avoiding confusion with the N2pb of (Luck & Hillyard, 1994a). Here, we adopted a different methodology based on a separate homogeneous distractor condition consisting entirely of distractors, without any oddball targets. For the sake of clarity, we summarize here our notation and the corresponding formulae for the various difference waves used throughout this study:

N2pc or N2pc$^{c–i}$ = contralateral minus ipsilateral;
N2p$^{c–h}$ = contralateral minus homogeneous;
N2p$^{i–h}$ = ipsilateral minus homogeneous[2];
N2pb$^{b–h}$ = bilateral minus homogeneous.

We define N2pb$^{b–h}$ only for midline oddballs, and we estimate the bilateral response for these conditions as the average of the left and right electrodes under consideration (e.g., (PO7 + PO8)/2).

After disentangling signals for upper and lower hemifield in the present study, some difference waves were positive for upper hemifield oddballs, and negative for lower hemifield oddballs. This required further nomenclature to distinguish between positive and negative attentional responses. Thus, these designations will be, respectively, declined as **P2p$^{c–h}$**, **P2p$^{i–h}$**, and **P2pb$^{b–h}$**. Some caution is required, as will be clear later, given that the positive waves observed for attended upper visual hemifield stimuli are not simple reflections about zero of the corresponding negative waves found for lower visual hemifield stimuli.

As illustrated in Figure 1, the present study investigated whether the N2pb$^{b–h}$ for vertical midline oddballs was modulated the same way as N2p$^{c–h}$ for oddballs presented laterally. For this endeavor, oddballs (pop-out stimuli by virtue of their color difference with distractors) were placed either laterally or on the vertical midline. Because the N2pc is elicited by lateral oddballs only, it will be blind to the selection of midline oddballs (Woodman & Luck, 2003). We used simple visual search tasks and four experimental manipulations, all known to modulate the amplitude of N2pc, in which color oddballs were presented in different numbers and locations. The tasks were performed in different blocks of trials and each trial involved the presentation of six visual search frames using a multiple-frame procedure (MFP; e.g., Pomerleau, Fortier-Gauthier, Corriveau, Dell'Acqua, & Jolicoeur, 2014). For each task, participants had to report how many frames in the sequence of six frames displayed a configuration of oddballs that matched the instructions for that block (see Figure 1). In the **spatial localization task** (Above/Below), participants had to report the number of frames that contained oddballs either in the upper hemifield (above, one block), or in the lower hemifield (below, another block). In the **number discrimination task** (Odd/Even), participants had to report the number of frames that contained either 0 or 2 oddballs (even number, in one block), or 1 or

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[1] or N2p by other authors (Schubo, Schroger, & Meinecke, 2004), or even more recently N2i (Loughnane et al., 2016).

[2] N2p$^{i–h}$ in this article corresponds to the signal Luck and Hillyard (1994a) called N2pb but measured on the ipsilateral hemisphere.

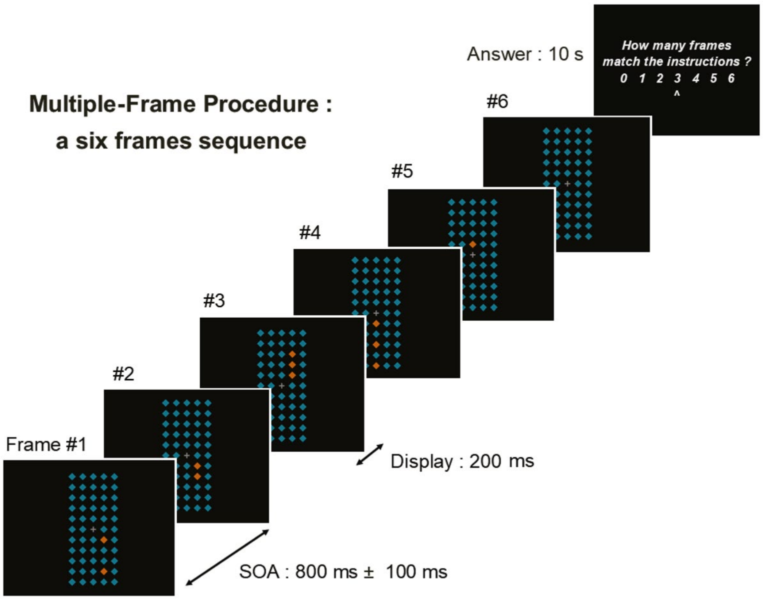

FIGURE 1 Illustration of the Multiple-Frame Procedure (MFP) with Match and Mismatch frames. One, two, or three color oddballs were placed either laterally or on the vertical midline, either in the upper or lower hemifield) or were absent to create homogeneous distractor frames as a control condition. For example, in the Above/Below task (spatial localization), in one block of trials participants were asked to count the frames containing oddballs in lower hemifield only. For the frame sequence shown here, the correct answer would have been 3, the Matching frames being #1, #2, and #4. In the Odd/Even task (number discrimination), in one block participants were asked to count the frames containing an odd number of oddballs (1 or 3) only, the correct answer would also have been 3, the Matching frames, thus being #3, #4, and #5

3 oddballs (odd number, another block). In the **simple detection task** (Present/Absent), participants had to report the number of frames that contained the presence of at least one oddball (two blocks with the same instructions).

The four manipulations (vertical hemifield, number of oddballs, type of task, and match type), and our rationale for each choice are further described in Section 2.

2 | MATERIALS AND GENERAL METHODS

2.1 | Multiple-frame procedure

Participants were seated 54 cm from a computer screen in a dark electrically shielded room, where they completed a visual search task using the MFP. The MFP is an efficient way to increase the total number of search displays without compromising cognitive processes underlying target selection in a given time period (Aubin & Jolicoeur, 2016; Drisdelle & Jolicoeur, 2018; Fortier-Gauthier & Jolicoeur, 2018; Maheux & Jolicoeur, 2017).

Each trial consisted of six consecutive frames each presented for 200 ms with a stimulus onset asynchrony (SOA) of 800 ± 100 ms, allowing enough time to ensure that perceptual and cognitive processes deployed for each frame would not cause interference with following or preceding frames (Dux & Marois, 2009; Jolicoeur, 1998).

Participants pressed the spacebar to initiate each trial. The first frame was presented 1,000 ± 100 ms following trial initiation. After the presentation of all frames (total of 6), participants were instructed to indicate how many Match frames were presented (0 to 6) in the sequence, according to instructions for that block, by moving a cursor left or right, using the keys on a standard computer keyboard, to indicate the desired response. Feedback on response accuracy was reported immediately after participants responded ("+" sign if the answer was correct, "−" if the answer was incorrect, and "|" if no response was given after 10 s).

Note that participants only reported how many frames matched the definition given at the beginning of each block. For example, for the block in which frames with an odd number of oddballs were to be counted, they did not need to remember whether the particular number was 1 or 3, whether the oddballs were in the left, right, or midline locations, or whether in the upper or lower visual field. They only needed to increment a counter when a frame matched the definition of frames to be counted and to report the final count at the end of the trial.

2.2 | Visual stimuli

Stimuli were presented on a computer screen on a black background. A light gray fixation cross was presented in the center of the screen during trials. As illustrated in Figure 1, each frame contained 54 equiluminant diamonds (each 0.7° wide), equidistant from neighboring diamonds (0.5° apart), arranged in a grid of five columns and 11 rows (the center of the grid being the fixation cross). Among these 54 items, 0, 1, 2, or 3 diamonds were salient by virtue of their color difference with distractors. Diamonds were orange or blue, and which color served as distractor and which as salient oddballs was counterbalanced between participants. All diamonds were equiluminant, measured using a Minolta Chromameter (orange = 11.1 cd/m^2, blue = 10.9 cd/m^2). Oddballs never appeared in the outermost columns.

We controlled and randomized three variables giving a $4 \times 3 \times 2$ experimental design for a total of 24 combinations of factor levels: number of oddballs (four levels: 0, 1, 2, or 3), location of oddballs (three levels: left, middle, or right column), and hemifield containing the salient items (two levels: upper or lower hemifield). Each participant had a different random order of frames, with the constraint that each of the 24 possible frame types occurred 18 times (i.e., 432 frames per block). A block consisted of eight practice trials (48 frames) followed by 72 experimental trials (432 frames). The probability of a particular number of oddball stimuli (0, 1, 2, or 3) was the same (.25), and, when there were oddball stimuli in the display (.75 of all frames), each of the six general screen areas were equally likely (upper/lower × left/middle/right; .75/6 = .125). The experiment was programmed using a combination of custom MATLAB code and functions from the Psychtoolbox-3.

2.3 | Experimental design: Four manipulations

We manipulated four variables. The first experimental manipulation was the **vertical placement** of oddballs (upper vs. lower hemifield). Previous research suggested that attended stimuli located in the lower hemifield produce a larger N2pc compared with those in the upper hemifield (Bacigalupo & Luck, 2019; Luck, Girelli, McDermott, & Ford, 1997; Perron et al., 2009), which could be the result of extrastriate neural generators of the N2pc that would be topographically mapped to different locations in the brain. Hansen, Kay, and Gallant (2007) proposed that the upper hemifield is represented in the ventral part of the occipital lobe, while most of the lower hemifield is represented in the dorsal part, closer to the occipital and temporal electrodes, as previously measured by Sereno et al. (1995). Therefore, a stimulus appearing in the upper hemifield is suggested to generate an activation in a cortical region that would have an equivalent dipole that would not point directly at the posterior electrodes, which could result in a lower amplitude in the posterior EEG signal (Perron et al., 2009). The impact of the vertical hemifield location on N2pc has been recently confirmed and decoded in single trials by machine learning tools, and, more critically, recorded with an opposite polarity for upper hemifield oddballs compared with lower hemifield oddballs, as can be seen in figures published by Fahrenfort, Grubert, Olivers, and Eimer (2017).

Second, we manipulated the **number of pop-out stimuli** (color oddballs among distractors) presented within each search display. Example displays are shown in Figure 1. Previous work has suggested that N2pc may be a correlate of object individuation in the visual field. This mechanism would allow the separation and recording of one element from another according to its spatial information when several visual objects are processed (Xu & Chun, 2009). In particular, N2pc amplitude increased with the number of objects to individuate, reaching an asymptote between three and five elements (Drew & Vogel, 2008; Mazza & Caramazza, 2015; Mazza et al., 2013).

Third, we manipulated the **task** participants performed, which was either a spatial localization task (Above/Below) or a number discrimination task (Odd/Even). Mazza and Caramazza (2011) presented search displays containing 1, 2, or 3 color pop-out items among distractors. For each display, participants had to count and report the number of pop-out items, or to report if the number of pop-out items matched a previously specified number of targets (1, 2, or 3, in different blocks of trials), or simply to report the presence or absence of any pop-out item regardless of how many there are, anywhere in the display. The results showed that N2pc amplitude increased significantly with the number of oddballs to be counted or matched, but that amplitude was not modulated in the detection task (see also Benavides-Varela et al., 2018). Mazza and Caramazza proposed a model in which the mechanism underlying the individuation of objects is flexible and dependant on whether the task required individuation. In other words, if knowing the number of oddballs was not relevant for the task, such as in the detection task, then there would be no need for individuation, leading to a smaller amplitude of the N2pc (the neural correlate of attention) that should be independent of the number of oddballs, as was found in the detection task. Because the stimuli were exactly the same under all tasks and only the instructions differed, their results suggest that this was a top-down effect. In our design we supposed that knowing whether oddballs were above, or below, the horizontal midline would not require knowing how many there were, and hence the amplitude of N2pc should not depend on the number of oddballs.

Finally, we manipulated whether the display in a given frame matched the search instructions, or not (later called **match type** condition). In Figure 1, we show different examples of Match and Mismatch frames. The general task in the MFP was to count the number of frames that matched the search instructions. This type of manipulation has been used in many studies to assess how attention is deployed to stimuli, in a top-down fashion (Luck, Chelazzi, Hillyard, & Desimone, 1997). The contrast between Match and Mismatch conditions has sometimes been studied under the term Selection Negativity (SN) for multidimensional selection of lateral oddballs (Bartsch, Donohue, Strumpf, Schoenfeld, & Hopf, 2018), or for centered oddballs (Harter, Aine, & Schroeder, 1984; Kimura, Katayama, & Murohashi, 2005, 2006; Smid, Jakob, & Heinze, 1997). The definition of what counts as a match or mismatch frame is often manipulated in a blocked fashion, with match and mismatch displays interspersed randomly within blocks, which is what we also used here at the level of frames within trials. In cases when Match and Mismatch frames are very easy to discriminate, one may observe a larger N2pc for Match frames. However, the N2pc triggered in Mismatch frames by oddball patterns that are similar to Match frames, so-called "near" distractors, is often not different from the N2pc triggered in Match frames, or for tasks in which distinguishing between Match and Mismatch frames requires item individuation (Mazza & Caramazza, 2011).

For each of these four manipulations, we compared factor effects across the posterior signals observed for frames containing lateral or vertical midline oddballs, which enabled a systematic comparison of their effects across the associated components under study, previously named N2pc and N2pb.

2.4 | EEG recordings

EEG data from 64 active Ag/AgCl electrodes were recorded using an Biosemi Active Two system and placed at the following sites: Fp1, Fpz, Fp2, AF7, AF3, AFz, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCz, FC2, FC4, FC6, FT8, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P9, P7, P5, P3, P1, Pz, P2, P4, P6, P8, P10, PO7, PO3, POz, PO4, PO8, O1, Oz, O2, and Iz. In order to measure horizontal eye movements, a horizontal electrooculogram (HEOG) was calculated offline by taking the difference in signals between electrodes placed at the external canthi of the right and left eye. Vertical eye movements and blinks were measured using a vertical electrooculogram (VEOG), which was the difference between signals at electrode Fp1 (located above the left eye) and an electrode placed below the left eye. EEG was recorded at a sampling frequency of 512 Hz from active electrodes mounted on an elastic cap positioned using the International 10–10 System (Sharbrough et al., 1991). Re-referencing of the EEG to the average of the right and left mastoid electrodes was performed offline during initial signal processing. A high-pass filter at 0.1 Hz and a low-pass filter at 30 Hz were applied to the EEG signals offline post-recording. The HEOG and VEOG signals were filtered with a high-pass filter of 0.1 Hz and a low-pass filter at 10 Hz to facilitate trial-by-trial artefact detection. Stimulus-locked frames from all trials were epoched from 100 ms pre-stimulus to 700 ms post-stimulus and baseline corrected to the average voltage of the 100 ms pre-stimulus period. An independent component analysis technique was used to remove blink artifacts (see Drisdelle, Aubin, & Jolicoeur, 2017) for a detailed description of the method and validation for use with N2pc). Epochs were further screened for remaining artefacts (VEOG deflection > 50 μV within a time window of 150 ms; HEOG deflection > 35 μV within a time window of 300 ms; or signal exceeding ± 100 μV anywhere in the epoch) were excluded from final analysis. On average, less than 1% of the epochs were lost as a result of these exclusion criteria.

2.5 | Waveforms and statistical analyses

The mean amplitudes of the ERP components of interest were measured at PO7 and PO8, for each combination of the four independent variables (vertical hemifield, number of oddballs, task, and match type).

N2pc (or N2pc$^{c–i}$) difference waves were computed for conditions with lateral oddballs, by subtracting ipsilateral activity (e.g., activity from electrodes over the right hemisphere activity when the pop-out stimuli are presented in the right hemifield) from the contralateral activity to the salient item (e.g., activity from electrodes over the left hemisphere when oddballs were presented in the right hemifield) at the PO7/PO8 electrodes (Luck, 2014).

The standard logic of subtracting ipsilateral from contralateral ERP waveforms cannot be applied to frames that contain non-lateralized oddballs on the vertical midline. So, the bilateral signal triggered by vertical midline oddballs was computed using the average of signals at the left and right posterior electrodes (i.e., PO7 and PO8). To isolate activity related to attention, ERPs elicited by homogeneous frames (no oddballs) were subtracted from the ERP elicited by frames with oddballs on the vertical midline (N2pb$^{b–h}$). We also examined the posterior activity separately for ipsilateral and contralateral activity, where, for ipsilateral (N2p$^{i–h}$), the signal elicited by homogeneous frames was subtracted from the signal at PO7 for left oddballs and PO8 for right oddballs (reverse for N2p$^{c–h}$). Subtracting the homogeneous distractors condition from the various oddball conditions allowed us to compare ipsilateral, contralateral, and bilateral attentional responses in the ERPs.

For statistical analysis, we estimated the amplitude of **N2p$^{c–h}$** and **N2pb$^{b–h}$** by computing the mean amplitude in a window of 50 ms centered on the approximate peak of the component in the grand average waveforms (see Drisdelle and Jolicoeur, 2018; Drisdelle, Konishi, et al., 2017). The time window used was, respectively, for **N2p$^{c–h}$/N2pb$^{b–h}$** for lower hemifield 205–255/210–260 ms and **P2p$^{c–h}$/P2pb$^{b–h}$**

for upper hemifield 135–185/140–190 ms, following stimulus onset.

Using jackknifed waveforms, latencies of the waveforms were estimated as the time at which the area under the curve was 50% of the total positive area in a window of 135 to 240 ms. These jackknife estimates were subsequently back-transformed to the individual participant latency estimates (see Brisson & Jolicoeur, 2008; Kiesel, Miller, Jolicoeur, & Brisson, 2008; Smulders, 2010) and submitted to a repeated-measures ANOVA.

Repeated measures or mixed design ANOVAs were used. When appropriate, a Greenhouse-Geisser correction was applied when sphericity was violated for the number of oddballs factor (three levels). For significant effects, Bonferroni corrected pairwise comparisons were calculated to test specific differences between levels of conditions. Effect sizes are reported as partial eta squared (η_p^2) for all significant ERP effects.

2.6 | Scalp potentials and scalp current density

Scalp potential topographic maps were generated using a 2-dimensional spherical spline interpolation (Perrin, Pernier, Bertrand, Giard, & Echallier, 1987). Epoched data were transformed to scalp current density (SCD) using a spherical spline surface Laplacian (spline flexibility constant $m = 4$, regularization constant $\lambda = 10 - 5$, 50 iterations) (Kayser & Tenke, 2015a, 2015b; Perrin, Pernier, Bertrand, & Echallier, 1989). Beyond providing reference-free mapping of scalp-recorded electrical activity (rendering ERP polarity unambiguous), SCD's provide a sharper topography (Pernier, Perrin, & Bertrand, 1988) by reducing the impact of volume conduction, which blurs the scalp-recorded EEG voltage signal. We used a 2-D SCD inverse solution to render our SCD topographies. Compared to 3-D inverse solutions, the 2-D SCD technique does not makes assumptions about the neuroanatomy or about the number, orientation, or independence of the underlying neuronal generators. The sign of these estimates directly reflects the direction of the global radial currents underlying the EEG topography, with positive values representing current flow from the brain toward the scalp, and negative values representing current flow from the scalp into the brain.

3 | EXPERIMENT 1

3.1 | Participants

Twenty-nine participants were compensated 20$ for voluntarily participating in the experiment, which had been vetted by the Ethics Committee of the Faculty of Arts and Science at Université de Montréal. They reported being neurologically normal and having normal color vision and normal or corrected-to-normal visual acuity. Of the 29 participants, one participant was removed due to technical problems that could not be corrected in post-recording processing and two more were rejected because they obtained less than 60% in accuracy in the experiment. Thus, 26 participants were kept for final analysis (age: $M = 22.2$, $SD = 3.24$, seven males, four left-handed).

3.2 | Instructions

There were four blocks that differed according to the task instructions. Each block had 72 trials (with six frames per trial), yielding 432 frames per block (total of 1,728 frames in the experiment). Two blocks used a spatial localization task (Above/Below). In one block, the task was to count how many frames in the trial (0 to 6) contained oddballs in the upper hemifield (localization above the horizontal midline). In the other block, the task was to count frames with oddballs in the lower hemifield (localization below the horizontal midline), regardless of the number of oddballs. Note that a frame became a Match frame if the oddballs were in the designated hemifield for that block, otherwise it was called a Mismatch frame. In the remaining two blocks, participants performed a number discrimination task (Odd/Even). In one block they counted frames containing 1 or 3 targets (“match odd numbers” block). In another block they counted frames with 0 or 2 targets (“match even numbers” block[3]), regardless of their position in the visual field. Thus, in the Odd/Even task, a frame was a Match frame if the number of oddballs matched the instructions (“odd” vs. “even”), otherwise it was considered a Mismatch frame. Importantly, the same stimuli were used in frames in all four types of blocks, and only the instructions varied across blocks. In addition, the order of the blocks was counterbalanced across the subjects using a Latin square.

First, we expected the amplitude of both N2p$^{c\text{–}h}$ and N2pb$^{b\text{–}h}$ to be more negative for oddballs in the lower hemifield versus the upper hemifield. Second, the amplitude of both components should increase with the number of oddballs when the participants perform the number discrimination task (when an item individuation process is required), but not for the Above/Below task (in which the mere presence of

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[3] In this particular block, a homogeneous frame (containing no oddballs) was considered as a Match frame: this top-down effect triggered a slightly larger N2 compared to other homogeneous Mismatch frames, and also a small P3. For this reason, we always subtracted the same grand average of homogeneous Mismatch frames, coming from Above/Below blocks, even for Even/Odd task difference-wave computations.

oddballs in one vertical hemifield is sufficient to perform the task, regardless of how many are shown). Finally, the components should be larger for Match frames for the Above/Below task, and of the same amplitude for Match and Mismatch conditions in the Odd/Even task, where individuation is also needed for Mismatch frames.

3.3 | Results

3.3.1 | Behavioral performance

The mean overall accuracy was 90.9% ± 4.3% across all participants, with individual participant accuracy ranging from 79.2% to 97.8%. Given possible frame counts (e.g., possible response options) were from 0 to 6, chance probability over these response alternatives was equal to 1/7 (14.2%), and so all participants had accuracy levels well above chance. Furthermore, to a first approximation, the probability of obtaining a correct answer after six frames requires a correct decision for each frame (the probability of two errors canceling is negligible under current conditions), and so the frame-by-frame probability of a correct judgment is about equal to the sixth root of the overall proportion correct computed over trials. Thus, judgment accuracy on any given frame ranged from about .96 to .996.

3.3.2 | Electrophysiology: Comparing ipsilateral, contralateral, and bilateral signals

One of our goals was to determine if the N2pb$^{b\text{–}h}$ for vertical midline oddballs reflects similar attentional mechanisms to the N2p$^{c\text{–}h}$ or N2p$^{i\text{–}h}$ signals. The ERP elicited on ipsilateral and contralateral sides for lateral oddballs at posterior electrodes (PO7 or PO8), and the average of ERPs at PO7 and PO8 for vertical midline oddballs are displayed in Panel 1-a of Figure 2. Only Match frames were collapsed over the three other experimental factors (vertical hemifield, number of oddballs, and task). A posterior bilateral N2 for vertical

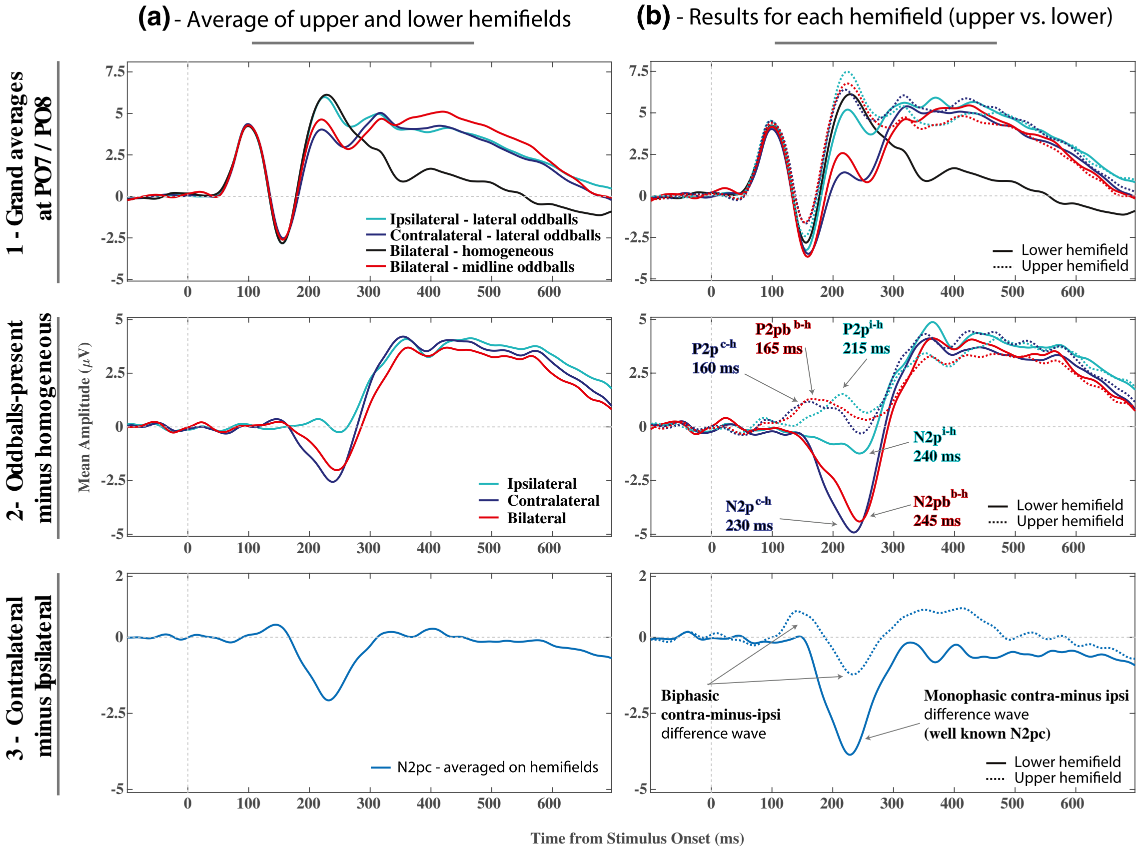

FIGURE 2 Grand average waveforms and difference waves for upper and lower hemifield averaged and separated—Experiment 1. (1) Grand average waveforms at PO7/PO8 electrodes, for ipsilateral (light blue) and contralateral (dark blue) activity elicited by lateral oddballs, or averaged over PO7/PO8 for bilateral activity elicited by vertical midline oddballs (red) and homogeneous frames (black). (2) Difference waves obtained by subtracting the ERP from homogeneous frames with no oddballs (black line of panels 1) from ERPs with oddballs frames. (3) Difference waves obtained by subtracting the ipsilateral signal from the contralateral signal for ERPs only from frames with lateral oddballs. Panels in column (a) show collapsed data on vertical hemifields while panels in column (b) show separated data on vertical hemifield. For display purposes, difference waves (2- and 3- panels) were filtered with a low-pass filter of 12 Hz

midline oddballs (N2pb$^{b–h}$) and a contralateral N2 for lateral oddballs (N2p$^{c–h}$) were elicited, but not an ipsilateral N2 (N2p$^{i–h}$), as this curve was very similar to the homogeneous-frame signal up to approximately 275 ms after stimulus onset.

In Panel 2-a of Figure 2, the ERP from homogeneous frames (black line from Panel 1-a) was subtracted from grand average ERP oddball-present frames. A one-way repeated measures ANOVA compared the amplitudes of the three difference waves (N2p$^{i–h}$, N2p$^{c–h}$, and N2pb$^{b–h}$) averaged on a 210–260 ms time window. Results showed a significant difference between waveforms ($F(1, 25) = 47.3$, $p < .001$, $\eta_p^2 = .65$). Subsequent t tests (corrected for multiple comparisons) showed a difference between each of the three components (N2pb$^{b–h}$ vs. N2p$^{i–h}$ ($t(25) = 7.1$, $p < .001$); N2p$^{c–h}$ vs. N2p$^{i–h}$ ($t(25) = 8.2$, $p < .001$); N2pb$^{b–h}$ vs. N2p$^{c–h}$ ($t(25) = 2.6$, $p < .015$), N2pb$^{b–h}$ and N2p$^{c–h}$ being however of a comparable shape and magnitude. N2p$^{i–h}$ was not different from 0 ($t(25) = .07$, $p > .94$).

Panel 3-a shows the usual N2pc$^{c–i}$, contra-minus-ipsi difference wave, here peaking at 230 ms. A significant t test shows we replicated the usual N2pc difference wave estimated as the average on the interval from 205 to 255 ms ($t(25) = 8.06$, $p < .001$).

3.3.3 | Vertical hemifield impact on N2 components

The amplitude of the N2pc difference wave has been shown to vary depending on the location of attended stimuli, and in particular there are large differences across the upper and lower visual fields (e.g., Luck, Girelli, et al., 1997; Perron et al., 2009). As such, we performed analyses separating data on the vertical hemifield factor.

Difference waves

Panels in Column (b) of Figure 2 show the grand average signals and difference waves for the same conditions as in Column (a) but separated by vertical hemifields (upper vs. lower). As can be seen in Panel 2-b, for lower hemifield oddballs (continuous-line waveforms) we observed clear negativities peaking at similar times (230 ms for N2p$^{c–h}$, 240 ms for N2pb$^{b–h}$, and 245 ms for N2p$^{i–h}$), all significant when tested against zero for a mean between 210 and 260 ms (all $t(25) > -10.4$, $p < .03$). In contrast, when oddballs were in the upper hemifield (dashed-line waveforms), attention produced a set of positive components peaking earlier (160 ms for P2p$^{c–h}$, 165 ms for P2pb$^{b–h}$, and 215 ms for P2p$^{i–h}$), all components were significant when tested against zero for a mean calculated on a 50 ms window centered on their respective peak (all $t(25) > 3.78$, $p < .001$).

The latencies of the P2p$^{c–h}$ and P2p$^{i–h}$ across participants were also examined. Jackknife statistics (described in General Method section) show a significant difference between both latencies ($F(1, 25) = 11.01$ $p < .003$, $\eta_p^2 = .31$).

The waveforms in Panel 3-b of Figure 2 shows the contralateral minus ipsilateral difference waves separated for each hemifield. Lower hemifield results showed a typical single negative deflection, peaking at 230 ms. In contrast, the results for the upper hemifield had a positive lobe peaking at 140 ms followed by a negative lobe peaking at 230 ms. This biphasic wave resulted from the subtraction of two positive deflections of about equal amplitude but occurring at different latencies, contralateral followed by ipsilateral (as can be seen in Panel 2-b of Figure 2). Importantly, neither the contralateral, nor the ipsilateral waves for upper hemifield oddballs were negative relative to homogeneous distractor displays, and the negative lobe in the contra-minus-ipsi wave in Panel 3-b is thus, potentially misleading, given that its peak latency coincides with the large negative peak of the lower visual field N2pc. We discuss this further in the Discussion section.

The negative lobes were significant when tested against zero for a mean between 205 and 255 ms (lower hemifield $t(25) = 10.6$, $p < .001$; upper hemifield $t(25) = 3.2$, $p < .004$) with a subsequent t test showing a significant difference between them ($t(25) = -7.45$, $p < .001$). The positive lobe for upper hemifield ERP was also significant ($t(25) = 4.84$, $p < .001$), estimated on a 115–165 ms window.

Finally, a later positivity for the upper hemifield signal had an observable mirroring negativity of the lower hemifield signal, although less ample. The negative deflection for the lower hemifield previously described as a sustained posterior contralateral negativity (SPCN; Jolicoeur, Brisson, and Robitaille (2008)), was significant ($t(25) = -2.4$, $p < .023$), as was the sustained positive deflection for upper hemifield oddballs (SPCP) ($t(25) = 2.7$, $p < .011$), both estimated on a 350–500 ms window.

Scalp plots

We examined posterior scalp voltage distributions to understand better the upper versus lower hemifield differences found in the foregoing results. We computed the average voltage for lower and upper hemifields to capture the main contralateral response, respectively, from 140 to 190 ms, for upper, and from 210 to 260, for lower hemifield oddballs to compare the distribution of these positivities compared to the well-known N2pc. Voltage isocontour backview maps are plotted in Figure 3a. Data are taken from N2p and P2p difference waves for Match frames separated on vertical hemifield and task factors, and separated for left, right, and vertical midline oddballs.

Although there are slight differences in the scalp distributions between the two tasks, the general patterns are very similar (the task factor is considered in detail in subsequent

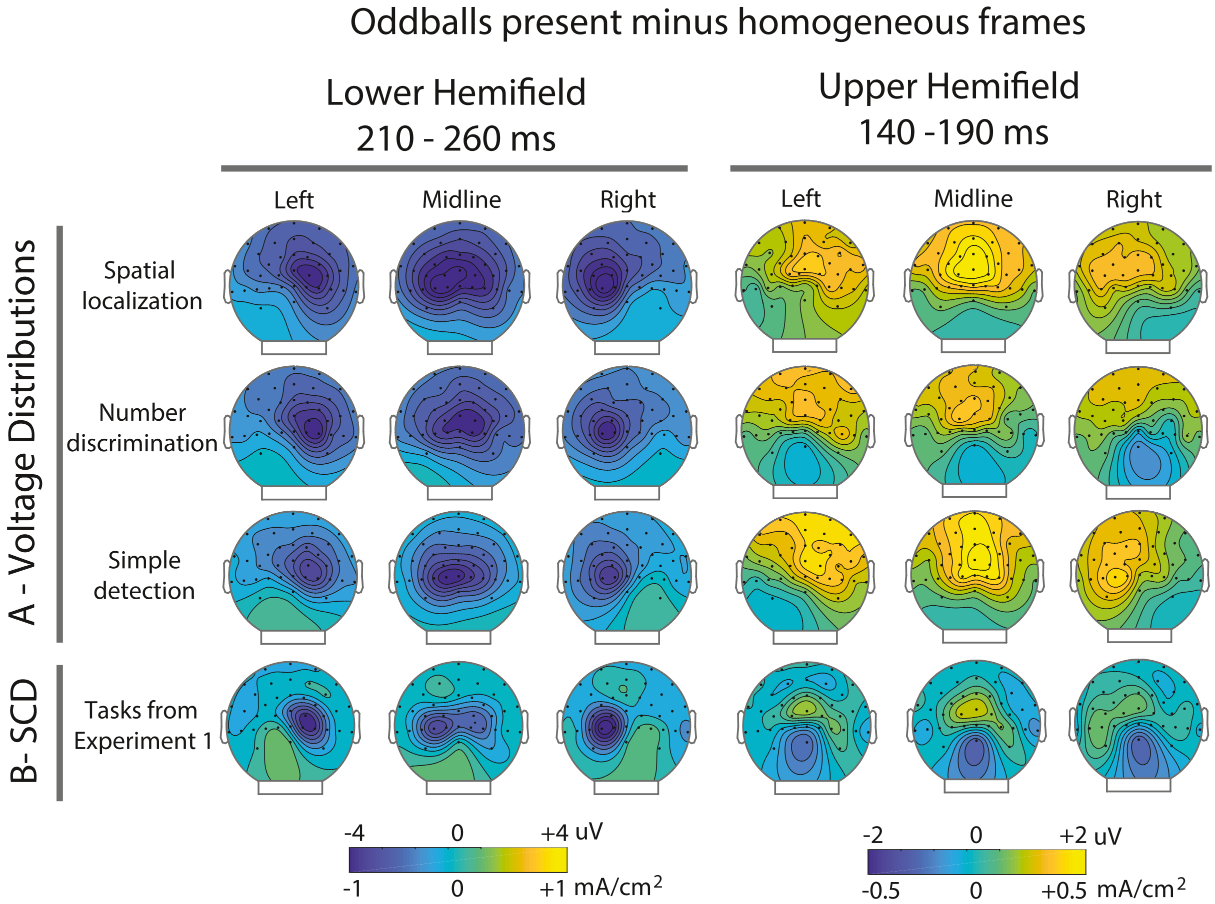

FIGURE 3 Voltage and Scalp Current Density distributions. (a) Topographic backview voltage maps of N2p difference waves (oddball-present minus homogeneous frames) constructed by spherical spline interpolation for Match frames only, for left, right, or midline oddballs, averaged on an interval of 50 ms centered on the respective peaks of N2p^{c-h} and N2pb^{b-h}. Above/Below task (spatial localization) and Odd/Even task (number discrimination) were taken from Experiment 1 and Present/Absent task (simple detection) from Experiment 2. (b) Scalp current density (SCD) maps from data collapsed on the two tasks in Experiment 1

sections). For the lower hemifield, we observed the expected contralateral negativity for lateral oddballs, with a peak in the neighborhood of PO7/PO8, and a bilateral negativity for vertical midline oddballs. For upper hemifield oddballs, we observed distributions that were dominated by a posterior positive field that was less focused than for lower hemifield oddballs, but nonetheless lateralized over the contralateral hemisphere for lateral oddballs, and bilateral for vertical midline oddballs. The more diffuse upper hemifield distributions make it more difficult to identify a clear peak in the distributions, but the region around PO7/PO8 and PO3/PO4 would be a plausible choice for representative signals. Note that the amplitudes of the oddball minus homogeneous waveforms and distributions had about half of the amplitude observed for the lower hemifield, and the scalp distributions are plotted on different scales to make the shape of the distributions easier to visualize in Figure 3.

Scalp Current Density (SCD) maps are shown in Figure 3b, with data collapsed over the task factor as the voltage scalp distributions were very similar. SCD distributions refine and corroborate the voltage scalp distributions from Figure 3a. In addition, they show less than half power for upper hemifield, peaking around -1 mA/cm^2 at PO7/PO8 for the lower hemifield and around $+0.3$ mA/cm^2 at PO3/PO4 for the upper hemifield. The more diffuse voltage field and SCD maps with less prominent peaks near the field maxima for the upper hemifield attentional responses and the more focal fields and SCD peaks for lower hemifield responses are consistent with a deeper (or less radial) set of neuronal generators for attention to upper hemifield oddballs and relatively shallower (and/or more radial) generators for attention to lower hemifield oddballs.

3.3.4 | Number of oddballs, task, and match type effects

N2p^{c-h} and N2pb^{b-h} act similarly

A within-subject 2 × 3 × 2 × 2 omnibus repeated-measure ANOVA was conducted (vertical hemifield [Upper, Lower] × number of oddballs [1, 2, 3]) × Task [Above/Below, Odd/Even]) × match type [Match, Mismatch]), examining the mean amplitude of N2p$^{c–h}$/P2p$^{c–h}$ and N2pb$^{b–h}$/P2pb$^{b–h}$ for each combination of the four independent variables. Descriptive statistics are shown in Figure 4. N2p$^{c–h}$/P2p$^{c–h}$ waveforms are represented in the left column and N2pb$^{b–h}$/P2pb$^{b–h}$ in the right column. Match and Mismatch frames ERP for Above/Below task are presented in the top four panels. Match and Mismatch frame ERP for Odd/Even task are presented in the four middle panels. Each panel shows waveforms for each combination of number of oddballs and vertical hemifield. Also, in order to improve the readability of the results section, statistics are summarized in Table 1.

At first glance, both component amplitudes show very similar modulation patterns for all factors: all effects are in the same direction for both components and for all conditions. Table 1 results show for both components the same significant main effects and interactions.

Vertical hemifield effect

In particular, we would like to emphasize the robustness of the main effect of the vertical position of the attended stimuli for both components, ($F(1, 25) = 105.5$, $p < .001$, $\eta_p^2 = .81$) for N2p$^{c–h}$/P2p$^{c–h}$ and ($F(1, 25) = 69.3$, $p < .001$, $\eta_p^2 = .74$) for N2pb$^{b–h}$/ P2pb$^{b–h}$.

Item individuation

It is not of immediate interest to us to understand the specific underlying mechanisms of all the significant two-way and three-way interactions because we had no a priori hypotheses for most of them, so we will not describe them. We were mainly interested in comparing patterns of results across the N2p$^{c–h}$/P2p$^{c–h}$ and N2pb$^{b–h}$/ P2pb$^{b–h}$. However, we consider in some details the results associated with two predictions: (a) the predicted significant two-way interaction of Task × Match type and (b) the unexpected non-significant two-way interaction of Task × Number, which is relevant for the hypothesized role of individuation on the amplitude of the N2 components.

In the Task × Match type interaction, we observed that different task instructions induced a different consequence on attention deployment for Match versus Mismatch frames. On the one hand, Above/Below task induced a global increase of amplitude for both components for the Match condition compared with the Mismatch condition. This effect probably reflects an early "*deselection*" of the oddballs that are localized in the "ignored" hemifield. On the other hand, Odd/Even task induced a similar amplitude across Match and Mismatch conditions (for both components). We argue that attention had to be deployed in a similar way for Match or Mismatch conditions, because participants needed to "*select*" (individuate) the oddballs to be able to decide if they were odd or even in number. On that point, we reproduced results from Mazza and Caramazza (2011) as their Match and Mismatch conditions did not show any difference in N2pc amplitude. These observations were substantiated by statistical analyses of significant two-way interactions including the match type factor. First, Task × Match type interaction (see Table 1) confirmed that smaller components where observed for Mismatch frames compared to Match frames in Above/Below task (spatial localization), but not in Odd/Even (number discrimination).

In the Task × Number interaction, N2p$^{c–h}$/P2p$^{c–h}$ and N2pb$^{b–h}$/P2pb$^{b–h}$ amplitudes were clearly both modulated by the number of oddballs when presented in the lower visual hemifield (more negative with more oddballs) and in upper hemifield (more positive with more oddballs), for the Odd/Even task, but more surprisingly, also for Above/Below task (spatial localization), rendering Task × Number interaction nonsignificant. Thus, we found different results than expected based on the work of Mazza and Caramazza (2011), given we expected that individuating the oddballs should not be required to know their presence or absence in a given vertical hemifield.

4 | EXPERIMENT 2

Experiment 2 was a control experiment for the impact of instructions on the number individuation process. Our aim was to extend and replicate the findings on the posterior attentional component inversion as a function of vertical hemifields N2p/P2p, while dealing with one potential limitation of the Above/Below task. As our results differ from Mazza and Caramazza (2011) concerning the modulation of individuation process by instructions, we supposed that this spatial localization task may have, somehow, triggered a process of item individuation, despite our original supposition that determining whether oddballs were above versus below fixation would not require individuation. Perhaps associating a property or feature to a stimulus (or group of stimuli), even a coarse spatial tag, requires they be individuated (Pylyshyn, 1989). In this view, participants may not have been able to assign as single tag to the group, but rather each oddball would have received a tag. To clear up this point and reproduce more closely the instructions of Mazza and Caramazza (2011), in a second experiment, we replaced the Odd/Even task by a simple detection task instructions (Present/Absent, simple presence vs. absence of oddballs, regardless of location).

If this simple detection task does not trigger a modulation of amplitude by the number of oddballs (particularly for the lower hemifield) on N2p/P2p components, this would add evidence to the proposed model of individuation manipulation by instructions. Otherwise, the results would pose an empirical challenge for the individuation hypothesis or suggest

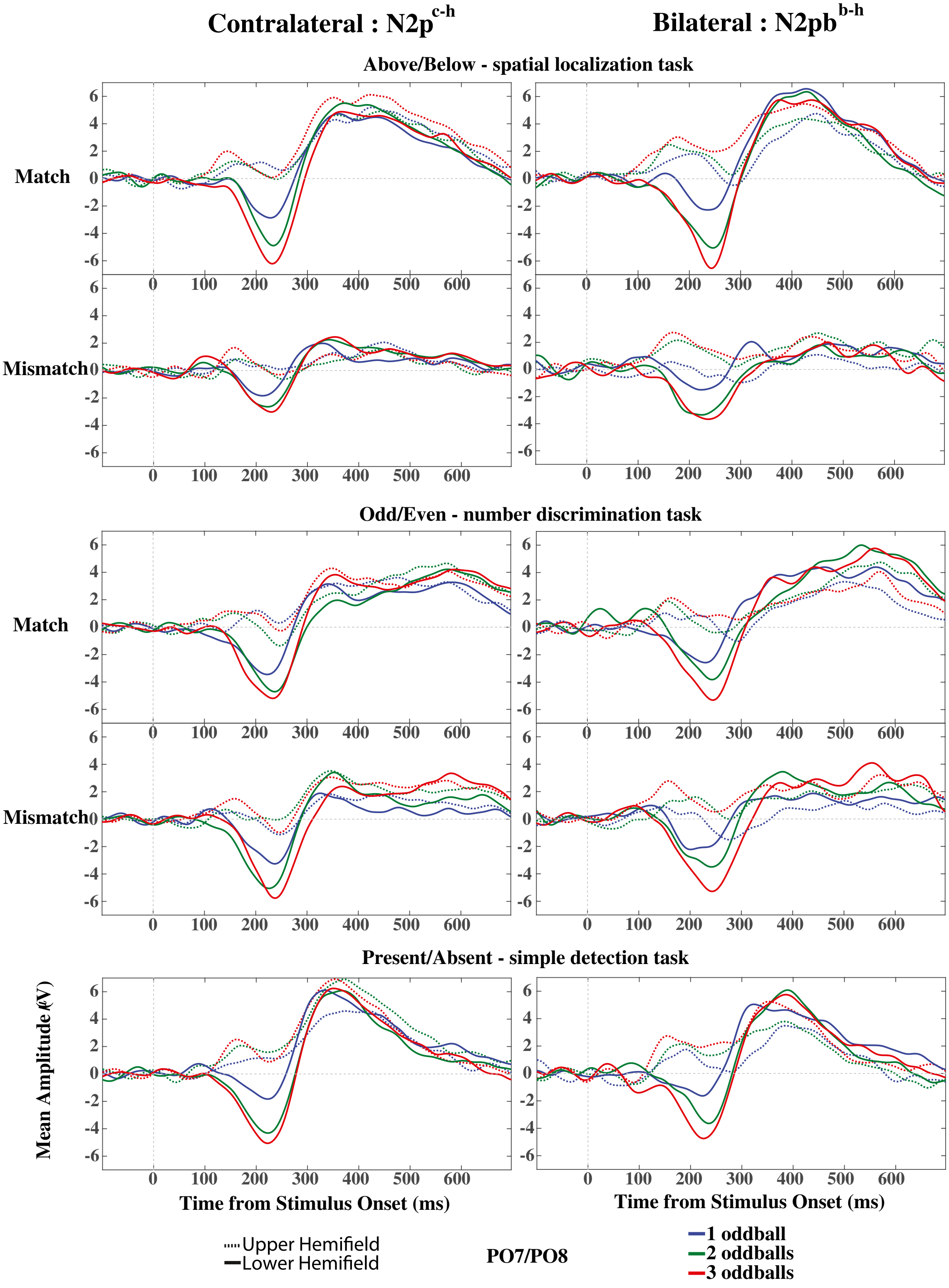

FIGURE 4 Difference waves for each condition across participants recorded from electrodes PO7 and PO8. The N2p$^{c–h}$ and N2pb$^{b–h}$ (lower hemifield) waveforms and P2p$^{c–h}$ and P2pb$^{b–h}$ (upper hemifield) waveforms were computed by subtracting waveforms elicited by homogeneous frames from waveforms elicited by, respectively, contralateral activity for frames with lateral oddballs (left column), and respectively bilateral activity for frames with midline oddballs (right column). The top four panels represent Match and Mismatch frames in Above/Below (spatial localization) from Experiment 1, the four middle panels represent Match and Mismatch frames in Odd/Even (number discrimination) from Experiment 1, and the last two panels represent Match frames for Present/Absent (simple detection) from Experiment 2. In each panel, lines represent 1 (blue), 2 (green), and 3 (red) oddballs, for upper (dashed lines) or lower (filled lines) hemifield oddballs. For display purposes, waveforms were filtered with a 12 Hz low-pass filter

TABLE 1 Repeated measures Omnibus ANOVA. N2p^{c-h} are grand averaged for lateral oddballs and N2pb^{b-h} for midline oddballs at PO7/PO8 based on their own peak regarding component and hemifield

		Contralateral: N2p^{c-h}			**Bilateral: N2pb^{b-h}**		
	Omnibus ANOVA	***F***	***p***	η_p^2	***F***	***p***	η_p^2
Main effects	Vertical hemifield (Hemifield)	105.5	.000	.81	69.3	.000	.74
	Match type (Match)	5.1	.033	.17	8.2	.008	.25
	Number of oddballs (Number)	6.6	.007	.21	11.3	.000	.31
	Task	4.2	.051	.14	0.5	.483	.02
Two-way interactions	Match × Hemifield	13.9	.001	.36	5.3	.030	.18
	Number × Hemifield	54.9	.000	.69	56.6	.000	.69
	Number × Match	0.7	.502	.03	1.4	.255	.05
	Task × Match	8.0	.009	.24	13.0	.001	.34
	Task × Number	0.3	.715	.01	0.8	.447	.03
	Hemifield × Task	2.3	.140	.09	0.8	.377	.03
Three-way interactions	Number × Task × Match	1.8	.182	.07	1.9	.165	.07
	Task × Match × Hemifield	12.8	.001	.34	16.1	.000	.39
	Task × Number × Hemifield	0.2	.803	.01	0.5	.624	.02
	Number × Match × Hemifield	0.8	.451	.03	0.7	.487	.03
Four-way interaction	Task × Number × Match × Hemifield	2.3	.122	.09	0.7	.471	.03

heretofore unsuspected boundary conditions for the individuation hypothesis.

4.1 | Material and methods

4.1.1 | Participants

Twenty-seven volunteers participated in Experiment 2. Data from three participants were removed due to technical problems that could not be corrected in post-recording processing. Twenty-four participants were kept for final analysis (age: $M = 21.6$, $SD = 3.6$, six males, two left-handed).

4.1.2 | Instructions

The experiment was the same as Experiment 1 except that we replaced the Odd/Even task by two blocks of Present/Absent task (simple detection), during which participants had to count the frames that displayed the presence of one or more oddballs, regardless of their number or position in the visual field.

4.1.3 | Simple detection task

For the detection task, we kept a general probability of occurrence of Match frames equal to 50% by increasing the proportion of homogeneous frames displayed from .25 in the Above/Below task to .50. We also maintained a similar signal to noise ratio with a minimum of 18 trials per condition, by increasing the number of experimental trials to 108 for each of the four experimental blocks.

4.2 | Results

4.2.1 | Behavioral performance

The mean overall accuracy was 95.0 ± 4.0% across all participants, with individual subject accuracy ranging from 83.2% to 98.9%, which was similar to what we found in Experiment 1 (estimated accuracy on a frame-by-frame basis of .970 to .998).

4.2.2 | Electrophysiology

The results from Above/Below task of Experiment 2 were virtually identical to those found in Experiment 1 in terms of mean values and patterns of statistical results. For this reason, we do not present them in detail in the article. Results of Present/Absent task are shown in Figure 4 (bottom panels). All frames containing oddballs were Match frames (Present), as a consequence there was no Mismatch condition with oddballs (unlike the two other tasks). For lower hemifield oddballs, the amplitude of both components increased (became more negative) with the number of oddballs (N2p^{c-h}: $F(1.88, 43.19) = 20.7$ $p < .001$, $\eta_p^2 = .47$;

N2pb$^{b\text{–}h}$: $F(1.58, 36.39) = 9.1$, $p < .001$, $\eta_p^2 = .28$). For upper hemifield oddballs, the P2p$^{c\text{-}h}$ increased in amplitude (became more positive) as the number of oddballs was increased (P2p$^{c\text{–}h}$: $F(1.79, 41.14) = 7.2$, $p < .003$, $\eta_p^2 = .24$), but the effect of the number of oddballs was not significant for the P2pb$^{b\text{–}h}$ even if the three waves appear visually different (P2pb$^{b\text{–}h}$: $F(1.78, 41.06) = 1.2$, $p > .30$, $\eta_p^2 = .05$). All in all, we did not replicate what was found by Mazza and Caramazza (2011) neither in the spatial localization nor in the simple detection task, as the authors did not measure a significant amplitude difference between 1, 2, and 3 oddballs for the simple detection task but we did.

Voltage isocontour backview maps are plotted in Figure 3a (row 3) for the Present/Absent task. They clearly show a similar distribution as for the two other tasks, extending the results of Experiment 1.

4.3 | Discussion

The results of Experiment 2 were clear-cut. First, the results for the spatial localization (Above/Below) replicated those found in Experiment 1, with identical patterns of factor effects, including the significant effects of the number of oddballs for the N2p and P2p components, as well as the positive polarity of contralateral (P2p$^{c\text{–}h)}$, ipsilateral (P2p$^{i\text{–}h)}$, and bilateral (P2pb$^{b\text{–}h}$) attentional waves. Second, we found very similar results for the simple detection task (Present/Absent) as for the spatial localization task (Above/Below), including a significant increase in the amplitude of N2p components as more oddballs were added to the displays, and a significant increase for the P2p$^{c\text{–}h}$. While a similar increase could be seen in the waveforms for the P2pb$^{b\text{–}h}$, this effect was not statistically significant. Overall, however, the results clearly showed an effect of the number of oddballs even in the simple detection task, suggesting boundary conditions on the notion that N2p and P2p components are indices of item individuation.

5 | GENERAL DISCUSSION

The initial goal of this study was to compare how experimental manipulations affect two ERP components, the N2p$^{c\text{–}h}$ and N2pb$^{b\text{–}h}$, to determine their degree of functional similarity, and presumably the similarity of the underlying neural mechanisms. Thanks to a subtraction of a homogeneous condition, we examined the posterior contralateral and midline bilateral signals, and found that both signals responded in a similar manner to four variables (vertical hemifield, number of oddballs, task instruction, and match type), as expected if they are produced by the same underlying mechanisms, except for variations in the location, and orientation of the generators with respect to retinotopy. More interesting, analysing midline electrodes (invisible in contra-minus-ipsi difference waves analyses) brought critical new data on the polarity of attentional ERPs, suggesting an inversion of the posterior attention potentials for upper compared with lower hemifield attended stimuli.

5.1 | Teasing apart the posterior N2 components: Ipsilateral (N2p$^{i\text{–}h}$), contralateral (N2p$^{c\text{–}h}$), bilateral (N2pb$^{b\text{–}h}$), and SN

The posterior N2 components are ERPs first seen in the laboratory in the 1980s by asking participants to attend to one kind of stimulus and not another, for instance letters versus digits, both presented centrally. A bilateral N2 (measured at PO7/PO8 or other occipital electrodes) has been commonly interpreted as reflecting partially overlapping sequential stages of processing associated with visual pattern recognition and stimulus classification (Renault, Ragot, Lesevre, & Remond, 1982; Ritter et al., 1984). Without eye movements, visuo-spatial attention can be deployed to a region of interest in the peripheral visual field in order to facilitate task-relevant information processing. For a lateral locus of attention, the posterior N2 had been described as a bilateral plus a contralateral subcomponent (Luck & Hillyard, 1994a, 1994b).

In the present, work we isolated separate contralateral and ipsilateral responses by subtracting activity from homogeneous distractor displays, separately also for upper versus lower visual field locations, which helps to see different phenomena and components. We found that the contralateral attentional response occurred before the ipsilateral response, with an apparently longer lag for attention engaged in the upper visual field. The N2p$^{i\text{–}h}$ peaked, at 240 ms, 10 ms after the contralateral peak for the lower hemifield, whereas a P2p$^{i\text{–}h}$ peaked at 215 ms, 55 ms after a contralateral positive peak (P2p$^{c\text{–}h}$) for the upper hemifield. The delayed onset of the ipsilateral response is not very surprising, and is likely to reflect interhemispheric communication delays. What is perhaps more surprising is the apparent difference in the magnitude of the delay across the upper versus lower hemifields. The small amplitude of the **N2p$^{i\text{–}h}$** (lower hemifield) made it more difficult to provide a definitive estimate of the time course of this component. In contrast, the phase lag of the P2p$^{i\text{–}h}$ relative to the P2p$^{c\text{–}h}$ was very clear, and was seen in every task in each experiment in the present work (particularly clearly for Match, 3-oddball trials, where the signal amplitude was largest), and was further replicated in recent extensions of the work in our laboratory. To our knowledge, the onset-delay of the ipsilateral attentional response in this type of experiment has not been described before. In the Introduction section, we mentioned that Luck and Hillyard

(1994b) described the N2pb as occurring slightly after the N2pc. One may wonder if they were, in fact, seeing a delayed N2p^{i-h} wave.

In addition to similar magnitudes, similar scalp distributions, and similar latencies, N2p^{c-h} (P2p^{c-h}), and N2pb^{b-h} (P2pb^{b-h}) were sensitive to, and reacted in the same way (e.g., increase in amplitude), for all the manipulated experimental variables included in the present work; namely vertical hemifield, number of oddballs, task, and match type. All in all, these similarities suggest that N2pb^{b-h}, as described by Renault et al. (1982) for stimuli at fixation, involved in categorization, is a bilateral N2 (P2) acting like a “double N2pc.” This phenomenon could reflect a recruitment of more attentional resources (some in each hemisphere), or a collaboration between the two hemispheres for processing midline stimuli. This proposition is supported by data from (Doro, 2017) who found a significant advantage in mean accuracy for reporting a target presented on the midline (mean = .89) against one in the left visual hemifield (mean = .85) or in the right (mean = .86), with no significant difference found between the accuracy in reporting a target in left compared to one in the right.

However, another study founds no difference in behavioural results for lateral versus vertical midline targets (Verleger, Dittmer, & Smigasiewicz, 2013). Instead of a bilateral processing advantage, these authors proposed there was a competition between hemispheres with the right hemisphere directing attention to salient events more rapidly than the left. Further research will be needed to clarify this point.

The SN is a difference wave for which one subtracts the Mismatch condition from the Match condition. The idea is to isolate activity triggered by task-relevant stimulus features and described as the selection process for a stimulus requiring further processing to complete the task. Typically in these experiments the stimuli are presented centrally and results are contrasted for variations in task instructions for equivalent stimuli (Aine & Harter, 1984; Anllo-Vento, Luck, & Hillyard, 1998; Bartsch et al., 2018; Harter et al., 1984; Hillyard & Munte, 1984; Keil & Muller, 2010; Kimura, Katayama, & Murohashi, 2005; Smid et al., 1997), for a review see Folstein and Van Petten (2008). In particular, when color served as a selection cue (e.g., in Above/Below task “attend to the orange oddballs when they appear in the lower hemifield”), specific ERP responses can be observed that are related to the selective, task-directed, processing of stimuli with the cued attribute (Smid et al., 1997). In Experiment 1 (and replicated in Experiment 2), **N2pb^{b-h}** and **N2p^{c-h}** amplitude decreased significantly from the Match to the Mismatch condition in the Above/Below task, the difference between the two possibly reflecting a form of SN (and selection positivity for upper hemifield for an extended logic), even if the task concerns localization and not features. The smaller activity for the Mismatch condition in Above/Below task may be seen as a “baseline” **N2/P2 p^{c-h}** and **N2/P2 pb^{b-h}** triggered by bottom-up saliency of oddballs. In Odd/Even (Number Discrimination), in contrast, there was no amplitude difference between Match and Mismatch conditions because presumably both had to be selected to be processed sufficiently to discriminate their number.

Luck and Gold (2008) highlighted the distinction between input selection and rule selection. Input selection determines which of multiple possible stimuli are processed in greater depth. Rule selection determines which of many possible cognitive operations would be applied to the selected inputs. Here, the N2p components presumably reflected input selection processes, triggered by the color feature, rather than rule selection. For example, in Odd/Even task, participants presumably first deployed attention to the colored items (no matter how many), this process being represented by N2p and P2p components. The individuation process may then belong to a more complex phase of information processing than spatial localization and may take place only after participants initially engage attention on the salient items. This process may happen more diffusely in time, as it seems to affect the amplitude of N2pc and extend into the SPCN time range (e.g., Mazza & Caramazza, 2011). Perhaps, in the present paradigm, the N2p (lower field) or P2p (upper field) increase in amplitude with the number of oddballs would not represent a process of individuation, per se, but instead would reflect recruitment of additional activity with the addition of more pop-out stimuli. We note that Mazza and Caramazza (2011) also found no difference in the amplitude of N2pc between Match and Mismatch trials in their number discrimination tasks.

5.2 | P2 attentional components for upper hemifield oddballs: A new good practice for research

Except for Fahrenfort et al. (2017) who recently found opposite contralateral polarities for upper and lower visual field potentials (but which was not discussed in their article), the apparition of a contralateral positivity for upper field stimuli has not been described previously.

However, work by (Hickey, Di Lollo, & McDonald, 2009) suggests a similar effect as they conducted additional ANOVAs in order to examine the effect of stimulus elevation on N2pc, decomposed in two subcomponents, the Nt, a negativity due to target processing, and the Pd, a positivity related to distractor processing. Interestingly, they found a larger positivity for distractor processing (Pd) when the distractor was in the upper hemifield compared to when it was in the lower hemifield. However, in the time range of their Pd, there was no effect of the vertical position of the target. But as they collapsed over upper versus lower hemifields in their other analyses, the results and the discussion do not give further information concerning the role of vertical position on component polarity or amplitude, as do other authors exploring these ERPs (Hilimire, Mounts, Parks, & Corballis, 2009). However, 2 years later, Hilimire and colleagues published another study in which they separated the data based on vertical hemifields (Hilimire et al., 2011). Here, they measured a positive component they called Ptc (because more temporal), which did not vary in amplitude, whereas the N2pc did vary with the same experimental conditions. Their conclusions suggest that more work is needed to elucidate the relationship between Ptc and N2pc, to localize the neural generators contributing to the positive component, and to address "*whether the Ptc component is truly elicited only by distractor objects and not target objects*." It suggests these ERPs are perhaps not caused by the role of the stimuli in the experiment (distractor vs. target) but by other factors (like vertical hemifield in which distractors or targets may appear), or the salience of certain colors (Fortier-Gauthier, Dell'acqua, & Jolicoeur, 2013). Another interesting study from Toffanin, de Jong, and Johnson (2011) designated as P4pc the positive signal following the N2pc, underlying a possible disengagement from a target, in the same range of time as the components named Pd and Ptc (300–400 ms), but this time not linked to an experimental design including distractors, but an experiment including a temporal delay with several consecutive displays.

More critically, considering our results, our advice for further investigations on these positive components is to separate stimuli presented for processing in the upper versus lower hemifield, and also to include a control condition containing only distractors. The subtraction of this control condition from target-present displays can be used to estimate contralateral and ipsilateral responses separately. This approach complements and extends the now standard N2pc method in which the ipsilateral response is subtracted from the contralateral response. However, the N2pc contra-minus-ipsi approach creates an inherent ambiguity because a change in N2pc, say an increase in amplitude, could be due to an increase in contralateral negativity, a decrease in ipsilateral negativity, or both (in unknown proportion). The method we used here of subtracting the homogeneous condition from a left or a right stimulus condition revealed that both the contralateral and the ipsilateral attentional responses were positive for upper hemifield stimuli. Furthermore, there was a phase lag between them (ipsi following contra by about 55 ms). The separate estimates of the contralateral and ipsilateral responses shed a new light on the oft-reported leading positivity, sometimes called P1pc, before N2pc, which may well be a simple consequence of the contra-ipsi phase difference. These observations may provide a re-interpretation of what has sometimes been called the Ppc, the posterior contralateral positivity peaking prior to N2pc (at about 140 ms, visible in Panel 3-b of Figure 2, and also described in other work (Corriveau et al., 2012; Pomerleau et al., 2014). Rather than reflecting a distinct component, the leading positivity in the contralateral minus ipsilateral response in the present work was simply the initial contralateral positivity for upper hemifield stimuli (in the absence of the ipsilateral response for about 27 ms, or half of the 55 ms ipsilateral lag). Given this analysis, this contralateral positivity is better measured in oddball-present minus homogeneous difference wave, peaking at 160 ms, slightly more centrally, toward PO3/PO4 and POz as shown in Figures 2 and 3. Note that while the isolated $\mathbf{P2p^{c-h}}$ peaks at about 160 ms, when we subtract the phase lagged $\mathbf{P2p^{i-h}}$, the positive peak of the subtraction contra-minu-ipsi wave shifts to the left (to about 140 ms). These results provide a beautiful example of the principles and considerations illustrated in Figure 2.5 of Luck (2014), namely that one must understand how amplitudes and latencies of sums or differences of underlying components can vary as we change parameters (amplitude, latency) of the original components.

Given that the pre-N2pc (i.e., the "classic" N2pc that averages across vertical hemifields) positivity likely reflects, at least in part, a contribution from the contralateral attentional response for upper hemifield attended stimuli, it would not be surprising if this component was sensitive to various factor manipulations that are known to affect N2pc (which is dominated by the contralateral response to lower hemifield stimuli). Furthermore, the later negativity in the contra-minus-ipsi difference wave for attended upper hemifield stimuli likely reflects mainly the lagged positive ipsilateral response (which is now subtracted from a waning contralateral positive response). Averaging over upper and lower hemifield contra-minus-ipsi waves thus, likely averaged a dominant lower hemifield contralateral response with a smaller upper hemifield ipsilateral response (Panels 3-a,b in Figure 2).

We also note that the scalp distributions and waveforms for the separate **N2p** for left, midline, and right attended oddballs, and their P2p homologues, provide compelling evidence that attentional effects for vertical midline stimuli correspond closely to a bilateral version of the contralateral wave for lateral stimuli.

5.3 | Implications for the neural substrates of visuo-spatial attention indices

These P2p components observed for upper hemifield oddballs can offer some clues concerning the neural sources of $\mathbf{N2p^{c-h}}$ and $\mathbf{N2pb^{b-h}}$. In the SCD maps, a more focal scalp distribution likely originates closer to the surface, whereas a more widely distributed component may be expected to have its origin deeper below the surface and an attenuated amplitude after the SCD transform. Also, at the surface of a conductive sphere, current density decreases more quickly than potential as the generator is moved from close to the surface toward the center of the sphere (Perrin et al., 1987).

So, the smaller absolute amplitude recorded for the P2p^{c-h} adds a clue to the hypothesis of an inverted generator for upper hemifield oddballs, as possibly situated further from the surface (deeper) than the lower hemifield N2p^{c-h} generators. Furthermore, the more central (less eccentric) voltage distribution for upper hemifield targets (compared with that for lower hemifield targets) would be consistent with a difference in the orientation of the equivalent dipoles for these sources (see Sereno et al., 1995, for relevant discussion).

We note that the C1 component, which peaks at about 80 ms following stimulus onset, is frequently taken to reflect the initial input to V1 and is positive for lower hemifield stimulation and negative for upper visual hemifield stimulation, relative to a mastoid reference. The polarity pattern (upper negative, lower positive) is opposite what we found for later attentional effects (upper positive, lower negative), and as such suggests the components under study here (N2p/P2p) originate in extrastriate cortex and that polarity inversions as a function of vertical visual field position extend beyond striate visual cortex.

Finally, the use of a multiple-frame procedure with a counting task did not allow us to perform a detailed analysis of possible relationships between electrophysiology and accuracy, on a frame-by-frame basis. Further study of such relationships would likely be useful. Furthermore, researchers may wish to address further the question of visual hemifield attentional resolution and filtering specialization, as highlighted by earlier psychophysical results (He, Cavanagh, & Intriligator, 1996), suggesting a functional advantage in the allocation of attention in favor of the lower visual field (better spatial resolution in lower visual field compared to upper). Another question concerns the earlier contralateral response for upper compared with lower visual field targets. Perhaps, this is the result of an anatomical difference between projections from V1 to the dorsal versus ventral paths in early visual processing, or some compensation across visual fields to synchronize processing of inputs from upper and lower hemifields. Alternatively, it may reflect years of reading practice in processing text and other graphical materials organized from top to bottom. Further research will be required to address these issues.

6 | CONCLUSION

Based on their similar responses to several independent variables, we propose that the **N2p^{c-h}** and **N2pb^{b-h}** components arise from essentially the same underlying mechanisms for, respectively, lateral or vertical midline stimuli in the lower hemifield. The subtraction of frames containing homogeneous stimuli (no oddball) from frames with left, right, or midline oddballs, highlighted a critical difference in the observed attentional responses to targets in the lower versus upper visual hemifields. Notably, whereas attention to the lower hemifield stimuli produces a familiar posterior negativity (N2pc, for lateral targets), attention to the upper hemifield produces a contralateral positivity best observed with a different type of difference wave, which we designated as the **P2p^{c-h}**. The contralateral minus ipsilateral difference wave for upper field targets was strongly biphasic, but reflects a more positive signal than the control condition (homogeneous frames). This raises the issue of whether the positive inflection that often follows the N2pc might, in part, reflect the subtraction of a delayed negative ipsilateral response (in the case of lower visual field targets). In any case, we argue that a systematic separate analysis of attentional responses to lower versus upper visual field targets is indicated on the basis of the present results.

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