

Cognition and Behavior

# P3b Does Not Reflect Perceived Contrasts

Yen-Kuang Chen,<sup>1</sup> Tony Cheng,<sup>2</sup> and Po-Jang Hsieh<sup>1</sup><https://doi.org/10.1523/ENEURO.0387-21.2022><sup>1</sup>Department of Psychology, National Taiwan University, Taipei City 10617, Taiwan and <sup>2</sup>Department of Philosophy, National Chengchi University, Taipei City 116302, Taiwan

## Abstract

It has been shown that P3b is not a signature of perceptual awareness per se but is instead more closely associated with postperceptual processing (Cohen et al., 2020). Here, we seek to investigate whether human participants' attentional states are different in the report and the no-report conditions. This difference in attentional states, if exists, may lead to degraded consciousness of the stimuli in the no-report condition, and it therefore remains unknown whether the disappearance of P3b is because of a lack of reportability or degraded consciousness. Results of our experiment 1 showed that participants did experience degraded contents of consciousness in the no-report condition. However, results of experiment 2 showed that the degraded contents of consciousness did *not* influence the amplitude of P3b. These findings strengthen the claim that P3b is *not* a signature of perceptual awareness but is associated with postperceptual processing.

**Key words:** attention; consciousness; ERP; neural correlate of consciousness; no-report paradigm; P3b

## Significance Statement

P3b, one of the most studied event-related potentials, has been claimed to reflect several cognitive activities, including consciousness. Although recent experiments with the new no-report paradigms suggest otherwise that P3b may not reflect human conscious activities, these results are not yet conclusive. In this study, we conducted a series of modified no-report paradigm experiments, and found that P3b was not modulated by the degrees of conscious perception of stimuli. These results support the claims that P3b may not be a neural marker of consciousness.

Received September 21, 2021; accepted March 3, 2022; First published March 28, 2022.

The authors declare no competing financial interests.

Author contributions: Y.-K.C. and P.-J.H. designed research; Y.-K.C. performed research; Y.-K.C., T.C., and P.-J.H. contributed unpublished reagents/analytic tools; Y.-K.C. analyzed data; Y.-K.C., T.C., and P.-J.H. wrote the paper.

This work was supported by the Ministry of Science and Technology (R.O.C.) Grant MOST 109-24710-H-002-004-MY3, the Yushan Young Scholar Program Grant NTU-108V0202, and the Ministry of Education Grant MOE 110L9A00701.

Acknowledgements: We thank Chen-Wei Wu, Yu-An Chen, and Yu-Hsin Lee for invaluable discussion and advice.

Correspondence should be addressed to Yen-Kuang Chen at [chen3210@gmail.com](mailto:chen3210@gmail.com) or Po-Jang Hsieh [hsiehpj@ntu.edu.tw](mailto:hsiehpj@ntu.edu.tw).

<https://doi.org/10.1523/ENEURO.0387-21.2022>

Copyright © 2022 Chen et al.

This is an open-access article distributed under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution and reproduction in any medium provided that the original work is properly attributed.

## Introduction

The debate about the exact location of the neural correlates of consciousness (NCCs) in our brain has lasted for decades. Some studies reported sensory NCCs in the anterior brain regions (Lumer and Rees, 1999; Dehaene and Naccache, 2001; Lau and Rosenthal, 2011; Cohen et al., 2012; Panagiotaropoulos et al., 2012; Noy et al., 2015; Huth et al., 2016; Dehaene et al., 2017; Siclari et al., 2017; Brown et al., 2019), while others hold that NCCs in the posterior brain regions only (Penfield and Jasper, 1954; Damasio and Van Hoesen, 1983; George et al., 1996; Markowitsch and Kessler, 2000; Mataró et al., 2001; Farah, 2004; Brown et al., 2010; Craig, 2010; von Arx et al., 2010; Barton, 2011; Quiroga, 2012; Seth et al., 2012; Kozuch, 2014; Koch et al., 2016). Many NCCs were found by using contrastive analysis (Baars, 1994) that suffered from a thorny methodological problem: most paradigms of NCCs require participants to report whether they consciously perceive the stimuli. Thus, it is difficult to tease

apart the NCC and the neural correlates of reports, and the so-called “NCCs” might reflect other cognitive processes than consciousness per se (Overgaard, 2004; Block, 2007; de Graaf et al., 2012; Neisser, 2012).

To address this issue, a variety of no-report paradigms have been developed in recent studies (Frässle et al., 2014; Shafto and Pitts, 2015; Koch et al., 2016; Pitts et al., 2018; Hesse and Tsao, 2020). Participants in no-report tasks are typically not asked to report during the stimuli-presentation phase and hence do not need to make any judgment about their conscious perceptual experiences. With these paradigms, neural activities related to postperceptual judgments are arguably minimized when comparing the conscious and unconscious conditions.

Using such a no-report paradigm, a recent study showed that P3b disappeared in the no-report condition but can still be observed in the report condition (Cohen et al., 2020). Based on this result, Cohen et al. (2020) claimed that “the P3b is not a signature of perceptual awareness per se and is instead more closely associated with postperceptual processing.” However, there is strong evidence that the shifting of spatial attention can alter observers’ perceived visual appearances, such as contrast, spatial, color, and temporal dimension, etc. (Carrasco and Barbot, 2019). We therefore suspect that participants’ attentional states may not be equal in the report and the no-report conditions, which may lead to more degraded consciousness of the stimulus in the no-report condition than in the report condition. Hence, it is unclear whether the disappearance of P3b was correlated with the reportability or the degraded consciousness.

We hypothesized in experiment 1a that, compared with the report condition, participants would experience degraded consciousness of the stimuli in the no-report condition because of a lack of attention. This hypothesis is supported by the results of experiment 1a: participants reported that they perceived lower-contrast stimuli in the no-report condition. Next, experiment 1b was conducted to control for the order/learning effect, and the results successfully ruled out this potential confounding factor.

To directly examine whether degraded consciousness of the stimuli modulates P3b, we manipulated the perceived contrasts of the experimental stimuli (i.e., conscious contents) and measured P3b in experiment 2. We reasoned that if P3b really reflects perceived stimulus contrast, differences in P3b should be observable while participants perceive higher-contrast stimuli versus lower-contrast stimuli. Otherwise, we should observe a similar P3b pattern while participants perceive different contrast levels of the stimuli. Our results showed a similar P3b pattern across conditions of different perceived contrasts, and therefore are in line with Cohen et al. (2020) supporting the claim that P3b may be more closely associated with postperceptual processing.

## Materials and Methods

### Experiment 1a, behavioral experiment

The experimental design was closely modeled on the no-report paradigm of Cohen et al. (2020) to investigate

**Table 1: Corresponding relation between Weber contrast and contrast in this study**

Contrast level	Weber contrast
0	0
0.1	0.09
0.2	0.23
0.3	0.41
0.4	0.57
0.5	0.71
0.6	0.95
0.7	1.15
0.8	1.35
0.9	1.52
1	1.87

whether the perceived contrast was lower in the no-report condition.

### Participants

Forty-eight young adults took part in this experiment (12 males). All of them were recruited within the National Taiwan University community with ages from 18 to 30 years (mean age = 21.3 years), had normal or corrected to normal vision, reported no neurologic and psychiatric disorders and received pecuniary remuneration after finishing the tasks. Three participants were excluded from the analyses because of outlier performances (out of 2 SEs from the average performances). This work was approved by the ethics committee of behavioral and social science at National Taiwan University and was conducted according to its guidelines. Before the experiment, the written informed consent was given by all participants.

### Experimental design

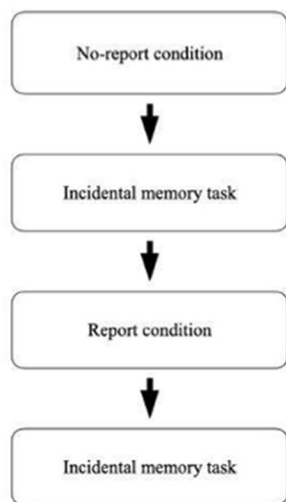
A mixed model design for three-factors (between-between-within design) was adopted. The first factor (between) was the pop-out times of green ring (Times): 4, 6, and 8. The second factor (between) was the contrast levels of the Gabor gratings at the beginning in the incidental memory task (Levels): 0.3 and 0.9. The contrast level was defined by the visibility of the stimulus relative to the white background, ranging from 0.0 (transparent) to 1.0 (opaque). Table 1 shows the corresponding relation between the Weber Contrast and the contrast defined in this study. The third factor (within) was the report/no-report condition

**Table 2: Table of the experimental design**

Times	Conditions		
	Levels	No-report	Report
4	0.3		N = 8
	0.9		N = 8
6	0.3		N = 8
	0.9		N = 8
8	0.3		N = 8
	0.9		N = 8

A mixed model design for three-factors. Times: pop-out times of green ring; Levels: the contrast levels of the Gabor gratings at the beginning in the incidental memory task; N: numbers of the participants. A total of 48 participants were divided into six groups, which is the combination of the three levels in Times and the two levels in Levels. All participants completed both no-report condition and report condition.

## A Whole procedure



## B Report vs no-report conditions

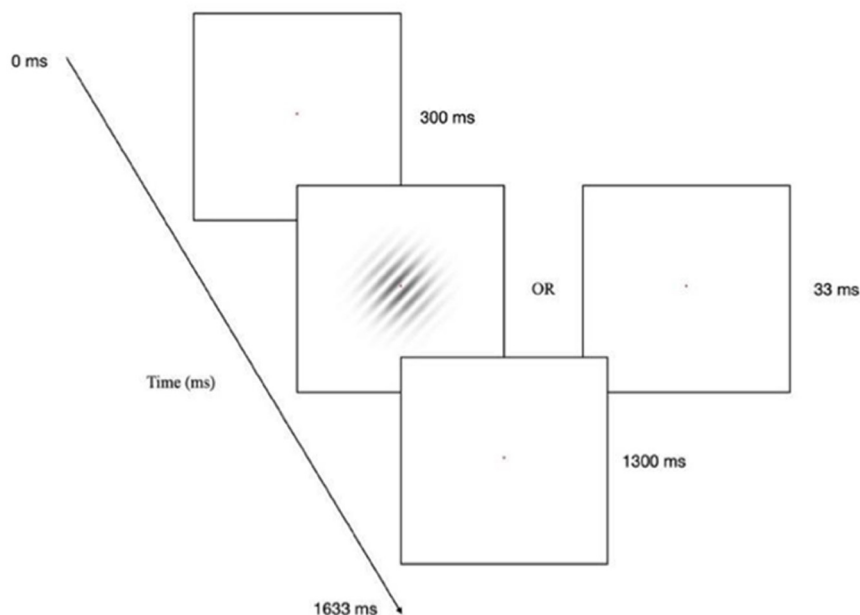
**No-report condition task:**  
Count the pop-out times of green ring



300ms duration  
random onset (0-1266ms)  
4/6/8 times in both condition (~10%)

**Report condition task:**  
Did not see the Gabor/  
45-degree incline/  
135-degree incline

## C Trials in both condition



**Figure 1.** Design of the experiment. **A**, Each participant completed this experiment in the same sequence. **B**, In the no-report condition, the green ring was the target. Participants had to report how many times they saw the green ring. In the report condition, participants answered questions with regard to the Gabor grating they saw trial by trial. **C**, Each trial started with 300 ms of fixation followed by 33 ms of the stimulus, and then 1300 ms of ITI. ITI, Intertrial interval.

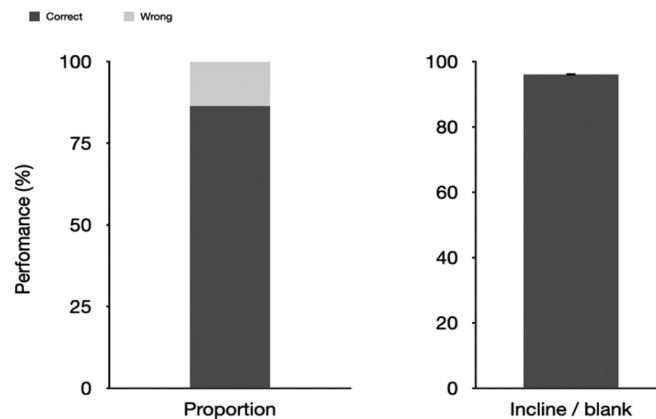
(R/NR). A total of 48 participants were randomly assigned to one of the six groups (Times  $\times$  Level = 6; Table 2).

The procedure of the experiment is shown in Figure 1. Each participant completed all four phases of the experimental procedure in a soundproof room with controlled illumination. All of them completed the experiment in a

fixed order: (1) the no-report condition with 64 trials; (2) an incidental memory task on the critical stimuli; (3) the report condition with 64 trials; (4) an incidental memory task on the critical stimuli.

The no-report condition consisted of 32 critical trials and 32 blank trials with randomized sequence. Each

## A Pop-out times of the green ring    B Incline degrees of gratings task



**Figure 2.** Results from both conditions in experiment 1a. The percentage correct (i.e., performance) is plotted on the y-axis. **A**, The proportion that the participants correctly counted the pop-out times of the green ring. **B**, Performance on the Gabor grating task in the report condition. The error bar indicates the SE (0.097%). SE, Standard error.

critical trial began with a red dot at the center of the screen for 300 ms, followed by a Gabor grating with 45° incline or 135° incline for 33 ms, and then a white background for 1300 ms as the intertrial interval (ITI). The Gabor gratings were 300 × 300 pixels (px) in size with a Gaussian mask: spatial frequency = 0.035 (10.5 cycles across 300 px; opacity = 0.6; 0 as transparent and 1 as opaque). In blank trials, the 33-ms Gabor grating was replaced with a blank screen. A green ring appeared in some of the trials and served as the target in the no-report condition. The green (RGB: 196, 255, 199) ring was a circle dug out with a smaller circle from the center (longer diameter = 750 px; shorter diameter = 400 px). The onset of the green ring within a trial was selected randomly from 0 to 1266 ms, and the duration was always 300 ms. The pop-out times of green ring (the number of trials containing a green ring) depended on which group the participants were assigned (4, 6, 8 times, respectively). Participants in this condition were instructed to fixate at the red dot at the center of the screen and count how many times they see a green ring. After the participants passively viewed these 64 trials (~106.6 s in total), they were unexpectedly asked to report the pop-out times of the green ring.

In the incidental memory task, participants were presented with the same stimuli as in the no-report condition except that the contrasts of the Gabor gratings were different. The contrast of Gabor gratings in both the report and the no-report conditions were always 0.6. However, in the incidental memory task, the Gabor gratings had an initial contrast of either 0.3 or 0.9. Participants were instructed to adjust the contrast of the Gabor gratings to match what they just saw in the previous phase (i.e., in the no-report or the report condition).

In the report condition, the stimuli and procedure were identical to those in the no-report condition (Fig. 1C) except the participants were instructed to respond to the Gabor gratings rather than the green rings. Participants were asked to provide a 3-AFC button-press response which indicated whether they saw a “Gabor grating

inclined to 45 degrees,” a “Gabor grating inclined to 135 degrees,” or “nothing” in each trial. The green rings were still randomly presented in some trials, and the pop-out times depended on which group the participants were assigned. However, participants were not asked to report anything about the green rings.

All the experimental stimuli were controlled using Psychopy version 3.0, a psychology software in Python. All of the stimuli were displayed on a white background and located at the center of the screen. Participants perceived the stimuli with their chin resting on a chin rest to keep visual angles the same. Distance between the participant’s eyes and the monitor was 78.5 cm, making the critical stimuli 6.27°, and the green ring 15.88°. Also, participants were asked to maintain fixation on a red dot with a visual angle of 0.31° in the center of the screen throughout the whole procedure.

### Statistical analysis

Statistical analyses were performed in R 4.0.4, using packages tidyverse, ggpubr, rstatix, and all the respective dependencies. The significance level was set at  $p = 0.05$ , and generalized  $\eta^2$  was used as a measure of effect size. The null hypothesis was that there were no main effects in Times, Levels, R/NR factors.

### Experiment 1b, behavioral experiment

In this experiment, the same report condition was repeated twice to investigate whether there is a sequence effect that might influence participants’ performances in the two incidental memory tasks.

### Participants

Forty-eight young adults took part in this experiment (12 males). They were recruited within the National Taiwan University community and voluntarily participated in this experiment with ages from 18 to 30 years (mean age = 21.4 years). Four participants were excluded from the analyses because of outlier performances (the

**Table 3: Three-way ANOVA in experiment 1a**

Source	df1	df2	F-ratio	p-value	$\eta^2$
Times	2	38	0.292	0.749	0.008
Levels	1	38	1.177	0.285	0.016
R/NR	1	38	45.35	5.64e-08**	0.361
Times $\times$ Levels	2	38	0.596	0.556	0.016
Times $\times$ R/NR	2	38	0.316	0.731	0.008
Levels $\times$ R/NR	1	38	0.082	0.776	0.001
Times $\times$ Levels $\times$ R/NR	2	38	0.634	0.536	0.016

\*\* $p < 0.01$ .

**Table 4: 2  $\times$  2 mixed ANOVA**

Sources	df1	df2	F-ratio	p-value	$\eta^2$
Levels	1	17	2.427	0.138	0.068
R/NR	1	17	4.631	0.046*	0.118
Levels $\times$ R/NR	1	17	0.615	0.444	0.017

\* $p < 0.05$ .

difference of reported contrast levels between the first and the second report conditions were out of 2 SEs from the group mean).

#### Visual stimulation and experimental design

All stimuli and procedures were identical to those in experiment 1a except that there was no no-report condition in this experiment. Participants were asked to complete two phases of report condition and two phases of incidental memory task in a fixed order: (1) the first report condition with 64 trials; (2) an incidental memory task on the critical stimuli; (3) the second report condition with 64 trials; (4) an incidental memory task on the critical stimuli.

## Experiment 2

### EEG experiment

In the behavioral experiment, the results supported our hypothesis that participants in the no-report condition perceived lower contrasts of the stimuli than in the report condition. We further conducted an EEG experiment to investigate whether the difference between these two conditions affected the amplitude of the P3b component.

### Participants

Twenty-two young adults took part in this experiment (12 males) with ages from 20 to 33 years (mean age = 26.0 years). They were recruited within the National Taiwan University community and voluntarily participated in this experiment. All of them reported being free of neurologic and psychiatric disorders and received pecuniary remuneration after finishing the tasks. The participants were also informed to avoid caffeine-containing drinks and any kind of medicine a few days before the experiment. Two participants were excluded from the analyses (one because of the hardware-facility problem and the other one because of high artifacts).

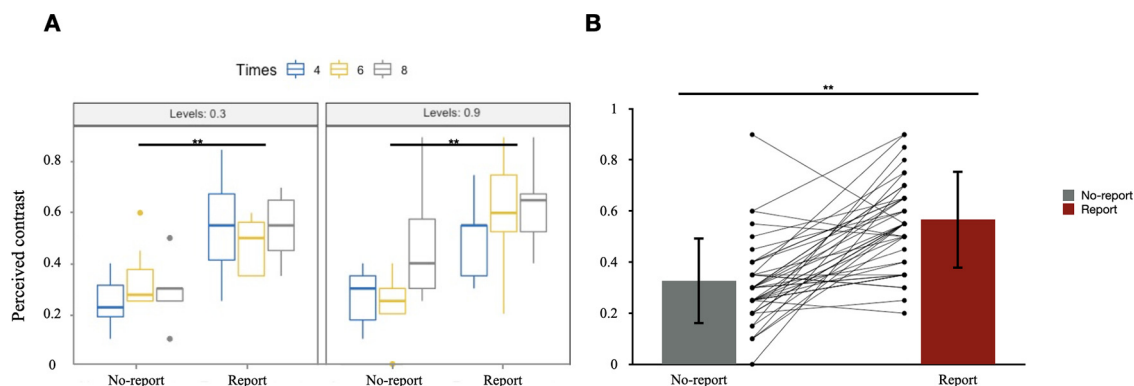
### Apparatus

The data were recorded with a 32 Channel EEG Quick-Cap connected to a NuAmps monopolar digital amplifier (a 40-channel-EEG-ERP-amplifier, Neuroscan) and a computer running SCAN 4.5 software. Electrode positions on the Quick-Cap follow the International 10–20 system. Electrode impedances were kept below 10 kV and band-pass filtered from 0.1 to 150 Hz. Eye movements were monitored by left and right horizontal EOG channels, and the blinks were recorded by two vertical EOG electrodes (one above and the other below the left eye).

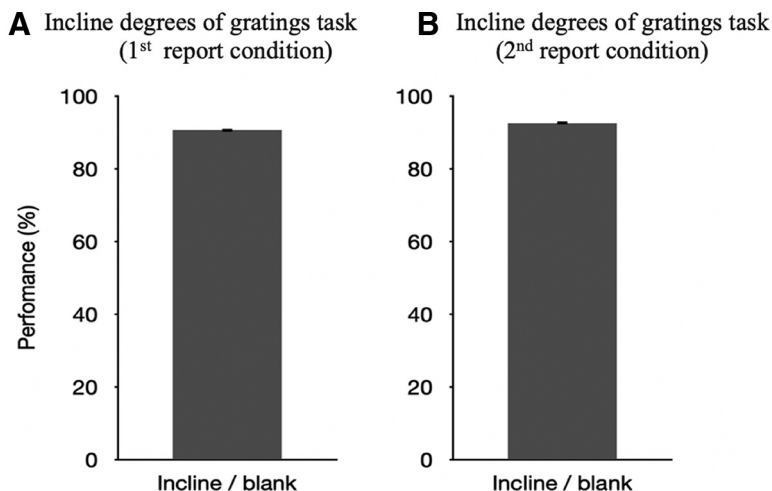
### Visual stimulation and experimental design

All stimuli and procedures were identical to those in experiment 1a except for the following. Each participant completed all six phases of the experimental procedure in a fixed order: (1) six no-report blocks with 64 trials in each block; (2) an incidental memory task on the critical stimuli in the previous no-report blocks; (3) six report blocks with 64 trials in each block; (4) an incidental memory task on the critical stimuli in the previous report blocks; (5) six report blocks with 64 trials in each block with reduced contrasts of critical stimuli comparing to those in the first and the third phases (reduced from 0.6 to 0.3); (6) an incidental memory task on the critical stimuli in the last six report blocks.

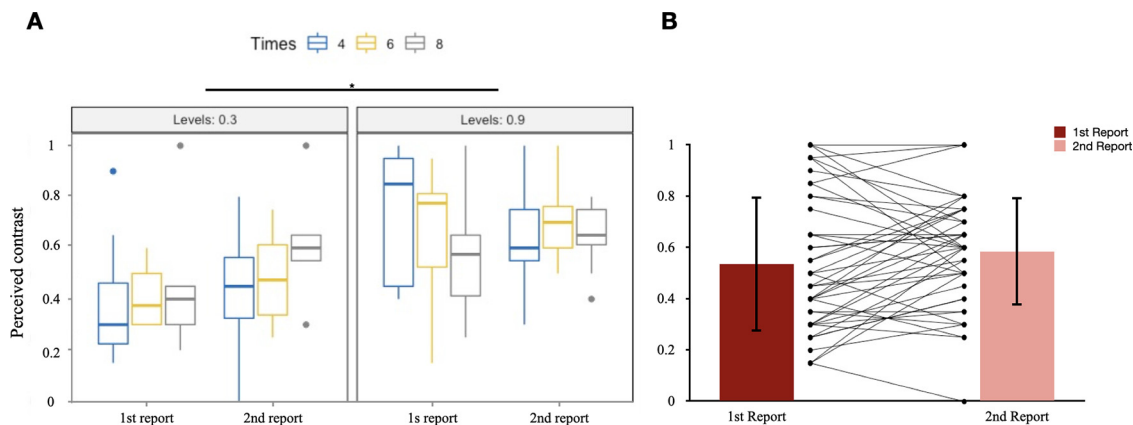
For the six blocks in the no-report and the report conditions, two contained four pop-out times of green ring, another two contained six times, and the other two



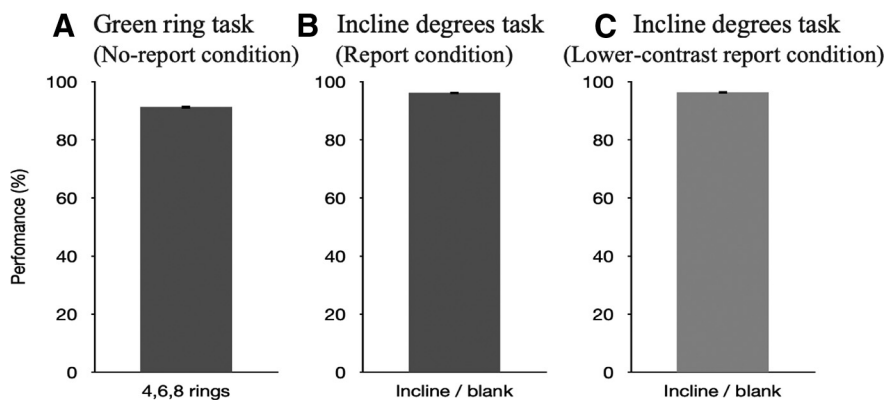
**Figure 3.** **A**, Perceived contrasts in the incidental memory tasks within all conditions. Three levels in Times: 4, 6, 8; two levels in Levels: 0.3, 0.9; two levels in R/NR: No-report, Report. y-axis: contrast of the Gabor grating; x-axis: conditions. **B**, Comparison between the performances in the no-report (SD=0.16) and report conditions (SD=0.17) of each participant. y-axis: contrast of the Gabor grating; x-axis: conditions. SD, Standard deviation.



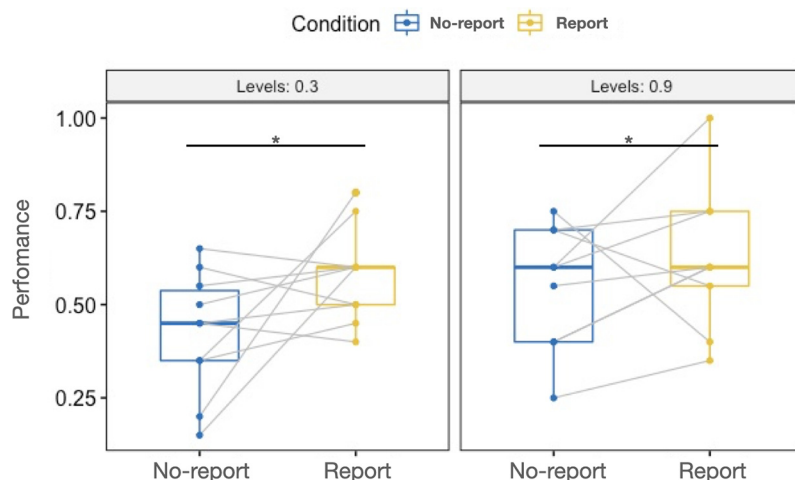
**Figure 4.** Results from both conditions in experiment 1b. In all plots, percentage correct (i.e., performance) is plotted on the y-axis. **A**, Performance on the 45° incline/135° incline/blank task in the first report condition. The error bar indicates the SE (0.27%). **B**, Performance on the 45° incline/135° incline/blank task in the second report condition. The error bar indicates the SE (0.28%). SE, Standard error.



**Figure 5. A**, Perceived contrasts in the incidental memory tasks within all conditions. Three levels in Times: 4, 6, 8; two levels in Levels: 0.3, 0.9; two levels in R1/R2: first Report Condition, second Report Condition. y-axis: contrast of the Gabor grating; x-axis: conditions. **B**, Comparison between the performances in the first report (SD=0.26) and the second report (SD=0.21) conditions of each participant. y-axis: contrast of the Gabor grating; x-axis: conditions. SD, Standard deviation.



**Figure 6.** Results from all conditions in experiment 2. In all plots, percentage correct (i.e., performance) is plotted on the y-axis. **A**, Performance on the green ring counting task in the no-report condition. The error bar indicates the SE (0.54%). **B**, Performance on the 45° incline/135° incline/blank task in the report condition. The error bar indicates the SE (0.19%). **C**, Performance on the 45° incline/135° incline/blank task in the lower-contrast report condition. The error bar indicates the SE (0.23%). SE, Standard error.



**Figure 7.** Boxplot with paired data; \* $p < 0.05$ . Two levels in Levels: 0.3, 0.9; two levels in Condition: no-report condition, report condition. y-axis: contrast of the Gabor grating; x-axis: conditions.

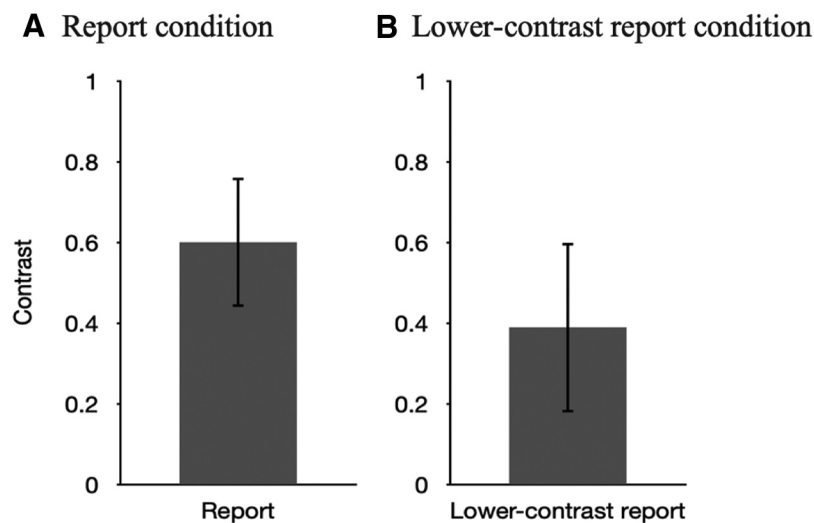
contained eight times, making the pop-out times of green ring around ten percent of the trials on average. The sequence of the blocks was randomized. Participants with odd subject numbers were assigned to the 0.3 Levels group, and those with even subject numbers were assigned to the 0.9 Levels group. Also, the orders of critical trials and blank trials were randomized in the incidental memory tasks. Trial structures were identical to those in Experiment 1a except that each trial started with a red dot with a duration randomly jittered from 200 to 400 ms, and the ITI was lengthed to 1633 ms.

*Statistical analyses*

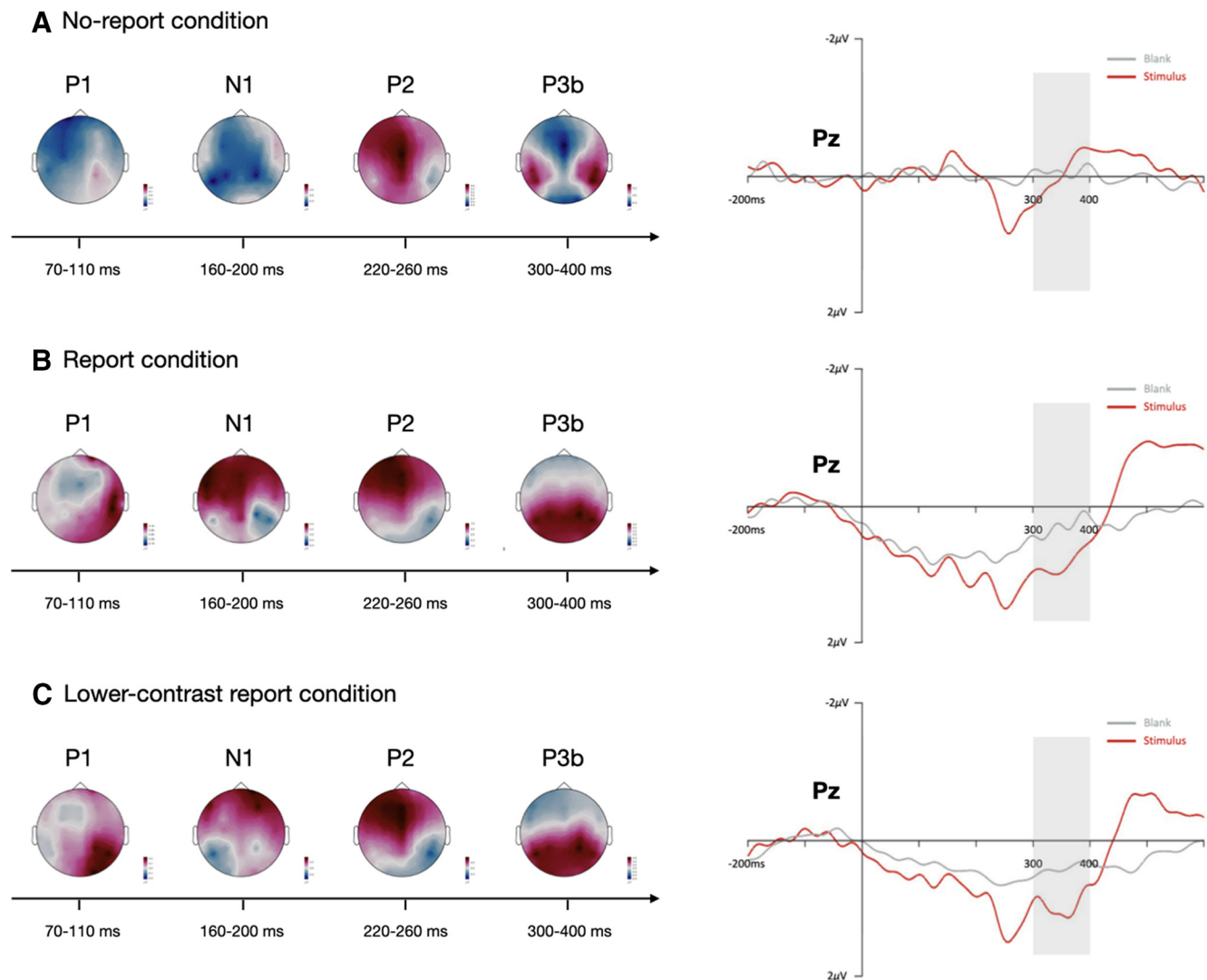
The EEG data were recorded at a sampling rate of 1000 Hz and processed with the Brainstorm software package (Tadel et al., 2011). Recordings were low-pass filtered at 25 Hz with a 24 dB/Oct roll-off, and referenced to the average of the left and right mastoids. The

independent component analysis (ICA) was adopted for rejecting the artifacts, and the ICA components were sorted based on their correlation with the EOGs and ECG channels. ICA components with their topographies reflected artifacts such as blinks, eye movements, muscle activities, and heartbeats were removed. Artifacts not cleaned by the filter and ICA cleaning were marked as bed segments for rejecting the “Detect other artifacts” function in the Brainstorm and further removed manually. On average, 7.2% of trials were excluded because of artifacts among recruited participants, leaving on average around 178 trials for analysis per condition.

ERPs were time-locked to the onset of critical stimulus or blank in each trial. The baselines were corrected from -200 to 0 ms. Time windows and electrodes for statistical analyses were based on former studies using similar targets (Gabor gratings) or tasks. The spatial-temporal regions (ROIs) of interest for the P3b is between 300 and



**Figure 8.** In both plots, reported contrast of the stimuli is plotted on the y-axis. **A**, Average perceived contrast after the report condition. The error bar indicates the SE (0.21%). **B**, Average perceived contrast after the lower-contrast report condition. The error bar indicates the SE (0.16%). SE, Standard error.



**Figure 9.** ERP results for no-report (top row; **A**), report (middle row; **B**), and lower-contrast report (bottom row; **C**) conditions. For all conditions, topographical voltage distributions over a series of time windows and waveforms from a representative (Pz) electrode are plotted. Gray curves reflect the ERP of the critical stimuli, red curves reflect the ERP of blanks. Gray areas represent the ROIs of P3b. In both report and lower-contrast report conditions, clear P3b amplitudes could be observed during the 300- to 400-ms time window while critical stimuli were presented. However, the P3b amplitude vanished in the no-report condition regardless of whether the participants saw the stimuli or not.  $^*p < 0.05$ . Amplitude scales for the topography maps are as follows: **A**,  $\pm 0.3 \mu V$  (P1);  $\pm 0.4 \mu V$  (N1);  $\pm 0.7 \mu V$  (P2);  $\pm 0.4 \mu V$  (P3b); **B**,  $\pm 0.15 \mu V$  (P1);  $\pm 0.4 \mu V$  (N1);  $\pm 1.0 \mu V$  (P2);  $\pm 0.6 \mu V$  (P3b); **C**,  $\pm 0.2 \mu V$  (P1);  $\pm 0.4 \mu V$  (N1);  $\pm 1.0 \mu V$  (P2);  $\pm 0.6 \mu V$  (P3b).

400 ms (Marzecová et al., 2017; Barceló and Cooper, 2018; Brydges and Barceló, 2018). Since P3b is a component usually observed in the posterior brain area (Schröder et al., 2016; Porcaro et al., 2019), we quantified the P3b component in each condition by computing the mean voltage from 300 to 400 ms in a pool of three electrodes centered around Pz (Pz, P3, P4) for the following hypothesis-driven statistical analyses (Sardari et al., 2019).

The behavioral analyses were performed in R 4.0.4, using packages tidyverse, ggpubr, rstatix, and all the respective dependencies. The significance level was set at  $p = 0.05$ , and generalized  $\eta^2$  was used as a measure of effect size. The null hypothesis was specified as that there is no difference between results of the first incidental

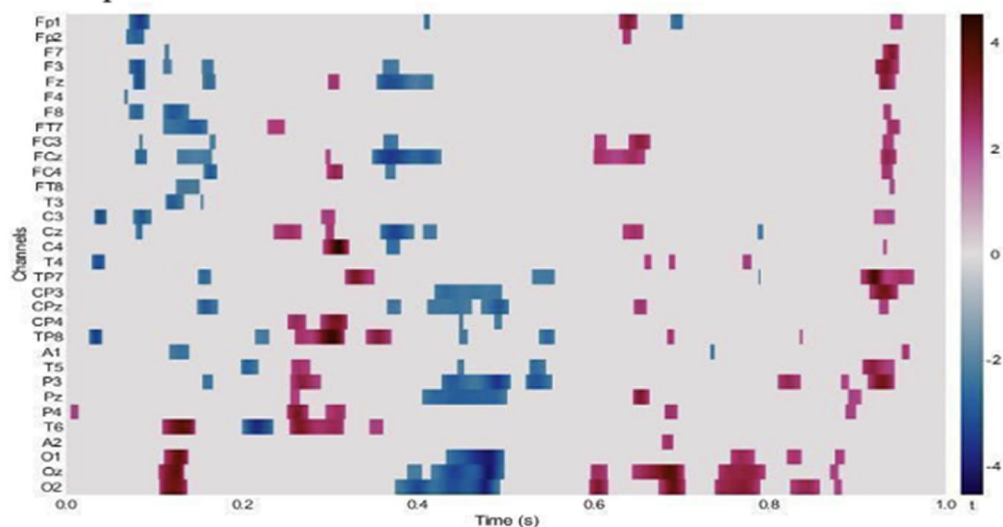
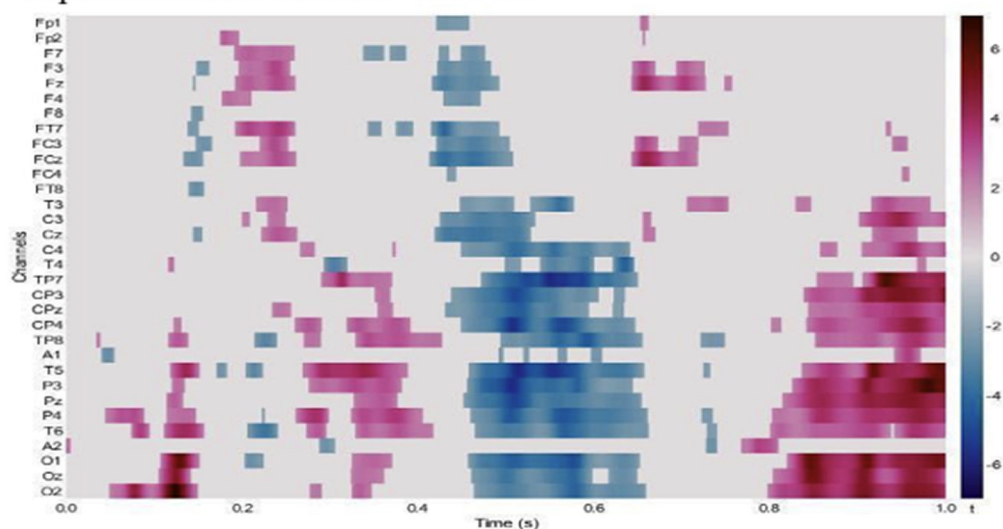
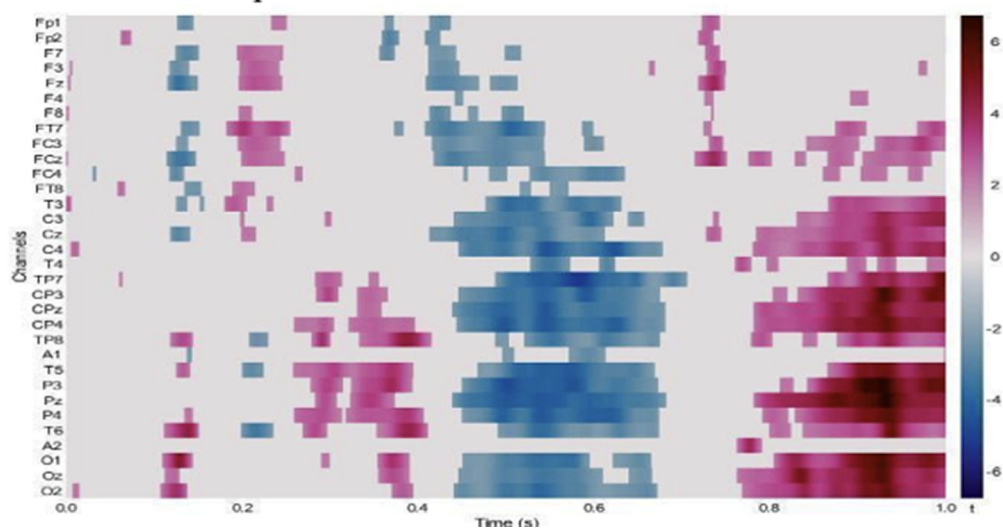
memory task and the second incidental memory task, and no main effect in the Levels factor.

## Results

### Experiment 1a

In the no-report condition, 86.36% of the participants correctly reported the pop-out times of green rings (Fig. 2A). The results of the incidental memory tasks showed that the mean value of perceived contrast of the Gabor gratings for the participants was 0.326. In the report condition, participants correctly reported 96.02% (SD = 0.097%) of trials (Fig. 2B). In the subsequent incidental memory task, the mean value of perceived contrast of the Gabor gratings was 0.566.



**A** No-report condition: stimulus vs. blank**B** Report condition: stimulus vs. blank**C** Lower-contrast report condition: stimulus vs. blank

**Figure 10. A–C**, Results from the mass univariate analyses for all conditions. **A**, No-report condition. **B**, Report condition. **C**, Lower-

*continued*

contrast report condition. Each individual electrode is plotted as a row on the y-axis, while time (in seconds) is plotted on the x-axis. Only significant t values (5% FDR) are plotted in this figure. FDR, False discovery rate.

A significant main effect of R/NR ( $F_{(1,38)} = 45.35$ ,  $p < 0.001$ ,  $\eta^2 = 0.361$ ) was observed (Table 3). There was no significant difference among the factors Levels and Times, and no interaction effect of any pair of factors. As for the incidental memory tasks, participants reported significant lower perceived contrast of the Gabor gratings after the no-report condition than that after the report condition. This result supported to our hypothesis that the participants experienced degraded contents of consciousness during the no-report condition. Figure 3A shows the boxplot of the performances under these three factors. Figure 3B shows the result by averaging all factors.

### Experiment 1b

In the first report condition, participants correctly reported what they saw on 90.6% (SD = 0.27%) of the trials (Fig. 4A). In the incidental memory task, the mean perceived contrast of the Gabor gratings was 0.534. In the second report condition, participants correctly reported what they saw on 92.5% (SD = 0.28%) of the trials (Fig. 4B). In the second incidental memory task, the mean perceived contrast of the Gabor gratings for was 0.584.

There was no difference in perceived contrast ( $F_{(1,38)} = 2.689$ ,  $p = 0.109$ ,  $\eta^2 = 0.016$ , ANOVA) between the first and the second incidental memory task, suggesting that the results of experiment 1a were not caused by the order/learning effect. Figure 5A shows the box plot of the results and Figure 5B shows the result by averaging all factors.

### Experiment 2

#### *Behavioral results*

In the no-report condition, participants correctly reported seeing a green ring on 91.2% (SD = 0.54%) of trials (Fig. 6A). In the report condition, participants correctly reported seeing 45° incline Gabor gratings, 135° incline Gabor gratings, or blanks on 96.1% (SD = 0.19%) of trials (Fig. 6B). In the lower-contrast report condition, participants correctly reported seeing 45° incline Gabor grating, 135° incline Gabor grating, or blanks on 96.3% (SD = 0.23%) of trials (Fig. 6C).

For the incidental memory tasks after the first and third phases, a  $2 \times 2$  mixed design ANOVA was conducted (Table 4). Main effect of R/NR was observed ( $F_{(1,17)} = 4.63$ ,  $p = 0.046$ ,  $\eta^2 = 0.118$ , ANOVA). There was no significant difference between levels under the Levels factor ( $F_{(1,17)} = 2.427$ ,  $p = 0.138$ ,  $\eta^2 = 0.068$ , ANOVA), interaction effect of R/NR and Levels was not observed ( $F_{(1,17)} = 0.615$ ,  $p = 0.444$ ,  $\eta^2 = 0.017$ , ANOVA) either. Boxplot of the performances in these two factors was shown in Figure 7.

Since the stimuli in the lower-contrast report condition were different from the former two conditions, the results in the sixth phase were not included in the  $2 \times 2$  ANOVA test. Instead, we directly compared the average perceived

contrast in the sixth phase to that in the fourth phase. The perceived contrast in the sixth phase (average = 0.39, SD = 0.21) was significantly different from that in the fourth phase (average = 0.6, SD = 0.16), suggesting that the participants could accurately report contrast of the stimuli they saw in the report conditions (Fig. 8).

#### *EEG results*

*Hypothesis-driven analyses of the P3b.* In the first phase and the third phase, we manipulated the reportability of the stimuli. In the third phase and the fifth phase, we manipulated the perceived contrasts of the stimuli. ERP results within the phases were summarized in Figure 9 by plotting voltage distribution maps (stimuli minus blanks) from a series of time windows over all electrode locations. The early visual ERP P1 was clearly present in both report conditions, while N1 was uniquely present in the no-report condition. The P2 component over the frontoparietal scalp was apparent in all of the three conditions.

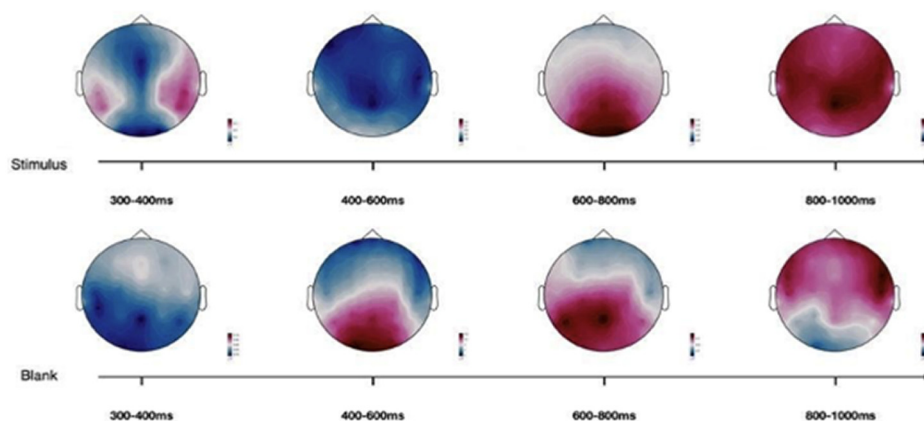
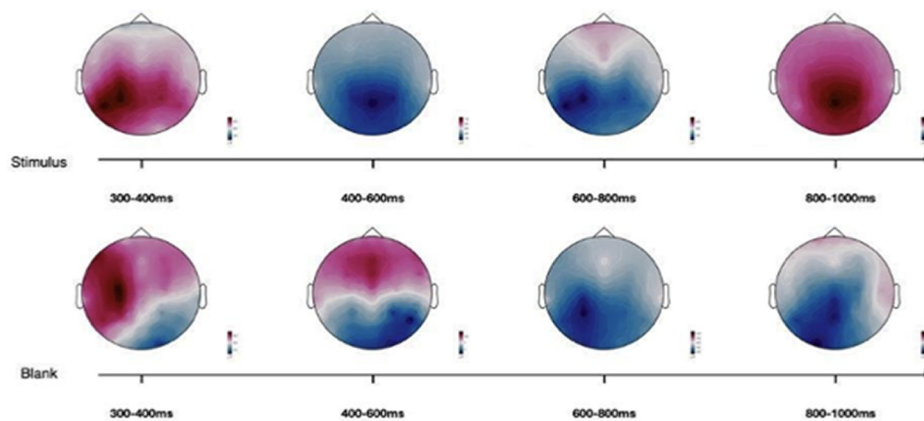
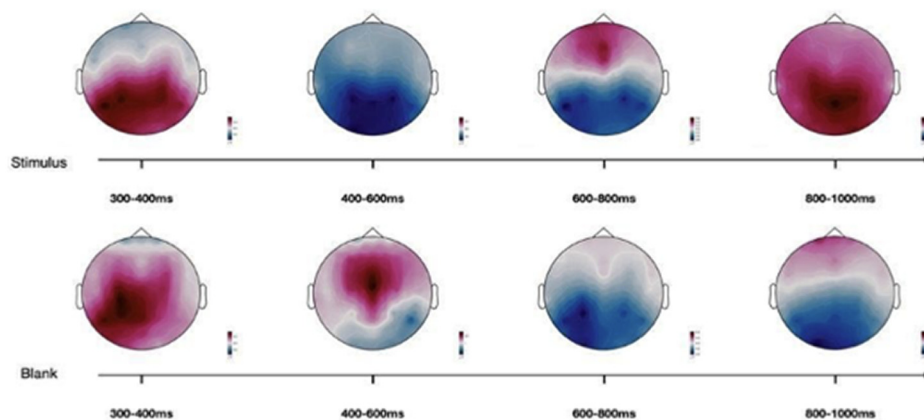
In the first comparison, significant main effects of stimulus presence ( $F_{(1,19)} = 8.53$ ,  $p = 0.009$ ,  $\eta^2 = 0.073$ , ANOVA) and reporting task ( $F_{(1,19)} = 7.361$ ,  $p = 0.014$ ,  $\eta^2 = 0.152$ , ANOVA) were observed. The interaction between stimulus presence and reporting task was also significant ( $F_{(1,19)} = 13.36$ ,  $p = 0.002$ ,  $\eta^2 = 0.024$ , ANOVA). In the second comparison, only the main effect of stimulus presence ( $F_{(1,19)} = 21.39$ ,  $p = 0.0002$ ,  $\eta^2 = 0.114$ , ANOVA) was observed. There was no main effect of perceived contrasts ( $F_{(1,19)} = 2.16$ ,  $p = 0.16$ ,  $\eta^2 = 0.012$ , ANOVA), and the interaction between stimulus presence and perceived contrasts was not observed ( $F_{(1,19)} = 0.058$ ,  $p = 0.81$ ,  $\eta^2 = 0.00006$ , ANOVA), either.

#### *Data-driven analyses*

In the no-report condition, amplitude differences were scattered and not as evident as the other two conditions. The differences concentrated at posterior P1, posterior P2, and anterior positivity around 900 ms. In both the report and the lower-contrast report conditions, amplitude differences were evident in the early (posterior P1; anterior P2) and late (posterior N400; posterior positivity, 800–100 ms) time windows. Unique to the report conditions, the P3b was evident from 300 to 400 ms, and the N400 was also evident from 400 to 600 ms (Fig. 10).

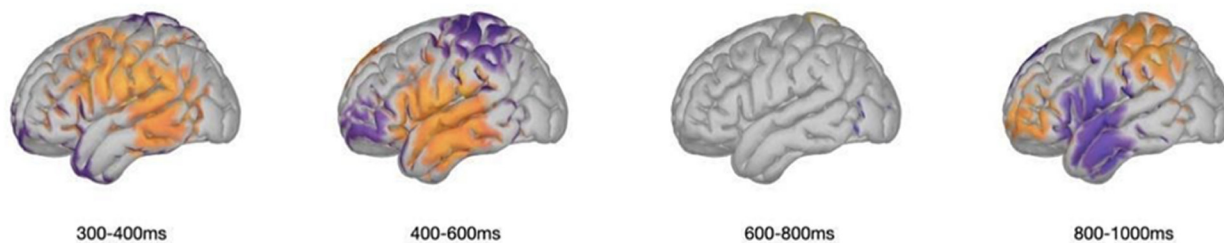
#### *Exploratory analyses and source analyses*

After replicating the results of P3b in Cohen et al. (2020), we further conducted exploratory analyses (Fig. 11) and source analyses (Fig. 12) to investigate the nature of the P3b. Patterns of the source estimation were shown in Figure 12. Between 300 and 400 ms, there were clear decreases in source activity in the parietal lobe in the no-report condition relative to the other two conditions. Similar patterns in the parietal lobe could be observed between 800 and 1000 ms, and opposite patterns could be seen between 400 and 600 ms. For the frontal lobe, clear decreases in source activity in the no-report condition relative to the other two

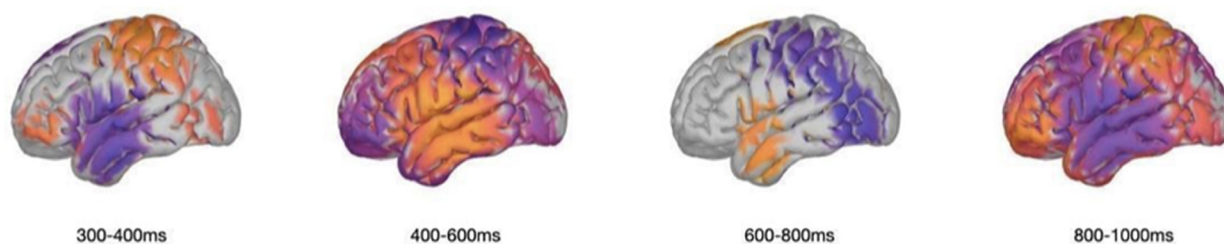
**A** No-report condition: stimulus vs. blank**B** Report condition: stimulus vs. blank**C** Lower-contrast report condition: stimulus vs. blank

**Figure 11.** ERP differences during late time windows revealed by exploratory analyses for all conditions. The topographical differential voltage distributions over a series of time windows starting at 300 ms and ending at 1000 ms are shown for all the conditions. **A**, No-report condition. **B**, Report condition. **C**, Lower-contrast report condition.

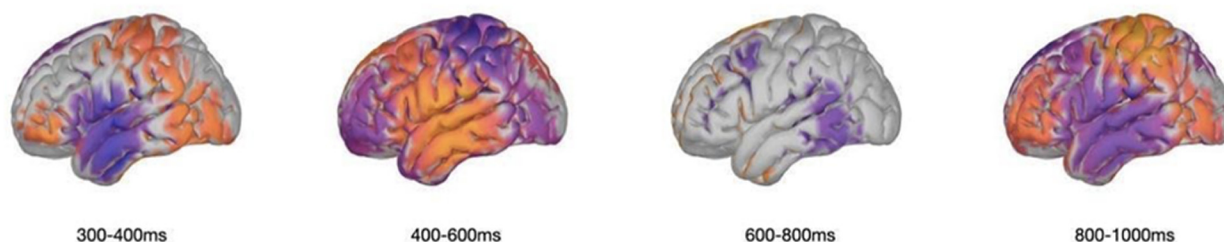
## A No-report condition: stimulus - blank



## B Report condition: stimulus - blank



## C Lower-contrast report condition: stimulus - blank



**Figure 12.** Source estimations of the differences between stimulus and blank for all conditions across four late time windows. **A**, No-report condition. **B**, Report condition. **C**, Lower-contrast report condition. The ERPs of the blank were served as the baseline, only differences bigger than  $2 \times 10^{-10}$  voltage are plotted on the lateral surface of the Montreal Neurologic Institute brain. Areas plotted by orange color reflect amplitudes of the stimulus bigger than amplitudes of the blank. For those areas colored by purple, the amplitudes of the stimulus were smaller than blank.

conditions could also be observed between 300 and 400 ms. Although source analyses from ERP data are imprecise and our experiment was not designed for optimized isolating sources, these findings could still be important as references for further investigations.

## Discussion

P3b, a subcomponent of P3, has been associated with a variety of perceptual and cognitive processes, including

novelty detection in oddball paradigms (Squires et al., 1975; Duncan-Johnson and Donchin, 1977; Knight and Scabini, 1998; Barceló et al., 2002; Debener et al., 2005; Fischer et al., 2008), workload processing in dual-task paradigms (Matthews et al., 2006; Johannes et al., 2001; Kok, 2001), uncertainty resolution in signal detection tasks (Sutton et al., 1965; Squires et al., 1973), recallability in incidental memory tasks (Donchin et al., 1986; Fabiani et al., 1986; Azizian and Polich, 2007), reaction time and completion time in speeded tasks (Polich et al.,

1983; Johnson et al., 1985; Emmerson et al., 1989; Pelosi et al., 1992a), expertise acquisition in learning tasks (Carrion and Bly, 2008; Seppänen et al., 2012; Morgan et al., 2016), etc. Some investigators also suggest P3b as a neural correlate of consciousness (Lamy et al., 2009; Dehaene and Changeux, 2011). However, this possibility has been challenged recently (Pitts et al., 2014; Shafto and Pitts, 2015; Cohen et al., 2020; Schröder et al., 2021).

In this study, we found that participants' perceived contrasts of an identical stimulus were lower in the no-report condition than in the report condition. Furthermore, these different perceived contrast levels did not induce different P3b amplitudes. Hence, our finding still supports the claim that P3b is *not* a signature of perceptual awareness but is associated with postperceptual processing.

For the early components, P1/N1 showed very different patterns between the no-report condition and the two report conditions. However, both P1 and N1 components did not differ between the report condition and the lower-contrast report condition. This difference could be caused by participants paying more attention to the stimulus in the report condition. These results were consistent to the pattern of P3b in the corresponding three conditions. In addition, there is a large section of overlap time period between P2 and P3a. P3a usually has a maximum amplitude over frontal/central electrode sites, and appeared to be correlated with the habituation and target discrimination (Soltani and Knight, 2000; Polich, 2007). In this study, the P2 (or P3a) component was present only when the participants could see the stimuli, which is consistent with the previous findings that P3a is associated with target discrimination.

There are a few limitations in the current study. For example, there is a possibility that the participants actually experienced the same contents of consciousness in both the no-report and the report conditions: the different performances we observed were merely because of faster declination of memory when less attended. However, this possibility appears to be inconsistent with the robust phenomenon that attention can alter subjective visual perception and arguably a mediating factor of consciousness (Hsieh et al., 2005; Ling and Carrasco, 2006; Carrasco et al., 2008). Also, it remains unknown whether the mechanisms are same or different when lower perceived contrasts were induced by less distributed attention versus weaker stimulus strength. Future experiments are required to investigate these possibilities.

## References

- Azizian A, Polich J (2007) Evidence for attentional gradient in the serial position memory curve from event-related potentials. *J Cogn Neurosci* 19:2071–2081.
- Baars BJ (1994) A thoroughly empirical approach to consciousness. *Psyche* 1.
- Barceló F, Cooper PS (2018) An information theory account of late frontoparietal ERP positivities in cognitive control. *Psychophysiology* 55:e12814.
- Barceló F, Periañez JA, Knight RT (2002) Think differently: a brain orienting response to task novelty. *Neuroreport* 13:1887–1892.
- Barton JJ (2011) Disorders of higher visual processing. *Handb Clin Neurol* 102:223–261.
- Block N (2007) Consciousness, accessibility, and the mesh between psychology and neuroscience. *Behav Brain Sci* 30:481–548.
- Brown EN, Lydic R, Schiff ND (2010) General anesthesia, sleep, and coma. *N Engl J Med* 363:2638–2650.
- Brown JA, Deng J, Neuhaus J, Sible IJ, Sias AC, Lee SE, Kornak J, Marx GA, Karydas AM, Spina S, Grinberg LT, Coppola G, Geschwind DH, Kramer JH, Gorno-Tempini ML, Miller BL, Rosen HJ, Seeley WW (2019) Patient-tailored, connectivity-based forecasts of spreading brain atrophy. *Neuron* 104:856–868.e5.
- Brydges CR, Barceló F (2018) Functional dissociation of latency-variable, stimulus- and response-locked target P3 sub-components in task-switching. *Front Hum Neurosci* 12:60.
- Carrasco M, Fuller S, Ling S (2008) Transient attention does increase perceived contrast of suprathreshold stimuli: a reply to Prinzmetal, Long, and Leonhardt (2008). *Percept Psychophys* 70:1151–1164.
- Carrasco M, Barbot A (2019) Spatial attention alters visual appearance. *Curr Opin Psychol* 29:56–64.
- Carrion RE, Bly BM (2008) The effects of learning on event-related potential correlates of musical expectancy. *Psychophysiology* 45:759–775.
- Cohen MA, Cavanagh P, Chun MM, Nakayama K (2012) The attentional requirements of consciousness. *Trends Cogn Sci* 16:411–417.
- Cohen MA, Ortego K, Kyroudis A, Pitts M (2020) Distinguishing the neural correlates of perceptual awareness and post-perceptual processing. *J Neurosci* 40:4925–4935.
- Craig AD (2010) The sentient self. *Brain Struct Funct* 214:563–577.
- Damasio A, Van Hoesen G (1983) Focal lesions of the limbic lobe. In: *Neuropsychology of human emotion* (Hellman K and Satz P, eds). New York: Guilford.
- Debenner S, Makeig S, Delorme A, Engel AK (2005) What is novel in the novelty oddball paradigm? Functional significance of the novelty P3 event-related potential as revealed by independent component analysis. *Brain Res Cogn Brain Res* 22:309–321.
- de Graaf TA, Hsieh PJ, Sack AT (2012) The 'correlates' in neural correlates of consciousness. *Neurosci Biobehav Rev* 36:191–197.
- Dehaene S, Naccache L (2001) Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. *Cognition* 79:1–37.
- Dehaene S, Changeux JP (2011) Experimental and theoretical approaches to conscious processing. *Neuron* 70:200e227.
- Dehaene S, Lau H, Kouider S (2017) What is consciousness, and could machines have it? *Science* 358:486–492.
- Donchin E, Karis D, Bashore TR, Coles MGH, Gratton G (1986) Cognitive psychophysiology: systems, processes, and applications. In: *Psychophysiology: systems, processes, and applications* (Coles MGH, Donchin E, and Porges S, eds), pp 244–267. New York: The Guilford Press.
- Duncan-Johnson CC, Donchin E (1977) On quantifying surprise: the variation of event-related potentials with subjective probability. *Psychophysiology* 14:456–467.
- Emmerson RY, Dustman RE, Shearer DE, Turner CW (1989) P3 latency and symbol digit performance correlations in aging. *Exp Aging Res* 15:151–159.
- Fabiani M, Karis D, Donchin E (1986) P300 and recall in an incidental memory paradigm. *Psychophysiology* 23:298–308.
- Farah M (2004) *Visual agnosia*. Cambridge: Massachusetts Institute of Technology.
- Fischer C, Dailier F, Morlet D (2008) Novelty P3 elicited by the subject's own name in comatose patients. *Clin Neurophysiol* 119:2224–2230.
- Frässle S, Sommer J, Jansen A, Naber M, Einhäuser W (2014) Binocular rivalry: frontal activity relates to introspection and action but not to perception. *J Neurosci* 34:1738–1747.
- George MS, Parekh PI, Rosinsky N, Ketter TA, Heilman KM, Herscovitch P, Post RM (1996) Understanding emotional prosody activates right hemisphere regions. *Arch Neurol* 53:665–670.

- Hesse JK, Tsao DY (2020) A new no-report paradigm reveals that face cells encode both consciously perceived and suppressed stimuli. *Elife* 9:e58360.
- Hsieh PJ, Caplovitz GP, Tse PU (2005) Illusory rebound motion and the motion continuity heuristic. *Vis Res* 45:2972–2985.
- Huth AG, Lee T, Nishimoto S, Bilenko NY, Vu AT, Gallant JL (2016) Decoding the semantic content of natural movies from human brain activity. *Front Syst Neurosci* 10:81.
- Johannes S, Wieringa BM, Nager W, Müller-Vahl KR, Dengler R, Münte TF (2001) Electrophysiological measures and dual-task performance in Tourette syndrome indicate deficient divided attention mechanisms. *Eur J Neurol* 8:253–260.
- Johnson R Jr, Pfefferbaum A, Kopell BS (1985) P300 and long-term memory: latency predicts recognition performance. *Psychophysiology* 22:497–507.
- Knight RT, Scabini D (1998) Anatomic bases of event-related potentials and their relationship to novelty detection in humans. *J Clin Neurophysiol* 15:3–13.
- Koch C, Massimini M, Boly M, Tononi G (2016) Neural correlates of consciousness: progress and problems. *Nat Rev Neurosci* 17:307–321.
- Kok A (2001) On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology* 38:557–577.
- Kozuch B (2014) Prefrontal lesion evidence against higher-order theories of consciousness. *Philos Stud* 167:721–746.
- Lamy D, Salti M, Bar-Haim Y (2009) Neural correlates of subjective awareness and unconscious processing: an ERP study. *J Cogn Neurosci* 21:1435–1446.
- Lau H, Rosenthal D (2011) Empirical support for higher-order theories of conscious awareness. *Trends Cogn Sci* 15:365–373.
- Ling S, Carrasco M (2006) When sustained attention impairs perception. *Nat Neurosci* 9:1243–1245.
- Lumer ED, Rees G (1999) Covariation of activity in visual and prefrontal cortex associated with subjective visual perception. *Proc Natl Acad Sci U S A* 96:1669–1673.
- Markowitsch HJ, Kessler J (2000) Massive impairment in executive functions with partial preservation of other cognitive functions: the case of a young patient with severe degeneration of the prefrontal cortex. *Exp Brain Res* 133:94–102.
- Marzecová A, Widmann A, SanMiguel I, Kotz SA, Schröger E (2017) Interrelation of attention and prediction in visual processing: effects of task-relevance and stimulus probability. *Biol Psychol* 125:76–90.
- Mataró M, Jurado MA, García-Sánchez C, Barraquer L, Costa-Jussà FR, Junqué C (2001) Long-term effects of bilateral frontal brain lesion: 60 years after injury with an iron bar. *Arch Neurol* 58:1139–1142.
- Matthews A, Garry MI, Martin F, Summers J (2006) Neural correlates of performance trade-offs and dual-task interference in bimanual coordination: an ERP investigation. *Neurosci Lett* 400:172–176.
- Morgan KK, Luu P, Tucker DM (2016) Changes in P3b latency and amplitude reflect expertise acquisition in a football visuomotor learning task. *PLoS One* 11:e0154021.
- Neisser J (2012) Neural correlates of consciousness reconsidered. *Conscious Cogn* 21:681–690.
- Noy N, Bickel S, Zion-Golumbic E, Harel M, Golan T, Davidesco I, Schevon CA, McKhann GM, Goodman RR, Schroeder CE, Mehta AD, Malach R (2015) Ignition's glow: ultra-fast spread of global cortical activity accompanying local "ignitions" in visual cortex during conscious visual perception. *Conscious Cogn* 35:206–224.
- Overgaard M (2004) Confounding factors in contrastive analysis. *Synthese* 141:217–231.
- Panagiotaropoulos TI, Deco G, Kapoor V, Logothetis NK (2012) Neuronal discharges and gamma oscillations explicitly reflect visual consciousness in the lateral prefrontal cortex. *Neuron* 74:924–935.
- Pelosi L, Holly M, Slade T, Hayward M, Barrett G, Blumhardt LD (1992) Event-related potential (ERP) correlates of performance of intelligence tests. *Electroencephalogr Clin Neurophysiol* 84:515–520.
- Penfield W, Jasper HH (1954) *Epilepsy and the functional anatomy of the brain*. Boston: Little Brown.
- Pitts MA, Padwal J, Fennelly D, Martínez A, Hillyard SA (2014) Gamma band activity and the P3 reflect post-perceptual processes, not visual awareness. *Neuroimage* 101:337–350.
- Pitts MA, Lutsyshyna LA, Hillyard SA (2018) The relationship between attention and consciousness: an expanded taxonomy and implications for 'no-report' paradigms. *Philos Trans R Soc Lond B Biol Sci* 373:20170348.
- Polich J, Howard L, Starr A (1983) P300 latency correlates with digit span. *Psychophysiology* 20:665–669.
- Polich J (2007) Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology* 118:2128–2148.
- Porcaro C, Balsters JH, Mantini D, Robertson IH, Wenderoth N (2019) P3b amplitude as a signature of cognitive decline in the older population: an EEG study enhanced by functional source separation. *Neuroimage* 184:535–546.
- Quiroga RQ (2012) Concept cells: the building blocks of declarative memory functions. *Nat Rev Neurosci* 13:587–597.
- Sardari S, Pourrahimi AM, Talebi H, Mazhari S (2019) Symmetrical electrophysiological brain responses to unilateral and bilateral auditory stimuli suggest disrupted spatial processing in schizophrenia. *Sci Rep* 9:16454.
- Schröder E, Kajosch H, Verbanck P, Kornreich C, Campanella S (2016) Methodological considerations about the use of bimodal oddball P300 in psychiatry: topography and reference effect. *Front Psychol* 7:1387.
- Schröder P, Nierhaus T, Blankenburg F (2021) Dissociating perceptual awareness and postperceptual processing: the P300 is not a reliable marker of somatosensory target detection. *J Neurosci* 41:4686–4696.
- Seppänen M, Pesonen AK, Tervaniemi M (2012) Music training enhances the rapid plasticity of P3a/P3b event-related brain potentials for unattended and attended target sounds. *Atten Percept Psychophys* 74:600–612.
- Seth AK, Suzuki K, Critchley HD (2012) An interoceptive predictive coding model of conscious presence. *Front Psychol* 2:395.
- Shaffo JP, Pitts MA (2015) Neural signatures of conscious face perception in an inattentive blindness paradigm. *J Neurosci* 35:10940–10948.
- Siclari F, Baird B, Perogamvros L, Bernardi G, LaRocque JJ, Riedner B, Boly M, Postle BR, Tononi G (2017) The neural correlates of dreaming. *Nat Neurosci* 20:872–878.
- Soltani M, Knight RT (2000) Neural origins of the P300. *Crit Rev Neurobiol* 14:199–224.
- Squires KC, Hillyard SA, Lindsay PH (1973) Vertex potentials evoked during auditory signal detection: relation to decision criteria. *Percept Psychophys* 14:265–272.
- Squires NK, Squires KC, Hillyard SA (1975) Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. *Electroencephalogr Clin Neurophysiol* 38:387–401.
- Sutton S, Braren M, Zubin J, John ER (1965) Evoked-potential correlates of stimulus uncertainty. *Science* 150:1187–1188.
- Tadel F, Baillet S, Mosher JC, Pantazis D, Leahy RM (2011) Brainstorm: a user-friendly application for MEG/EEG analysis. *Comput Intell Neurosci* 2011:879716.
- von Arx SW, Müri RM, Heinemann D, Hess CW, Nyffeler T (2010) Anosognosia for cerebral achromatopsia—a longitudinal case study. *Neuropsychologia* 48:970–977.