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Research Report

Neural bases of unconscious orienting of attention in hemianopic patients: Hemispheric differences

Javier Sanchez-Lopez [a,*], *Silvia Savazzi* [a,b,c,**], *Caterina A. Pedersini* [a], *Nicolò Cardobi* [a] and *Carlo A. Marzi* [a,c]

[a] *Psychology and Physiology Section, Department of Neuroscience, Biomedicine and Movement Sciences, University of Verona, Verona, Italy*

[b] *Perception and Awareness (PandA) Laboratory, University of Verona, Verona, Italy*

[c] *National Institute of Neuroscience, Verona, Italy*

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ABSTRACT

The aim of this research was to study the behavioral and neurophysiological correlates of visual attention orientation to unseen stimuli presented to the blind hemifield of hemianopic patients, and the existence of hemispheric differences for this kind of unconscious attention. Behaviorally, by using a Posner paradigm, we found a significant attention effect in speed of response to unseen stimuli similar to that observed in the sighted hemifield and in healthy participants for visible stimuli. Moreover, event-related potential (ERP) and oscillatory attention-related activity were present following stimulus presentation to the blind hemifield. Importantly, in patients this pattern of activity was different as a function of the side of the brain lesion: Left damaged patients showed attention-related ERP and oscillatory activity broadly similar to that found in healthy participants. In contrast, right damaged patients showed a radically different pattern. These data confirm and extend to neurophysiological mechanisms the existence of unconscious visual orienting and are in keeping with a right hemisphere dominance for both unconscious and conscious attention.

* *Corresponding author*. Psychology and Physiology Section, Department of Neuroscience, Biomedicine and Movement Sciences, University of Verona, Strada le Grazie 8, Verona, Italy.

** *Corresponding author*. Psychology and Physiology Section, Department of Neuroscience, Biomedicine and Movement Sciences, University of Verona, Strada le Grazie 8, Verona, Italy.

E-mail addresses: javier.sanchezlopez@univr.it (J. Sanchez-Lopez), silvia.savazzi@univr.it (S. Savazzi), caterinaannalaura.pedersini@univr.it (C.A. Pedersini), nicolo.cardobi@gmail.com (N. Cardobi), carloalberto.marzi@univr.it (C.A. Marzi).

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1. Introduction

Can one pay attention to a stimulus of which is unaware? This question has attracted a series of studies mainly in healthy participants tested in attentional tasks for detecting or discriminating visual stimuli rendered invisible by means of various psychophysical techniques. Some studies have demonstrated that this is indeed possible thus showing a dissociation between attention and awareness (Bahrami, Lavie, & Rees, 2007; De Brigard & Prinz, 2010; McCormick, 1997). Importantly, a few studies (Kentridge, Heywood, & Weiskrantz, 1999, 2004; Norman, Heywood, & Kentridge, 2015) found a similar effect in hemianopic patients with "blindsight", that is, visually guided unconscious behavior following presentation of visual stimuli to the blind hemifield (Danckert, Tamietto, & Rossetti, 2019; Trevethan & Sahraie, 2010; Weiskrantz, 2004). One important standing question concerns the neurophysiological mechanisms of visual attention without awareness. In principle, there are two possibilities, namely, that the mechanisms reflect those of conscious attention with a quantitatively lesser extent. Alternatively, that in the absence of perceptual awareness, different attentional processes take place. To investigate that, here we used the event-related potential (ERP) technique whose optimal temporal resolution is well suited for studying attention effects.

The main ERP components typically studied during cued spatial selective attention tasks in healthy and pathologic participants are the Contingent Negative Variation (CNV), P1, N1 and P3 (Clark & Hillyard, 1996; Gómez, Flores, Digiacomo, Ledesma, & González-Rosa, 2008; Hillyard & Anllo-Vento, 1998; Luck, Heinze, Mangun, & Hillyard, 1990; Walter, Cooper, Aldridge, McCallum, & Winter, 1964). CNV is a post-cue (prior to the target stimulus) slow negativity over frontal sites widely considered as a marker of expectancy evoked by the information content of the cue (Correa, Lupiáñez, Madrid, & Tudela, 2006; Mento, 2013; Mento, Tarantino, Vallesi, & Bisiacchi, 2015; Miniussi, Wilding, Coull, & Nobre, 1999). It has been proposed that P1 is related to a facilitation of early sensory processing for stimuli presented to a location where attention is already focused while N1 represents the orienting of attention to a task-relevant stimulus (Luck et al., 1990). P3 complex (P3a and P3b) is a late component which is larger for invalid than valid trials and is associated to a cognitive evaluation of invalidly cued targets (Digiacomo, Marco-Pallarés, Flores, & Gómez, 2008; Gómez et al., 2008).

The above ERP components are pre- or post-stimulus time-related changes in voltage. In terms of attention-related oscillatory activity, for the pre-stimulus period the most studied frequency modulation is pre-stimulus alpha characterized by a decreased synchronization between 8 and 14 Hz over the occipital lobe contralateral to the cued visual field (Kizuk & Mathewson, 2016; Sauseng et al., 2005; Thut, 2006). As to post-stimulus oscillations, several studies have reported modulations across various frequencies mainly in alpha, beta and gamma bands implicated in directed attention and stimulus classification, "status quo" maintenance, and integration of visual information facilitating attentional perceptual mechanisms (Digiacomo et al., 2008; Foxe & Snyder, 2011; Gruber, Müller, Keil, & Elbert, 1999; Klimesch, Schimke, & Pfurtscheller, 1993; Sterman, 1996).

This as far as the electroencephalography (EEG) correlates of conscious attention are concerned; turning to unconscious attention, pioneering neurophysiological studies have been carried out in one hemianopic patient (GY) by Schurger, Cowey, and Tallon-Baudry (2006), and Schurger, Cowey, Cohen, Treisman, and Tallon-Baudry (2008). In the first study, they tested blindsight patient GY on an orientation–discrimination task with stimuli at a contrast level sufficient for being consciously perceived about half of the times. They used magnetoencephalography (MEG) to relate evoked gamma-band oscillations (44–66 Hz) to perceptual awareness and found that there was a reliable correlation over the left occipito-parietal region. This was not the case, however, in the alpha band (8–12 Hz). In the second study (Schurger et al., 2008) they tested GY in a similar task but introduced an attentional variable by using a classic Posner endogenous attention paradigm. Thus, they had the opportunity of testing simultaneously the EEG correlates of perceptual awareness and attention. Interestingly, they found responses to unperceived stimuli that were independently associated to awareness or to unconscious attention in the gamma frequency range. Therefore, they concluded that orienting and re-orienting of spatial attention can operate without awareness and have an EEG correlate in the gamma band.

To try and cast some light on these questions, the present study was aimed at assessing the behavioral and neurophysiological response when hemianopic patients are asked to orient endogenous attention toward a quadrant of their blind hemifield and, in some trials, shift it to a different quadrant within the same hemifield. The reason why we chose to use an endogenous attention paradigm is twofold: First, because there is evidence in healthy participants that visual attention in absence of perceptual awareness is more likely to operate with endogenous rather that exogenous attentional paradigms (Chica, Bartolomeo, & Lupiáñez, 2013; Chica, Botta, Lupiáñez, & Bartolomeo, 2012), but see Norman et al. (2015) who, with only exogenous attentional control, found object-based attention without awareness. Second: Because the task we used, that is, the Posner paradigm of endogenous attention (for a review see Petersen & Posner, 2012) enables to tease apart the EEG correlates of the attentional components involved in pre- and post-stimulus processing, for both conscious and unconscious vision.

Another aim of the present study was to find out whether the neural mechanisms of unconscious orienting and shifting of attention might show hemispheric differences (Spagna, Kim, Wu, & Fan, 2018; Vallar & Calzolari, 2018). Several studies using functional magnetic resonance imaging (fMRI) have described the brain structures involved in top-down (dorsal system) and stimulus-driven (ventral system) orienting of visual attention (Corbetta, Patel, & Shulman, 2008; Corbetta &

Shulman, 2002; Shulman et al., 2010). These studies reported a dominance of the right hemisphere for stimulus-driven control during reorienting in response to invalidly cued stimuli (see Doricchi, MacCi, Silvetti, & MacAluso, 2010; Macaluso & Doricchi, 2013 for a discussion about the interactions between left and right hemisphere for invalidly cued stimuli). These attentional systems involve different areas of occipital, parietal, temporal and frontal cortex and integrate the information necessary for an optimal attentional processing.

2. Material and methods

We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures used in the study.

2.1. *Participants*

2.1.1. *Patients*

We recruited six hemianopic patients: (2 females; mean age = 59 years old, SD = 10.5). To be included in the study they had to meet the following criteria: Homonymous Hemianopia as a result of brain damaged occurred not earlier than three months before testing, availability of clinical visual *Humphrey* campimetry (provided by the patients) and structural brain MRI showing size and location of the brain damage. Lack of pre-existing neurologic or psychiatric disorders, drugs or alcohol addiction, cognitive impairments as documented by a score equal or less than 24 in the Mini Mental State Examination (Folstein, Folstein, & McHugh, 1975), and presence of spatial hemineglect as assessed with a neuropsychological battery including: Line Bisection (Schenkenberg, Bradford, & Ajax, 1980), Diller letter H cancellation (Diller, Ben-Yishay, & Gerstman, 1974), and Bell Cancellation (Gauthier, Dehaut, & Joanette, 1989), see Table 1. Patients' subjective impressions on visual abilities in everyday life were assessed with The Visual Function Questionnaire (VFQ25; Mangione et al., 2001). All patients were right handed and had normal or corrected to normal visual acuity. See Table 2 for detailed clinical information.

2.1.2. *Healthy controls*

Nine age matched healthy participants were recruited as controls (7 females; mean age = 58.5 years old, SD = 8.1). They were tested with the Mini Mental State Examination (Folstein et al., 1975) to screen for cognitive impairments (score equal or less than 24). No participant reported history of neurologic or psychiatric disorders, drugs or alcohol addiction. All were right handed and had normal or corrected-to-normal visual acuity.

To take part in the study patients and healthy participants were informed about their rights and were asked to sign an informed consent. The study was approved by the Ethics Committee of the European Research Council and of the Verona Azienda Ospedaliera Universitaria Integrata (AOUI), and have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Visual mapping: To determine the extension of the blind visual field a binocular visual mapping was performed in the lab (see Sanchez-Lopez et al., 2019 for a detailed description of the method). In Table 3 we report data of the extension of the blind visual field. Values are expressed in degrees of visual angle and percentage of the blind portion with respect to the whole hemifield tested. Group means and standard deviations (S.D.) are also reported.

Volume of brain lesion was calculated using masks manually designed by an expert neuroradiologist using the T1-weighted native brain image of each patient by means of the software ITK-SNAP (Yushkevich et al., 2006). Obtained masks of the lesion were registered to the standard MNI space with a spatial resolution of 1 mm using linear transformations (FLIRT). Volume of the lesion was estimated by quantifying the percentage of overlap between the masks and 30 ROIs extracted from occipital, temporal and parietal lobes on the basis of the probabilistic atlas of human cortical brain areas Harvard–Oxford implemented in FMRIB Software Library (FSL; (Jenkinson, Beckmann, Behrens, Woolrich, & Smith, 2012; Smith et al., 2004; Woolrich et al., 2009) and using a threshold value equal to 5. The distribution of the extent of lesion in the left and right patients is reported in Table 4 showing that damage to non-visual areas is minimal except for patient FB. However, it is important to underline that in

Table 1 – Patients' neuropsychological results and time elapsed (in months) from the stroke.

Patient	Time elapsed after stroke (months)	MMSE raw/ corrected	Line bisection bias in cm[a]	Diller letter H cancellation Asymmetry left-right missing	Bell cancellation Asymmetry left-right missing
FB[c]	7	30/maximum	−.34/Normal	+2/Normal	+2/Normal
BC	7	30/maximum	−.88/Normal	0/Normal	0/Normal
GS	37	30/maximum	−.84/Normal	0/Normal	0/Normal
SL	107	30/maximum	−.04/Normal	0/Normal	0/Normal
RF	8	29/30.2	+.70/Normal	−1/Normal	−1/Normal
ML	16	30/maximum	+1.2/Limit[b]	0/Normal	0/Normal

Note:
[a] For the values of the line bisection test negative numbers indicate a leftward bias while positive a rightward bias.
[b] Patient ML showed a borderline score toward a rightward bias.
[c] FB suffered from a closed-head trauma with consequent hemorrhage.

Table 2 – Patients' clinical details.

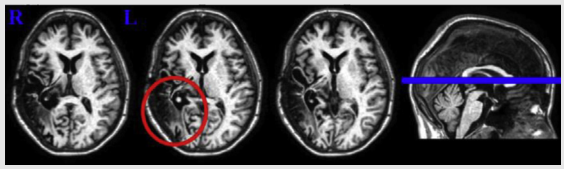
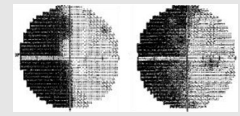
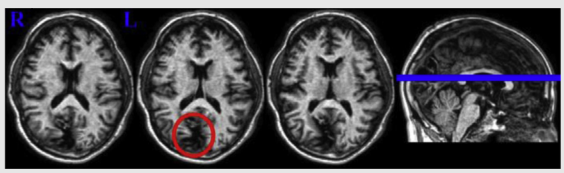
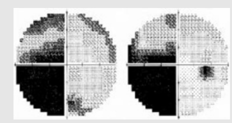
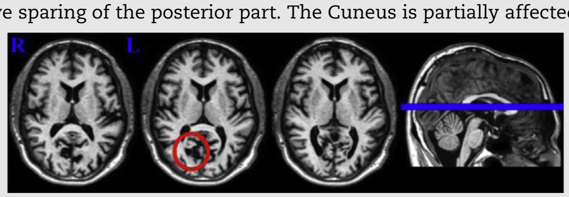
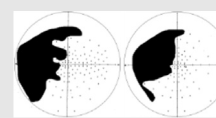
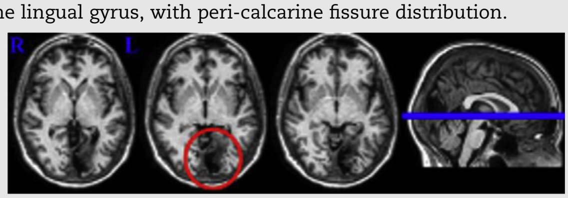
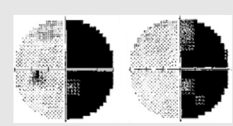
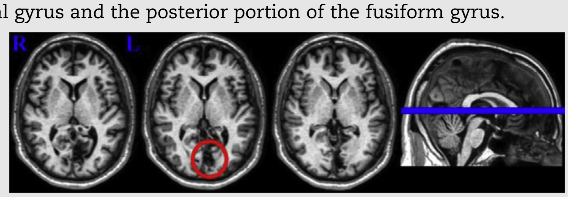
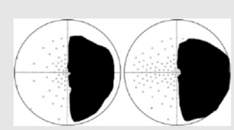
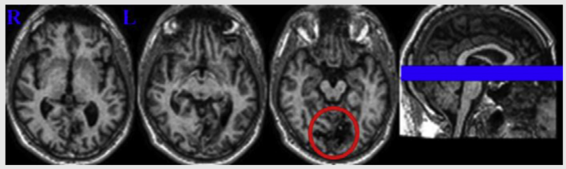
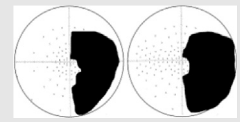
Patient (age, gender)	Lesion description Structural MRI	Campimetry Stimulus position Visual defect
FB (51, Female)	Lesion involving the temporal, parietal and occipital lobe. In the latter, the lesion includes the superior and part of the middle occipital gyri with interruption of the optic radiation. 	 x = 6°, y = 3° Left lateral homonymous hemianopia.
BC (69, Male)	Lesion involving the medial portion of right occipital lobe, with an extension over the parieto-occipital fissure. The lingual and fusiform gyri up to the occipital pole and the calcarine fissure are affected by the lesion. 	 x = 12°, y = 3°/10° (lower visual field) Left lower quadrantanopia.
GS (75, Male)	Lesion involving the antero-superior part of the right calcarine fissure with relative sparing of the posterior part. The Cuneus is partially affected. 	 x = 13°, y = 5° Left lateral (incomplete) homonymous hemianopia.
SL (50, Female)	Lesion involving the median para-sagittal portion of the left occipital lobe and the lingual gyrus, with peri-calcarine fissure distribution. 	 x = 8°, y = 7° Right lateral homonymous hemianopia.
RF (52, Male)	Lesion involving the anterior and middle portion of calcarine fissure, the lingual gyrus and the posterior portion of the fusiform gyrus. 	 x = 8°, y = 3° Right lateral homonymous hemianopia.

Table 2 – (*continued*)

Patient (age, gender)	Lesion description Structural MRI	Campimetry Stimulus position Visual defect
ML (57, Male)	Lesion of both inferior portions of the occipital lobes, more evident on the left side that involves the occipital pole, lingual and fusiform gyri. 	 $x = 8°, y = 5°$ Right lateral homonymous hemianopia.

Note: Neuroradiological description, MRI (radiological convention) and clinical *Humphrey* campimetry provided by the patients are shown. Stimulus eccentricities (third column) of stimulus presentation during the attention task are expressed in degrees from the centre of the screen to the centre of the stimulus and were symmetrical for the two hemifields. For patient BC, with left quadrantanopia, stimuli were positioned upper or lower in the lower quadrant.

this patient the proportion of damage to visual areas is within the range of the other patients.

2.2. *Attentional task*

The visual stimuli were black and white square gratings. Their width was 4° and height 4° of visual angle with a spatial frequency of .875 c/° (see Fig. 1). The Michelson contrast of the grating was 1 and the background luminance was the same as the mean luminance of the grating (17.7 cd/m^2). Stimulus flickered at a frequency of 30 Hz. The visual stimulation was performed by presenting the grating on a LED video monitor (resolution = 1920 pixels width × 1080 pixels height, and refresh rate = 60 Hz).

The task employed was a Posner-like endogenous attention paradigm. Participants were asked to discriminate the orientation of the grating (vertical or horizontal) by pressing two different buttons of a response box counterbalanced across participants. At the beginning of each trial a fixation black dot appeared in the center of the screen followed, after 500 msec, by a central cue (an arrow lasting 200 msec) presented between 300 and 600 msec prior to the target stimulus. The cue directed covert attention toward a quadrant (upper or lower) of one and the same visual field (left or right). The fixation dot was present throughout the whole trial. Fixation on the central spot was constantly monitored trial-by-trial by means of a closed-circuit TV system. Moreover, recording of the electrooculogram (EOG) enabled us to discard trials contaminated by eye movements. In valid trials the grating appeared in the cued quadrant (75% probability) while in invalid trials it appeared in the other quadrant (25% probability) of the same field. There were 4 trial blocks for each cued

Table 3 – Extension of blind visual field across patients with left or right hemispheric damage.

Left damage	Visual angle degrees	Percentage	Right damage	Visual angle degrees	Percentage
SL	480	62	FB	556	72
RF	636	82	BC	460	59
ML	624	80	GS	540	70
Mean	580	75	Mean	519	67
S.D.	87	11	S.D.	51	7

Table 4 – Brain damage across single patients and groups.

	Left damaged			Right damaged			Mean left damaged	Mean right damaged	Mean right damaged no-FB
	SL	RF	LM	FB	CB	GS			
Damage (Voxel)	27770	22046	43996	255095	39925	10872	31270.6	101964	25398.5
Damage (%)	8.1	6.4	9.9	50.5	12.7	5	8.2	22.8	8.8
Damage visual areas (%)	21.4	16.9	26.9	29.3	33.9	13.0	21.2	25.4	23.4
Damage non visual areas (%)	.5	.4	.1	62.8	.4	.3	.3	21.2	.4

Note: Extent of damage (in voxel) was calculated from the T1 MR images with resolution = 1 mm. Damage (%) represents the mean percentage of lesion across 30 occipital, temporal and parietal areas. Damage of Visual Areas (%) represents the mean percentage of lesion across 11 visual areas. Damage of non-Visual Areas indicates the mean percentage of lesion across 19 temporal and parietal areas that do not include visual areas. All values were taken from the Harvard–Oxford Atlas.

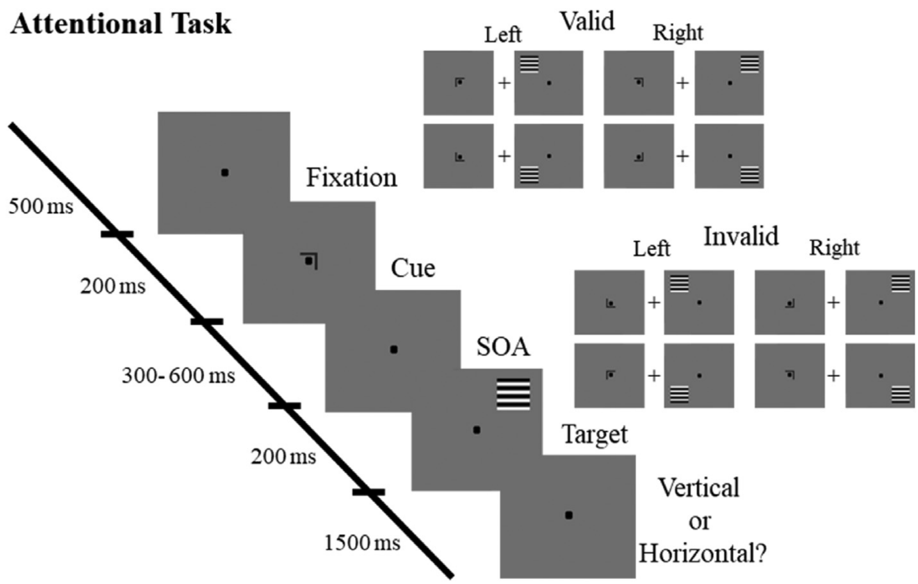


Fig. 1 – Attentional task. The time course of task events is shown on the left. On the right all possible combinations of valid and invalid conditions for stimuli presented in the left or the right upper or lower visual field are shown.

quadrant with a total of 64 stimuli each (48 valid and 16 invalid trials in a random sequence). Half of the stimuli were horizontal and the other half were vertical and they were presented in a random order.

For each patient, the stimulus was positioned in the blind or in a corresponding area in the intact field making sure with repeated pre-testing that in the former they could not consciously discriminate stimulus orientation (for further details see Sanchez-Lopez et al., 2019); in Table 2 are reported the eccentricities used for each patient. In each healthy participant stimulus eccentricity was chosen by matching her/him with one (or two) specific patient.

2.3. *EEG recording*

A 59 channels EEG was used during the experimental recording session. Active electrodes mounted on an elastic cap (ActiCap, Brain Products GmbH, Munich Germany) were placed on the scalp of the participant according to the 10-10 International System. The acquisition system consisted of two BrainAmp amplifiers and the software Recorder 1.2 (Brain Products GmbH). All electrodes were on-line referenced to an electrode placed on the left mastoid while the right mastoid electrode was used as offline reference to the average of the right and left mastoid electrodes. Four electrodes placed at the left and right canthi and above and below the right eye were used to record horizontal and vertical eye movements. The ground electrode was placed at the AFz electrode position. Four electrodes placed at the left and right canthi and above and below the right eye were used to record horizontal and vertical eye movements, respectively. Electrode impedance was kept below 5 KΩ. The EEG was recorded at 1000 Hz sampling rate with a time constant of 10 sec as low cut-off and a high cut-off of 1000 Hz with a 50 Hz notch filter.

2.4. *Data analysis*

2.4.1. *Behavior*

Behavioral analysis was performed on accuracy (correct responses) and reaction time (RT) for either hemifield. RTs faster than 150 msec from stimulus onset were considered as anticipations and were not included in the statistical analyses. In **healthy participants,** for statistical analysis we used mean percentage and RT of correct responses. In **patients**, given the small sample size of the two subsets with left and right lesions we used percentage of correct responses for accuracy estimation and RT of all responses. Results reported in Appendix A show that the analysis of correct versus all responses shows similar results. A non-parametric permutation test using 5000 permutations as implemented in EEGLAB function "statcond" (Delorme & Makeig, 2004) was used. Statistics were performed for each variable and group (healthy participants, all patients together, left and right damaged patients) using a non-parametric two-way repeated-measures ANOVA with Condition (valid and invalid) and Hemifield (left and right, or blind and sighted) as within factors. Pairwise comparisons were performed when significant interactions were observed. For the blind hemifield of hemianopic patients, accuracy was analyzed in each patient by means of binomial test to examine whether the proportion of correct responses was different from chance.

2.4.2. *EEG pre-processing*

EEG recordings were pre-processed off-line for all channels using EEGLAB toolbox (Delorme & Makeig, 2004), and personalized MATLAB (version R2018a, The MathWorks, Inc., Natick, MA, 2010) scripts. Channels were re-referenced to the average of the left and right mastoid electrodes. EEG signal was filtered using a FIR filter from .1 to 100 Hz. Independent Component Analysis (ICA) ocular correction (Makeig, Bell., Jung, &

Sejnowski, 1996) was used to correct for vertical eye movements. Continuous EEG recordings were segmented, locked to the target stimulus, in epochs from 1.5 sec before to 1.5 sec after target stimulus onset. Finally, for each participant, EEG segments with artefacts including those with saccadic eye movements (about 10%) were rejected by visual inspection.

2.4.3. *ERP analysis*

Statistical analysis of the ERPs was performed by means of cluster-based permutation test using 1000 randomizations for the permutation distribution as implemented in Fieldtrip (Oostenveld, Fries, Maris, & Schoffelen, 2011; see www.ru.nl/neuroimaging/fieldtrip). For statistical comparisons in healthy participants was used the averaged ERP from each single subject while in hemianopic patients (left and right lesioned patients), considering the small sample size were used all trials. Epochs were baseline corrected from 1 to .8 sec before stimulus onset and band pass filtered again from .1 to 40 Hz.

Pre-stimulus analysis was carried out to assess the presence of hemifield differences in sustained attention and expectancy during orientation to one or the other hemifield. To do that, the amplitude of the CNV identified from around −400 msec to stimulus onset (see Fig. 3) was compared between left and right or blind and sighted hemifield. Electrodes were flipped left to right in order to perform comparisons between the same ipsi- and contralateral scalp side across hemifield conditions. Statistical analysis was performed over frontal, fronto-central and central electrodes.

Post-stimulus analysis was carried out to study the difference in mean amplitude between valid and invalid conditions for the main attentional ERP components i.e., P1, N1, P3a and P3b. In patients, the time windows were selected by visual inspection considering the expected group difference in latency and morphology of the ERP components as a consequence of brain lesions (see Fig. 4). Parietal and occipital electrodes were analyzed for P1 while for N1, P3a and P3b all electrodes were included in the statistical analysis. Time windows used for the analysis of each ERP component are reported in Table 5.

2.4.4. *Time-frequency analysis*

Pre-processed epochs in time domain (without additional band pass filter) were subjected to time-frequency

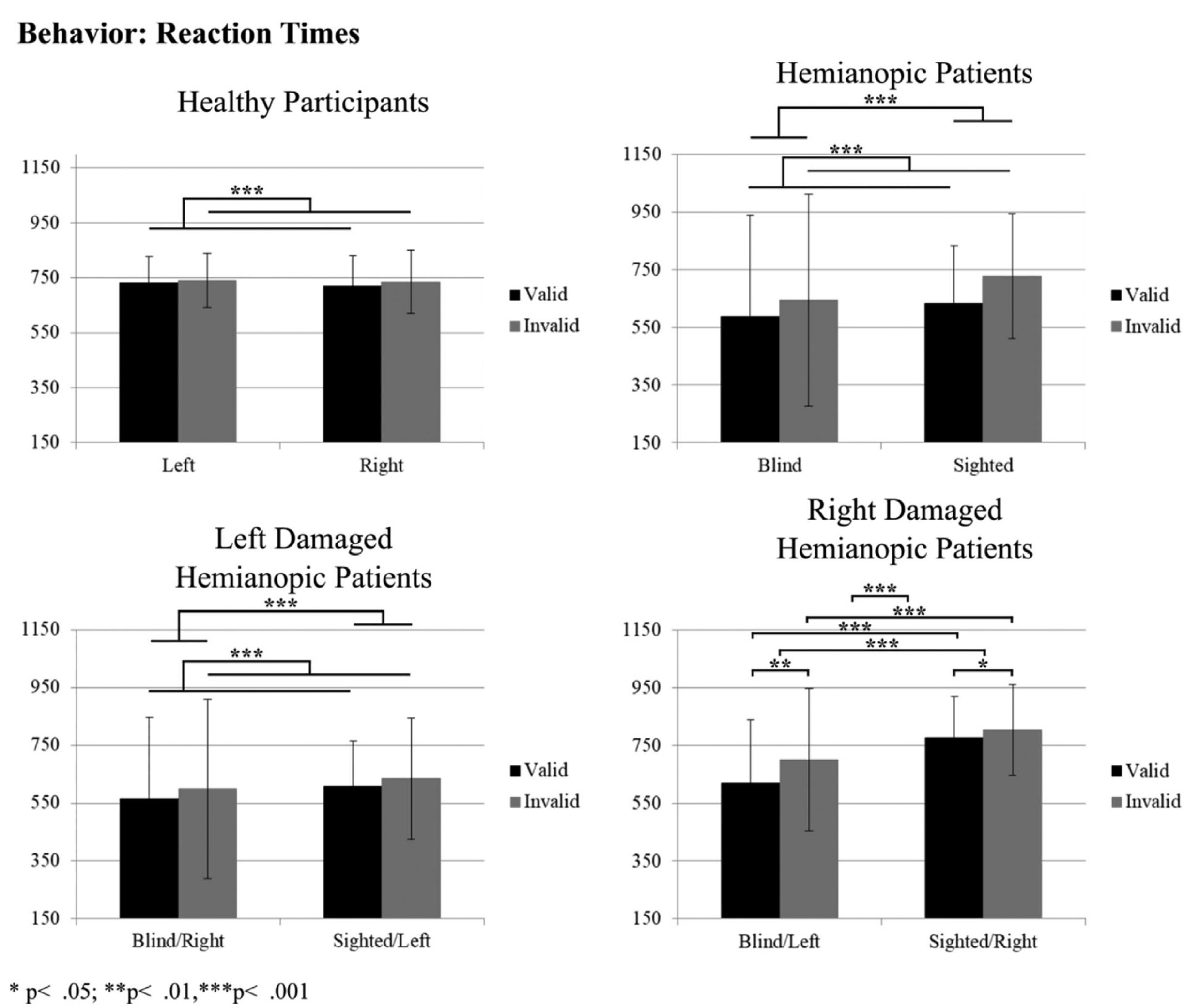


Fig. 2 – Behavioral results. RT for healthy participants, the whole group of hemianopic patients (top row), and the subgroups of patients with left and right lesions (bottom row).

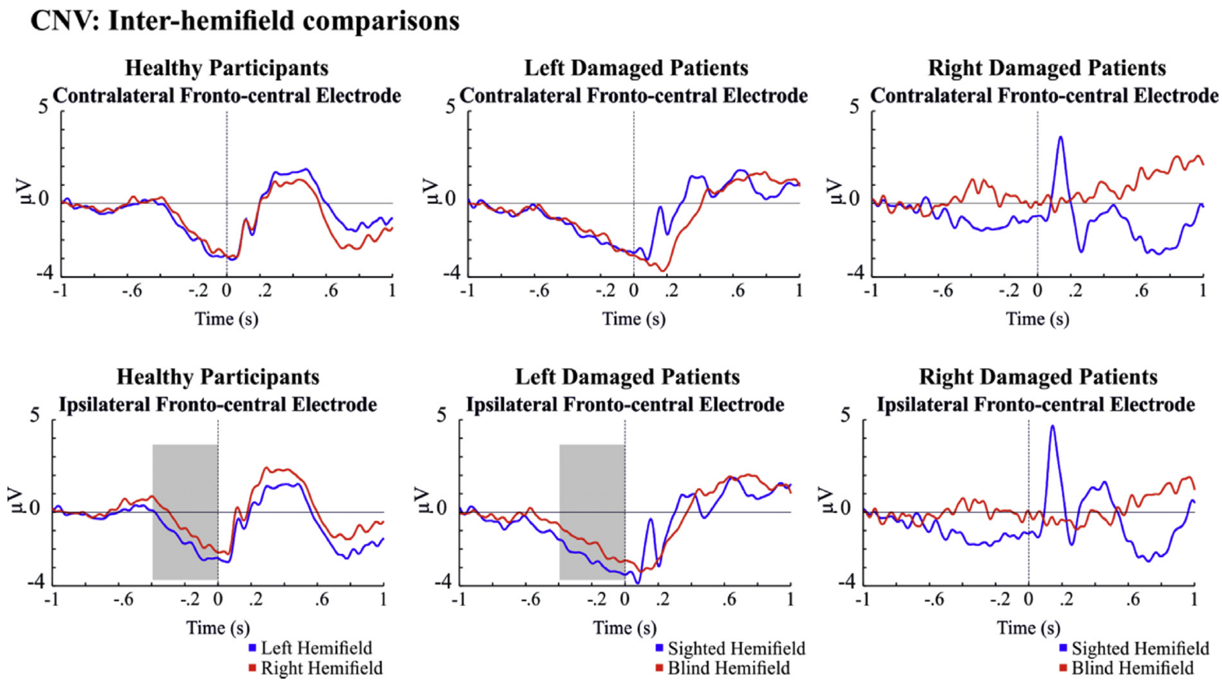


Fig. 3 – ERP results for pre-stimulus period. Comparisons between left and right and sighted and blind field are shown for contralateral and ipsilateral electrodes. Time periods where significant differences (p < .05) were found after clustered-based correction for multiple comparisons are highlighted in gray.

decomposition by means of Hanning taper calculation using frequency dependent window length as implemented in Fieldtrip (Oostenveld et al., 2011; see www.ru.nl/neuroimaging/fieldtrip). Frequencies were calculated from 3 Hz to 70 Hz in steps of 1 Hz considering time window "slides" from −1.5 to 1.5 sec in steps of .01 sec (10 msec), and using 3 cycles per time window. Finally, whole epochs were baseline corrected using decibel conversion relative to the time period between −1 sec and −.8 sec. Statistical analysis was carried out by means of cluster-based permutation test using 1000 randomizations for the permutation distribution using Fieldtrip. As in the analysis of the ERP data, for healthy participants averaged time-frequency epochs for condition were used for statistical comparisons, while in patients, statistical analysis was conducted using all trials.

Two separate statistical analyses were carried out for the pre- and post-stimulus period. In the **pre-stimulus** (from −400 to 0 msec) to evaluate the activity elicited by orienting of attention on the occipital cortex, the slow brain activity was compared between ipsi and contralateral hemisphere for each group and hemifield. Mean frequency activity of theta (4–8 Hz), low alpha (8–11 Hz) and high alpha (11–15 Hz) was analyzed across channels and time-frequency points by comparing contralateral parieto-occipital and occipital electrodes (PO3/PO4, PO7/PO8, PO9/PO10, O1/O2) with their counterpart in the ipsilateral hemisphere in four time windows of 100 msec (−400 to −300 msec, −300 to −200 msec, −200 to −100 msec, and −100 to 0 msec). For the **post-stimulus period** we assessed the difference between valid and invalid trials in each group. Comparisons were performed in two time windows after target stimulus presentation: from 0 to 500 msec, and from 500 msec to 1 sec. Mean frequency activity of theta (4–8 Hz), low alpha (8–11 Hz), high alpha (11–15 Hz), beta (15–25 Hz), low gamma (30–50 Hz) and high gamma (50–70 Hz) was analyzed across channels and time-frequency points.

No part of the study procedures or analysis were pre-registered prior to the research being conducted.

3. Results

3.1. Behavior

3.1.1. *Accuracy*

Table 6A shows mean accuracy for Group, Hemifield and Attentional Condition:

Healthy participants: A two-way repeated-measures ANOVA (Attentional Condition × Hemifield) yielded no significant main effect or interaction.

Hemianopic patients: There was a significant main effect of Hemifield (p < .05) with a better performance in the sighted than in the blind hemifield. As in healthy participants, no significant main effect of Condition or interaction was found.

Importantly, a Binomial test performed for the blind field of hemianopic patients showed that in all six patients the proportion of correct responses was not significantly different from chance.

3.1.2. *Reaction time*

Healthy participants. There was a significant effect of Condition (p < .001) with RT for valid (Mean = 716.5 msec; SD = 101.1) significantly faster than invalid trials (Mean = 732.5, SD = 104.1). No significant hemifield difference or interaction were found (see Table 6B and Fig. 2).

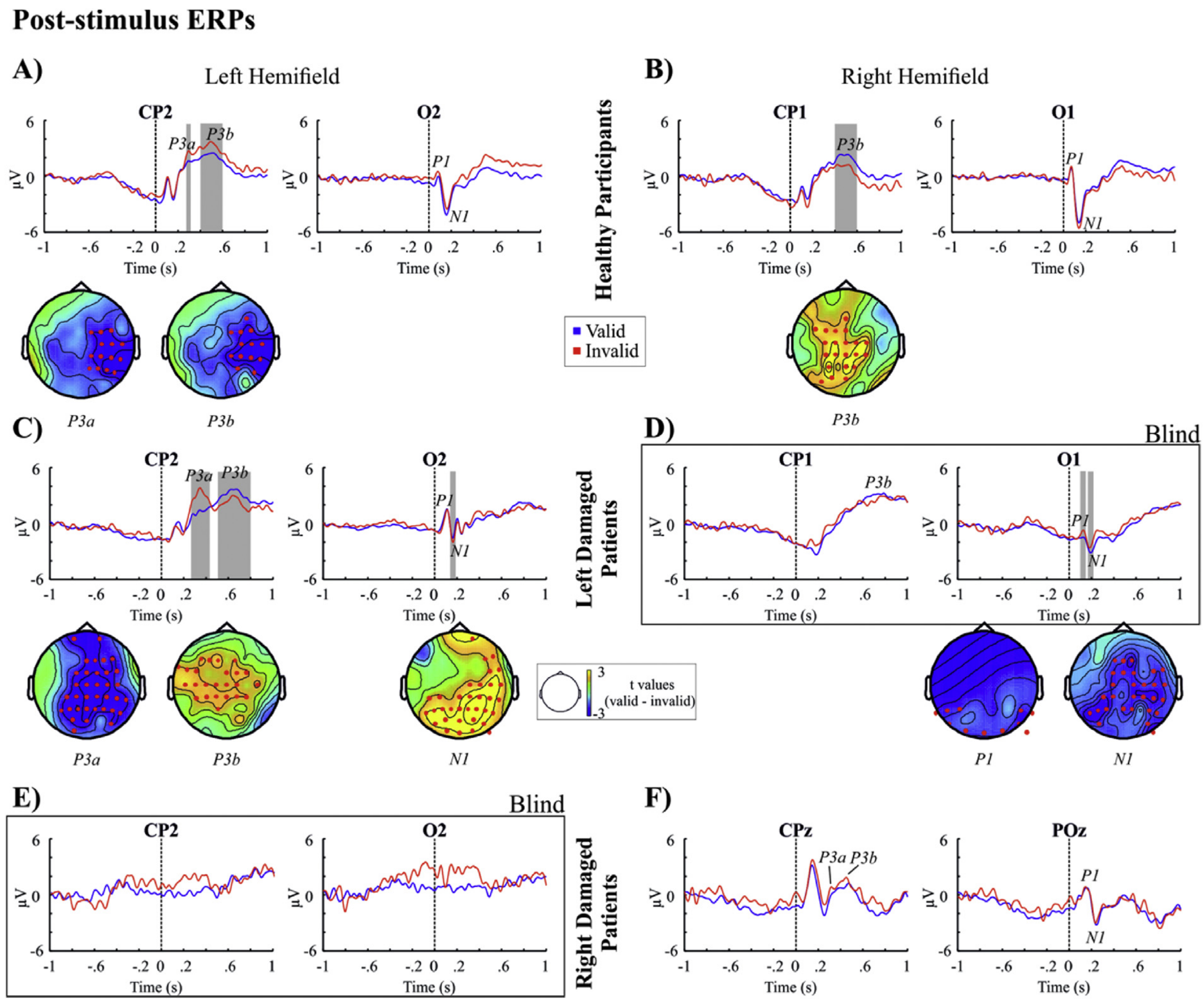


Fig. 4 – ERP results for post-stimulus period. Comparison between valid (blue) and invalid (red) conditions for left and right hemifield. Time periods where significant differences were found are highlighted in gray. Topographical maps show the distribution of t values (blue indicates that the amplitude of invalid was higher than that of valid trials and vice versa for yellow); red points represent the electrodes where these differences ($p < .05$) were found after clustered-based correction for multiple comparisons.

Table 5 – Time windows (msec) of ERP components identified by visual inspection. Comparisons were performed on the mean amplitude of the time period for each component separately. Notice that in the blind field of right damaged patients no reliable components were present either in the pre- or in the post-stimulus period, see below.

ERP component	Healthy participants	Left damaged patients		Right damaged patients	
		Sighted	Blind	Sighted	Blind
CNV	−400 to 0	−400 to 0	−400 to 0	−400 to 0	X
P1	70–90	70–90	100–150	70–90	X
N1	130–150	140–190	170–220	150–300	X
P3a	280–320	260–430	400–480	300–350	X
P3b	400–600	500–800	600–700	400–600	X

Hemianopic patients. In the analysis of the whole group of patients a significant main effect was found for Condition ($p < .001$) and Hemifield ($p < .001$): Valid (Mean = 657.5 msec, SD = 236.4) were faster than invalid (Mean = 695.7 msec, SD = 256.1) trials; and the blind (Mean = 601.8 msec, SD = 290.51) was faster than the sighted (Mean = 705.3 msec, SD = 198.6) hemifield. The interaction did not reach significance.

Two further non-parametric ANOVAs were carried out in the two subsets of patients divided according to the side of the lesion.

Left brain damaged. Significant main effects: Condition ($p < .001$) and Hemifield ($p < .001$). RT in valid (Mean = 590.3 msec, SD = 179.7) was faster than in invalid trials (619.57 msec, SD = 200.8). RT for the blind hemifield

Table 6 – Accuracy and reaction time across groups and visual fields.

	Right damaged patients				Left damaged patients				Healthy participants			
	Sighted		Blind		Sighted		Blind		Left		Right	
	Valid (SD)	Invalid (SD)	Valid (SD)	Invalid (SD)	Valid (SD)	Invalid (SD)	Valid (SD)	Invalid (SD)	Valid (SD)	Invalid (SD)	Valid (SD)	Invalid (SD)
A) Accuracy (%)												
	95.1 (1.3)	95 (3.5)	46.1 (3.5)	46.2 (5)	97 (2.3)	94.4 (5.4)	50.7 (1.3)	55.9 (4.4)	99 (1.5)	99.1 (1.7)	98.1 (1.7)	97.6 (4)
B) Reaction times (msec)												
Correct responses	777.2 (199.6)	803.6 (217.2)	610.5 (340.6)	667.4 (365.5)	609.3 (142.8)	634.9 (157)	571.1 (226.7)	592 (244.6)	719.6 (97.3)	728.7 (98.6)	713.5 (110.6)	736.3 (115.2)
All responses (only blind field)			620.1 (350.6)	699.9 (368.1)			564.3 (217.9)	599.1 (246.2)				

(Mean = 572.8 msec, SD = 225.6) was faster than for the sighted visual field (Mean = 615.3 msec, SD = 146.6). The interaction was not significant.

Right brain damage. Significant effect of Condition (p < .001) and Hemifield (p < .001) as in the group of left damaged patients, RT for valid (Mean = 728.4 msec, SD = 266.3) was faster than for invalid trials (Mean = 768.9 msec, SD = 280.9); and RT in the blind field (Mean = 641.7 msec, SD = 357.1) was faster than in the sighted hemifield (Mean = 783.8 msec, SD = 204.3). Additionally, a significant interaction Condition × Hemifield (p = .03) was found with the effect of validity significantly higher in the blind than in the sighted hemifield (Mean Difference = 53.5 msec; p < .001). RT in valid trials was faster than in invalid trials in both blind (Mean Difference = 79.8 m; p = .005) and sighted (Mean Difference = 26.3 msec; p = .02) fields. As in the left damaged group, the blind was faster than the sighted field for valid (Mean Difference = 157.1 msec; p < .001) and invalid trials (Mean Difference = 103.6 msec; p < .001). The difference between hemifields in the valid was significantly greater than in the invalid condition (Mean Difference = 53.5 msec; p < .001) (see Table 6B and Fig. 2).

It is important to point out that the analysis of correct responses only (as in healthy participants) or of all trials (as in patients) did not change the outcome of the results, see Appendix A for further analyses.

In short, the noteworthy finding of these results is the presence of an effect of endogenous attention for visual stimuli presented to the blind field. A puzzling result is the faster RT for the blind than the sighted field, see Discussion.

3.2. *Event-related potentials*

3.2.1. *Pre-stimulus*

Fig. 3 shows hemifield difference for orienting attention to left or right visual field as reflected by the CNV.

In **healthy participants** the cluster-based permutation test showed that the amplitude of the CNV evoked by orientating to left field was larger than for the right. This difference was significant (p < .004) for the ipsilateral electrodes.

In **left damaged patients** we found a similar pattern as in healthy participants with the amplitude of the CNV for orienting to the sighted (left visual field) larger in comparison with the blind (right) field (p < .01) for ipsilateral electrodes. Importantly, the CNV for the latter hemifield was smaller but clearly present.

In **right damaged patients** no statistical analyses were performed between hemifields since a CNV component was not found for the blind field.

3.2.2. *Post-stimulus*

Fig. 4 shows the ERP components evoked by the target stimulus in the two attentional conditions.

Healthy participants. P1 and N1: no significant attention effect for either field.

Left visual field: P3a (p = .04) and P3b (p = .04) larger in the invalid than in the valid condition over right fronto-parieto-temporal electrodes. *Right visual field*: smaller P3b (p = .01) in the invalid than in the valid condition (Fig. 4A and B).

Left damaged patients. *Sighted field:* N1 larger ($p = .03$) in the invalid than in the valid condition in central and posterior electrodes over the intact right hemisphere. P3a larger ($p = .004$) in the invalid than valid condition over anterior-central and posterior electrodes, bilaterally. P3b smaller ($p = .01$) in the invalid than valid condition over fronto-central and parietal electrodes (Fig. 4C and D).

Blind hemifield: P1 larger ($p = .01$) in the invalid than in the valid condition bilaterally in occipital electrodes. N1 larger ($p = .01$) in the valid than in the invalid trials over fronto-parieto-occipital electrodes, bilaterally.

Right damaged patients. *Sighted field*: No significant attention-related differences. *Blind field*: no reliable ERP components were recorded (Fig. 4E and F).

3.3. *Time-frequency*

3.3.1. *Pre-stimulus*

Fig. 5A shows pre-stimulus orienting of attention effects on time-frequency.

Healthy participants. *Left hemifield:* Orientation of attention produced a significant lower magnitude of the oscillatory activity in low ($p < .05$) and high ($p < .05$) alpha in the contralateral with respect to the ipsilateral hemisphere. In the former, the differences were found along the four temporal windows analyzed while in the latter were found from −400 to −300 msec and from −200 to −100 msec (Fig. 5A-1). *Right hemifield*: The only significant differences were found in high alpha where oscillatory activity in contralateral was lower than in ipsilateral occipital electrodes ($p < .05$) in two of the four temporal windows: from −300 to −200 msec and −200 to −100 msec (Fig. 5A-2).

Left damaged patients. *Sighted field*: Lower theta ($p < .04$) from −200 to −100 msec in the contra-than the ipsilateral hemisphere (Fig. 5A-3). *Blind hemifield:* Lower magnitude of theta in the ipsilateral with respect to the contralateral occipital lobe from −400 to −300 msec ($p = .01$; see Fig. 5A-4). No differences in alpha band were found for either field.

Right damaged patients: No significant contra-ipsilateral hemispheres differences in any frequency band analyzed (see Fig. 5A-5 and A-6).

3.3.2. *Post-stimulus*

Fig. 5B shows post-stimulus attention effects of time frequency.

Healthy participants. *Left visual field:* Higher theta between 0 and 500 msec ($p < .04$) in the invalid than the valid condition over posterior electrodes. Late differences were observed in high alpha from 520 to 830 msec ($p < .001$) and beta from 650 to 750 msec ($p < .003$) where oscillatory activity in valid trials was higher than in invalid trials over central and left temporal sites (Figs. 5B-1 and 6A). *Right visual field*: Late differences in low alpha from 740 msec to 1 sec ($p < .03$) and beta from 590 to 900 msec ($p < .007$) higher in valid than in invalid trials over left posterior and fronto-central electrodes, and right posterior and fronto-central electrodes respectively (Figs. 5B-2 and 6B).

Left damaged patients showed a similar pattern of oscillatory activity as that observed in healthy participants. *Sighted field:* Larger alpha (from 590 to 830 msec; $p < .02$) and beta (from 620 to 710 msec; $p < .02$) in valid than invalid. These differences were topographically observed in temporal sequence going from right temporal and posterior to central electrodes (Figs. 5B-3 and 6C). *Blind field:* Larger high alpha (from 500 to 800 msec; $p < .006$) and beta (from 550 msec to 1 sec; $p < .001$) in the valid than the invalid condition progressively in time from left posterior to fronto-central electrodes (Figs. 5B-4 and 6D).

Right damaged patients. *Sighted field:* Late differences in beta (from 580 to 730 msec; $p < .03$) higher in the invalid with respect to the valid condition going from anterior to central and posterior electrodes (Figs. 5B-6 and 6F). *Blind field:* Low and high gamma activity, from 240 to 360 msec ($p < .001$) and from 220 to 300 msec ($p < .008$) larger in valid than in invalid trials progressively from right posterior to left posterior and central electrodes (Fig. 5B-5 and 6E).

4. Discussion

4.1. *Behavior*

The most important general result is to have found evidence of an attentional effect in response to stimuli presented to the blind field of hemianopic patients. A broadly similar behavioral effect was previously observed in healthy participants using invisible cues (Kentridge, Nijboer, & Heywood, 2008) or in the blind field of the hemianopic patient GY (Kentridge et al., 1999, 2004). The novel aspect of the present study is represented by the finding of the existence of hemispheric differences in unconscious deployment of attention that was clearly impaired in right damaged patients as a consequence of an increased cost of attentional reorienting in invalid trials. This supports the view of a dominance of the right hemisphere in attentional reorienting (Corbetta et al., 2008) also for unconscious vision. Moreover, the effects of damage to visual centers in hemianopic patients extends to the occipital lobe the dominant role of the right temporo-parietal lobes in attention.

An intriguing finding is the faster RT for the blind with respect to the sighted field of both groups of patients. Given the overall chance orientation discrimination performance, one possibility is that responses to stimuli presented to the blind field might reflect unconscious stimulus detection rather than discrimination, and, being the former typically a faster process, this would explain the difference. In other words, while in the sighted field patients' RT would reflect the time needed for discrimination, in the blind field it would reflect detection time (see also Correa, Lupiáñez, Milliken, & Tudela, 2004).

In terms of accuracy, we did not find significant differences in the percentage of correct responses between valid and invalid conditions either in healthy participants or in hemianopic patients. This is not surprising given that the benefit of cue validity on response accuracy has not been consistently found (Clark & Hillyard, 1996; Kentridge et al., 2008, 2004; Prinzmetal, McCool, & Park, 2005; Whitehead, MacKenzie, Schliebner, & Bachorowski, 1997). This might depend on several factors like task difficulty, stimulus-onset asynchrony, stimulus size, contrast, spatial frequency and motion. Certainly, our task was very simple and this was purposely

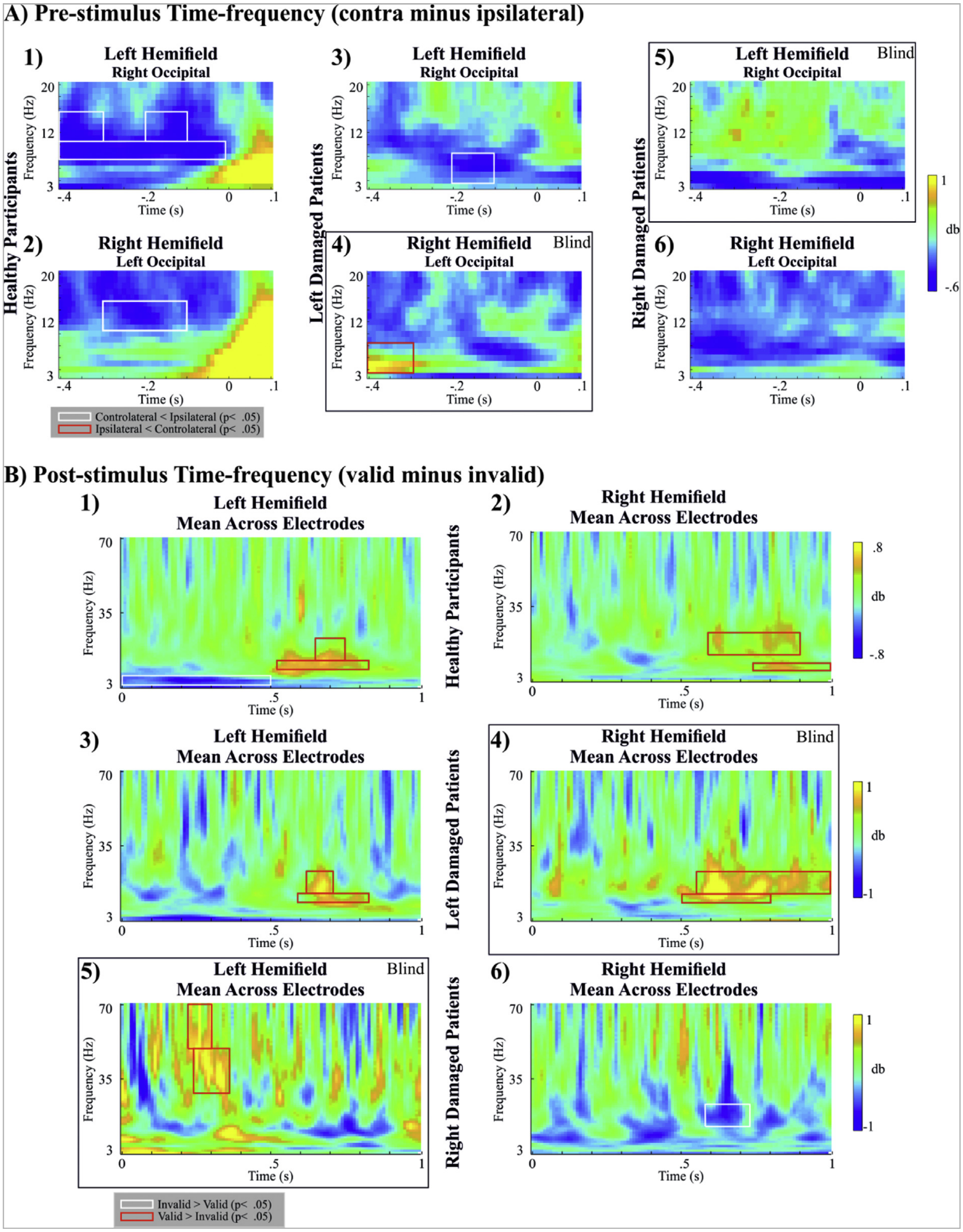


Fig. 5 — Pre (A) and post-stimulus (B) time-frequency results. A) Difference time-frequency maps (contralateral minus ipsilateral occipital electrodes) of the pre-stimulus period. White boxes show significant differences where contralateral was more negative than ipsilateral sites; red boxes show the reverse. B) Difference time-frequency maps (valid minus invalid condition) of the mean activity across electrodes of the post-stimulus period. White boxes indicate significant (p < .05) higher values in the invalid than in the valid condition and vice versa for the red boxes.

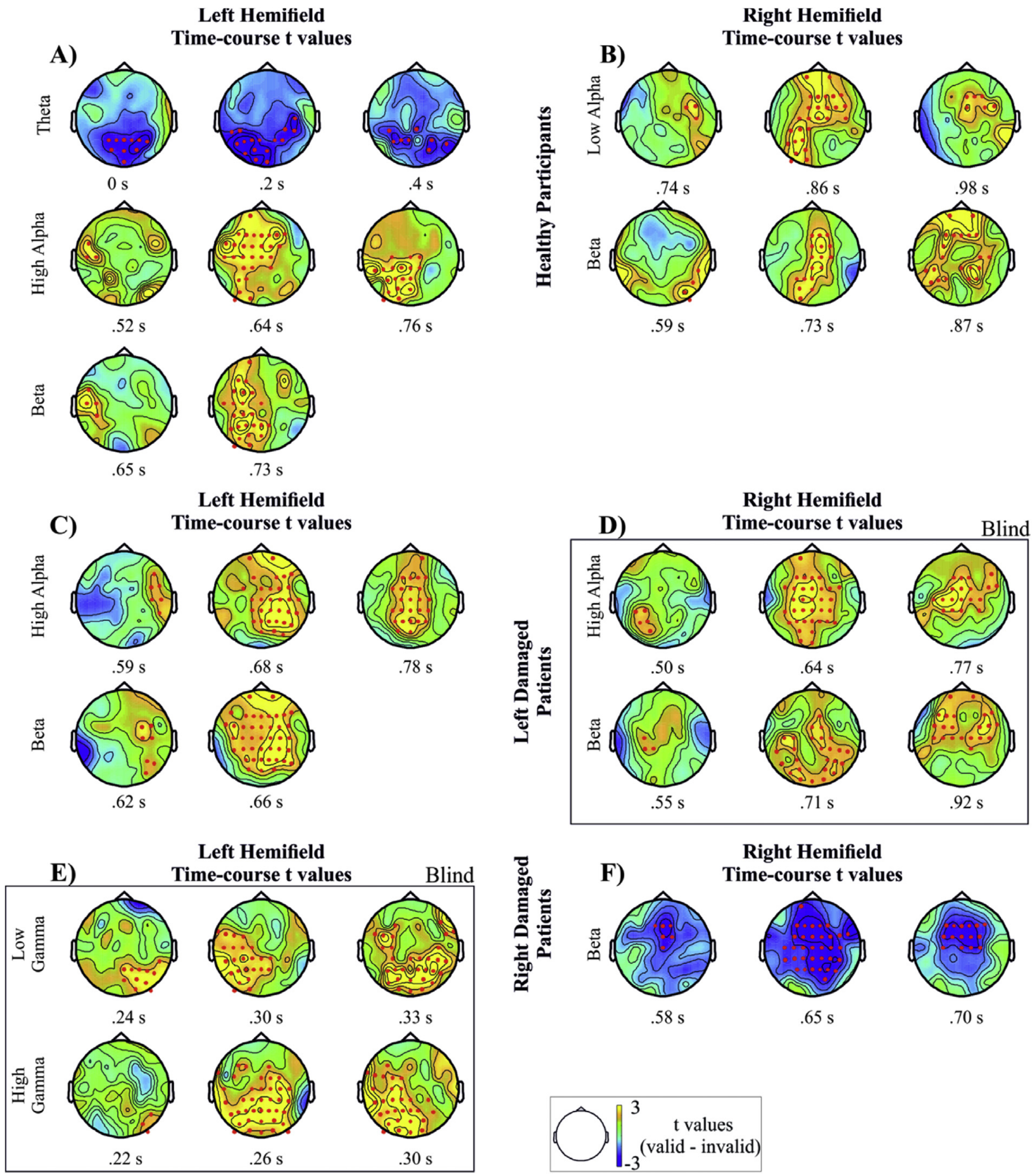


Fig. 6 – Time-course of the location of significant differences (t values) in the post-stimulus analyses for each hemifield and group. Blue in the topographic maps indicates that invalid was higher than valid condition and vice versa for yellow. Red dots represent the electrodes where significant differences ($p < .05$) were found.

done to increase the likelihood of finding above-chance unconscious responses.

4.2. ERP

4.2.1. Pre-stimulus

Confirming the behavioral hemispheric asymmetries, in the pre-stimulus period there was a CNV for orienting to either hemifield in both healthy participants and left damaged patients, while in right damaged patients a CNV was present for orienting to the sighted field only. As the CNV is considered a correlate of focused attention and expectancy (Correa et al., 2006; Mento, 2013; Mento et al., 2015; Miniussi et al., 1999), this finding provides electrophysiological evidence for a right hemispheric dominance in these aspects of endogenous allocation of attention (Mangun et al., 1994) since right hemisphere damage affects the neural mechanism for orienting to the contralesional hemifield while this is not the case for left damage. To note: these differences show that EEG asymmetries in implicit attentional orienting precede stimulus onset and, in principle, might be present even without a target stimulus. Thus, this evidence shows that the dorsal system of attention is still functioning in left lesioned hemianopic patients and that what is impaired is not the source of attention orienting but the locus of its effect on stimulus processing. This is not the case in right damaged patients.

4.2.2. *Post-stimulus*

Healthy participants: It is known that the attention effects on early ERP components such as P1 and N1 are mainly concerned with orienting to the cued location while the later effects are more involved with reorienting in invalid trials. We did not find attention effects on P1 and N1 but we did find them on later components. Previous studies found a higher amplitude of the P3 (a,b) in response to invalid trials suggesting that the modulation of this component is related to the evaluation of invalidity in a broadly similar way as for deviant stimuli in odd-ball paradigms either on the basis of low probability of presentation (Digiacomo et al., 2008; Gómez et al., 2008) or related to the perceived relevance of a stimulus and to context updating (Donchin, 1981; Duncan-Johnson & Donchin, 1982; Wright, Geffen, & Geffen, 1995).

In keeping with that, we found attention effects in P3a and P3b. However, these effects depended upon visual field of stimulus presentation and hemisphere. For the *left field* we found larger P3a and P3b in the invalid than the valid condition that was restricted to the right hemisphere. In contrast, for the *right field* we found a smaller invalid P3b with respect to the valid condition that was distributed bilaterally over central sites. These hemifield and hemisphere differences suggest that stimuli to the left field engage uniquely the dominant right hemisphere for reorienting while those to the right field involve the shared participation of both hemispheres to the reorienting process. This asymmetry is likely to be responsible for the well documented left visual field bias in spatial attention (Marzi, Bisiacchi, & Nicoletti, 1991; Nicholls, Bradshaw, & Mattingley, 1999; Nicholls & Roberts, 2002; Śmigasiewicz, Hasan, & Verleger, 2017) that reasonably depends on hemispheric asymmetries in the organization of the attentional networks (Gigliotta, Seidel Malkinson, Miglino, & Bartolomeo, 2017). In accord with that, previous studies demonstrated this bias in healthy participants and a selective disruption in patients with right brain damage (Chédru, Leblanc, & Lhermitte, 1973; De Renzi, Faglioni, & Scotti, 1970; De Renzi, Gentilini, Faglioni, & Barbieri, 1989; Gainotti, D'Erme, & Bartolomeo, 1991).

Left damaged patients. *Sighted field*: We found an enhanced P3a and N1 and a lesser amplitude of the P3b components in invalid trials. A functional dissociation between P3a and P3b has been proposed (Polich, 2007). The P3a would be an index of the processing of invalid trials subserved by frontal attention mechanisms driven by the unexpected stimulus. In contrast, the P3b, which originates from temporo-parietal activity, would be related to context updating and subsequent working memory processing (Gómez et al., 2008; Polich, 2007). According to this hypothesis, our results suggest that in left damaged patients stimulus-driven processing is accomplished as in healthy participants, with an added cost for context updating and working memory. Previous studies reported a specialization of the left occipital lobe in categorization processing in healthy participants and its impairment in left damaged hemianopic patients (Céline Perez et al., 2013).Thus, the reduced amplitude of P3b and its late latency with respect to healthy participants in the sighted field of left damaged patients could be related to an increased cost for context updating and categorization. This might explain the perceptual deficits found in the intact visual field of hemianopic patients described as "sightblind" by Bola, Gall, and Sabel (2013; see also (Chokron, Perez, & Peyrin, 2016; Chokron, Peyrin, & Perez, 2018). As to the unusual effect on N1 (greater for the invalid condition), it could reflect an enhanced attention to a salient visual input appearing in an unexpected location as has been reported in some studies (Fu, Caggiano, Greenwood, & Parasuraman, 2005, 2001; Lai & Mangels, 2007).

*Blind field***:** a paradoxical effect was found in P1 with a larger amplitude for the invalid condition while N1 showed the canonical pattern. A functional dissociation between P1 and N1 is widely accepted: P1 would be related to the early sensory processing of a stimulus presented in a specific location, while N1 would represent the orienting of attention to a task-relevant stimulus (Luck et al., 1990). Our results suggest an unconscious enhancement of visual processing in invalid trials (unexpected and salient stimuli) and a later unconscious attentional gain control for valid trials.

Right damaged patients. *Sighted field:* Even though ERP components were present, no difference between valid and invalid trials was found. The lack of attention effects in the early components (P1 and N1) suggests a similar processing of sensory inputs as in healthy participants. However, while in healthy participants there was a neural correlate of reorienting at later stages (P3), in this group of patients no late attention effects were observed and the amplitude of the P3 components was visibly smaller than that in healthy and left damaged participants. According to the context updating theory of P3 (Polich, 2007), the smaller amplitude and the lack of difference between conditions may be related to a reduced capability of the system to adequately process an unexpected stimulus. This finding fits with the "sightblindness" phenomenon described above (Bola et al., 2013; Chokron et al., 2018; Chokron et al., 2016) and supports the idea of the contribution of the right hemisphere to attentional processing in either visual field (Mangun et al., 1994).

Blind field: No reliable ERP components were found and this dramatically reflects the crucial role of the right hemisphere in visual attentional processing.

4.3. *Time-frequency*

4.3.1. *Pre-stimulus*

Healthy participants: We found the well-known reduction of alpha over the hemisphere contralateral to the attended field (Kizuk & Mathewson, 2016; Sauseng et al., 2005; Thut, 2006) which, however, was qualitatively different in left and right hemifield. In the *left field* it involved both low and high alpha in early and late time periods, while in the *right field* was found in a small time window and only in high alpha. Thut (2006) found a more negative alpha with leftward than rightward attention orienting and suggested that this is a correlate of a left attentional bias. Our results support this finding that is in accord with the results with the CNV.

Left damaged patients: While in both groups of patients no significant effects in alpha were found, in left damaged patients significant differences between contra and ipsilateral hemispheres were observed in the theta band. In the *sighted field* the contralateral side (intact hemisphere-right) showed a more negative theta, while in the *blind field* a greater negativity was found in the ipsilateral hemisphere (intact hemisphere-right). To our knowledge no study has reported an effect on pre-stimulus theta activity during cued attentional tasks in humans. However, this phenomenon has been observed in V1 and V4 of macaque monkeys during selective attention (Spyropoulos, Bosman, & Fries, 2018). In humans it might be due to a slowdown of the posterior dominant frequency rhythm of the EEG after brain injury (Ianof & Anghinah, 2017) which replaces the normal alpha modulation. Certainly, a relevant result in the pre-stimulus time frame and in this patients' group is the modulation of the theta band and in particular the paradoxical effect in the blind field with the ipsilateral showing a more negative theta than the contralateral hemisphere. This finding may represent a form of brain reorganization where the intact right hemisphere plays an important role in maintaining an efficient allocation of attention to the blind visual field.

Right damaged patients: No significantly different attentional hemispheric modulations were found and it might be the case that similar bilateral oscillations in the occipital cortex did not enable a spatially selective orientation of attention.

4.3.2. *Post-stimulus*

Healthy participants and left damaged patients: The EEG was characterized by a similar pattern of late oscillations (after 500 msec) in both visual fields of healthy participants and left damaged patients with higher values in valid than invalid conditions in alpha (high in the left field in healthy participants and in both hemifields of patients, and low in the right field of healthy participants) and beta. Alpha has been associated with directed attention and stimulus classification and is related to the modulation of the P3 component (Digiacomo et al., 2008; Klimesch et al., 1993; Sterman, 1996). The differential modulation of high and low alpha in the left and right hemifield of healthy participants might be related to the enhanced P3 effect in the left with respect to the paradoxical effect in the right field found in the pre-stimulus ERP results, see above. Beta modulations, on the other hand, might reflect the maintaining of the "status quo" (expectancy is respected) during the valid trials (Engel & Fries, 2010; Vázquez Marrufo, Vaquero, Cardoso, & Gómez, 2001). Additionally, in the left visual field of healthy participants we found an early higher theta activity in the invalid condition. Previous studies have linked this activity to attentional search (Dugué, Marque, & VanRullen, 2015) and therefore this could represent another neural basis of the leftward attentional bias.

Right damaged patients showed a very different pattern of oscillatory activity with respect to the other two groups that might be related to a mechanism of brain reorganization of attention reorienting. It is important to note that in the blind field even though there was no reliable orienting effect we found post-stimulus evidence of a reorienting effect (as shown by gamma band modulation) which might be considered part of a reorganization mechanism.

The *sighted field* was characterized by a paradoxical beta effect likely related to a reduced capability of the system to adequately process the presence of an unexpected stimulus as hypothesized for the ERP results. The *blind field* showed a modulation of the gamma oscillatory activity that was higher in the valid than in the invalid condition. Some authors (Gregoriou, Paneri, & Sapountzis, 2015; Gruber et al., 1999) have proposed that, during an attentional task, this modulation could be associated with motion perception and an effective integration of inputs. In our experiment we used a flickering stimulus and this could be a crucial feature for unconscious perception in this group of patients enabling them to enhance the response to valid trials, as witnessed behaviorally by the RT attention validity effect in the blind field.

To be noted, in healthy participants we found left-right asymmetries in both ERP and frequency modulation but not in behavior. This lack of reliable hemifield differences in accuracy is not surprising given the easiness of the discrimination and the notion that attentional effects on accuracy in a Posner spatial paradigm are rarely found. We believe that this is not in principle incompatible with different patterns of brain activity. The motor output is the final outcome of a complex interplay of central neural processes that may detect asymmetries that do not show up in the behavioral response. This is a prerogative of the EEG technique that is able to detect neural processes that are not obviously amenable to behavioral investigation.

5. Conclusions

In conclusion, we provided behavioral and neural evidence of an attentional modulation in the blind field of hemianopic patients. Moreover, we found substantial hemispheric differences in the effects of brain damage on unconscious visual attention: Right damaged were impaired with respect to left damaged patients who showed a pattern of behavioral and neural activity broadly similar to that of healthy participants even in the blind hemifield. Interestingly and importantly for visual rehabilitation (see for general reviews Larcombe et al., 2018; Melnick, Tadin, & Huxlin, 2016; Perez & Chokron, 2014; Sabel, Flammer, & Merabet, 2018; Zihl, 2013), the two groups of patients showed differential mechanisms of neural reorganization that suggest to use rehabilitation methods tailored to individual patients with right or left hemispheric damage. In principle, the reorganization after a unilateral cortical lesion could result either from interhemispheric cross talk through the callosal connections or from plastic neuronal mechanisms within the ipsilesional hemisphere. As discussed by Perez et al. (2013), this concept applies also to occipital lesions and according to these authors after a right occipital damage the former mechanism prevails while following a left occipital lesion there is a predominant ipsilesional reorganization. Our results in patients with occipital lesion show more severe consequences following right than left hemispheric lesion, especially in the post-stimulus ERP responses in the blind field. Although the present study was not specifically designed to analyze the mechanisms of post lesional reorganization, the unconscious attentional ERP and oscillatory activity effects in both left and right damaged patients were predominantly bilateral thus suggesting a contribution of the non-lesioned side. In fact, an important role of the intact hemisphere in reorganization is in keeping with what found in our previous studies in hemianopic patients carried out with various methods and tasks (Bollini, Sanchez-Lopez, Savazzi, & Marzi, 2017; Celeghin et al., 2017, 2015; Sanchez-Lopez, Savazzi, Pedersini, Cardobi, & Marzi, 2019). It is difficult to find patients with very similar lesions and therefore in principle the possibility of somewhat different reorganization taking place in different patients (especially in FB in our sample) cannot be excluded but we do not think this is likely in our study. Certainly, a meta-analysis of right-left asymmetries in reorganization of unilateral cortical visual impairments would be welcome. Finally, our results provide evidence of the importance of occipital visual areas in the modulation of orienting and reorienting of attention in addition to the well documented ventral and dorsal attention systems in parietal, temporal and frontal lobes. However, limitations regarding the small size of the sample require further research on this important topic.

Authors contributions

Javier Sanchez-Lopez, Silvia Savazzi, Caterina A. Pedersini and Carlo A. Marzi: Conceptualization, Methodology. **Javier Sanchez-Lopez, Caternia A. Pedersini and Nicolo Cardobi**: Investigation, Data curation. **Javier Sanchez-Lopez, Silvia Savazzi**: Formal analysis. **Javier Sanchez-Lopez and Carlo A. Marzi**: Writing - original draft preparation. **Carlo A. Marzi**: Supervision, Funding acquisition. **Javier Sanchez-Lopez, Silvia Savazzi, Caterina A. Pedersini and Carlo A. Marzi**: Writing – review & editing.

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Open practices

The study in this article earned Open Materials and Open Data badges for transparent practices. Materials and data for the study are available at https://figshare.com/s/8542139d4e175a5b9333.

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Appendix A. Reaction time results in patients using correct responses only

In the whole group of patients, a significant main effect was found for Condition ($p < .001$) and Hemifield ($p < .001$): Valid (Mean = 673.8 msec, SD = 220.2) were faster than invalid (Mean = 702.2 msec, SD = 238.6) trials; and the blind (Mean = 596.1 msec, SD = 248.4) was faster than the sighted (Mean = 705.3 msec, SD = 198.6) hemifield. The interaction did not reach significance.

Two further non-parametric ANOVAs were carried out in the two subsets of patients divided according to the side of the lesion.

In **left brain damaged** patients the main effects of Attentional Condition ($p = .01$) and Hemifield were significant ($p < .001$). RT in valid (Mean = 599.2 msec, SD = 170) was faster than in invalid trials (622.3 msec, SD = 188). RT for the blind hemifield (Mean = 576.6 msec, SD = 231.5) was faster than for the sighted visual field (Mean = 615.3 msec, SD = 146.6). The interaction was not significant.

In **right brain** damaged patients, as in the group of left damaged patients there was a significant effect of Attentional Condition ($p < .01$) and Hemifield ($p < .001$), RT for valid (Mean = 748.2 msec, SD = 238.7) was faster than for invalid trials (Mean = 778.2 msec, SD = 256.4); and RT in the blind field (Mean = 748.7 msec, SD = 347.8) was faster than in the sighted hemifield (Mean = 783.8 msec, SD = 204.3). The interaction was not significant.

Thus, the analysis of RT of correct responses yielded pretty similar results to those found with the analysis of all responses. Exception to that is that in the analysis of all trials in right brain damaged patients the interaction Attentional Condition by Hemifield was significant with the validity effect larger in the blind hemifield.

Appendix B. Further analysis to evaluate invalidity defect in right damaged patients

To evaluate a possible invalidity processing defect in the group of right with respect to left damaged patients and healthy participants, a direct comparison across groups was performed. A non-parametric two-way ANOVA with Group and Hemifield as factors was conducted to compare right with left damaged patients, and right damaged patients with healthy participants using the values of the effect of validity (invalid minus valid) of RT. To perform the analysis all responses from patients were used, while for healthy participants only correct responses were used.

Significant main effects of Group ($p < .001$), Hemifield ($p < .001$) as well as of the Interaction ($p < .001$) were found. Right damaged showed a larger validity effect (mean = 43.7 msec) than left damaged patients (mean = 29.13 msec). The validity effect was larger in the blind ($p < .001$; mean 54.49 msec) than in the sighted (mean 25.54) field. Post-hoc analysis showed significant differences of the effect of validity between blind and sighted hemifield in both groups ($p < .001$, right damaged patients = 52.54 msec; left damaged patients = 10.05 msec). Notice that the difference in the effect of validity is higher in right damaged with respect to left damaged patients (mean difference = 42.49 msec). The group comparison of the validity effect for the blind field showed a significant ($p < .001$) larger effect in right (mean = 78.67 msec) than left damaged (34.87 msec) patients. Comparison for the sighted visual field did not reach significance ($p = .052$).

Same analysis was also conducted to compare right damaged patients with healthy participants. Results showed significant main effects of Group ($p < .001$), Hemifield ($p < .001$) and of the Interaction ($p < .001$) as in the previous analysis. Right damaged patients showed higher validity effect (mean = 43.7 msec) than healthy participants (mean = 14.60 msec). Validity effect was higher in the sighted/right ($p < .001$; mean 23.10 msec) than the blind/left (mean 22.58 msec) field. Posthoc analysis showed significant differences of the effect of validity between blind and sighted hemifield in patients ($p < .001$; mean difference right damage patients = 52.54 msec higher in the blind field) and between left and right in healthy participants ($p < .001$; mean difference = 13.48 higher in the right field). Notice that the difference in the effect of validity is higher in patients with respect to healthy participants (mean difference = 39.06 msec). Comparison of the validity effect in the blind/left field between groups showed a significant ($p < .001$) higher effect in right damaged patients (mean = 78.67) than healthy participants (mean = 7.99 msec) patients. Comparison for the sighted/right visual field also showed a significant ($p < .001$) higher effect in patients (mean = 26.13 msec) than in healthy participants (mean = 21.47 msec). Notice that the difference found between blind and left fields were higher than that between sighted and right fields.

In conclusion this analysis confirms an increased cost for the "unconscious processing" of invalid trials in the blind visual field.

Appendix C. Behavioral and EEG results of patient FB

Accuracy and RT results of FB patients reported in Table C.1 show that the behavioral results are similar to that of the other patients of the right damaged group with faster RT for valid than invalid trials for all trials and for correct responses only.

As to ERP results, see Fig. C.1, patient FB shows a trend in the *pre-stimulus* CNV waveform pretty similar to that observed in the group of right damaged patients. This component can be observed for stimuli presented in the sighted but not in the blind field. The *post-stimulus* ERP components in the sighted field are similar to those of the other right brain damaged patients except for the P3 component that could not be clearly detected. The absence of reliable ERP components in the blind visual field is another characteristic that this patient shares with the group of right brain damaged patients. At a descriptive level, the *pre-stimulus* time-frequency maps show a similar pattern to that found in the rest of the group with lower contralateral slow frequency activity in both visual fields and a higher contralateral fast activity which is only observed for the blind field. By the same token, *post-stimulus* time-frequency activity shows the same trend as that found in the rest of the group which is characterized by higher early gamma activity in the valid condition for the blind field and smaller later beta activity in the sighted visual field.

In summary, the ERP and time-frequency activity of FB follow a similar pattern as that observed in the other patients with right brain damage.

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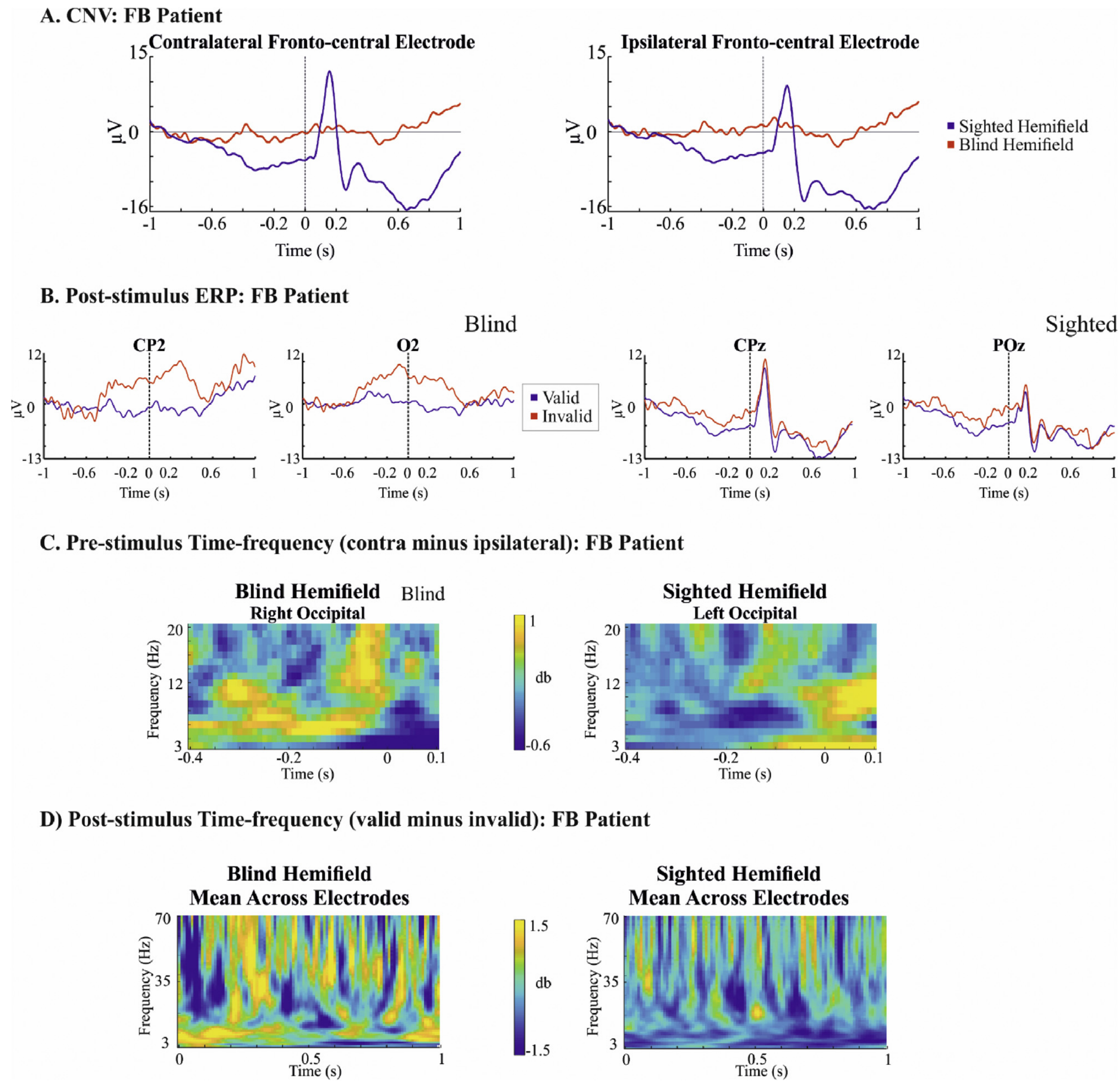

Fig. C.1 – EEG recording from patient FB. A and B: analysis of the EEG in time domain (pre and post-stimulus ERPs). C and D: pre and post-stimulus response in time-frequency domain.

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