# Highest performance requires an optimal effort: A MEG study on visual perception

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***Abstract*—Twelve subjects (6 males; 17-64 years) participated in magnetoencephalography (MEG) experiments designed to study visual response to flickering Necker cubes. Event-related fields in the lateral occipital complex and steady-state response in the visual region V1 and V2 were studied to characterise the early response time durations and attentional capacity during the trial time period of 5-s, respectively. We found that there was an optimal response time duration for which the attention capacity was maximum. The results also support the hypothesis that stimulus detection in brain is driven by coherence resonance.**

***Index Terms*—evoked response, lateral occipital, v1, v2, attention, coherence resonance**

## I. Introduction

An electrical potential with a specific waveform recorded from a specific part of the nervous system, such as the brain, following the presentation of a stimulus is called evoked potential (EP). Different types of potentials are observed depending upon the different modalities and types of stimuli [1]. Visual evoked potentials (VEP) are recorded from the central nervous system following stimulation of eyes using stimuli such as flashing light or changing pattern on a monitor [2].

An EP measured in the brain is termed as an event-related potential (ERP). It demonstrates stereotyped electrophysiological response to a specific sensory, cognitive, or motor-event. Since the signal is time-locked to the stimulus, repeated responses are often averaged out to improve the signal-to-noise ratio [3]. ERPs are measured using electroencephalography (EEG), while corresponding responses that are observed in the magnetic field surrounding the brain's electrical activity can be observed using magnetoencephalography (MEG) which are termed as event-related fields (ERF). These ERP/ERF waveforms consist of a series positive or negative deflections or components which are related to the underlying stages of brain response to the stimulus. It is common practice to label these deflections by a letter (N/P) indicating polarity (negative/positive), followed by a number indicating either the latency in milliseconds or the deflection's ordinal position in the ERP/ERF waveform. Although, the stated latencies for ERP components are often quite variable. For example, the P300 component can be observed anywhere between 250 ms – 700 ms. Some components are also referred to using acronyms of the identified processes they are related to, such as error-related negativity - ERN or contingent negative variation - CNV.

A popular region in brain to study visual response is the *lateral occipital complex (LO)* coined in the interesting review of functional magnetic resonance imaging (fMRI) studies, which demonstrate the region's lead role in object recognition [4]. This area includes parts of lateral occipital cortex, ventral occipito-temporal area, posterior and mid fusiform gyrus, and occipito-temporal sulcus. Studies based on ERPs on the LO have shown stronger ERP components for identifiable objects than to scrambled images [5]–[8]. Recently, Mikhailova, Gerasimenko and Prokudin [9] found P100 and N150 responses in the evoked response in the visual cortex in an experiment requiring the subject to match between the current and stored-in-memory orientations. to visual stimulus. The amplifications of the P100 and N150 components were found to be mismatch indicators. They used two kinds of patterns for stimuli, namely, rectangular grids of different orientations and modified chess patterns. N150 amplification occurred in both stimulus patterns, whereas P100 amplification only occurred in the rectangular grid stimulus. P100 corresponded to the early visual response due to the detection of an object whereas N150 was related to the stage of sensory categorisation.

Similarly, most studies that are based on ERPs are often only interested in the change in amplitudes of ERP components with a change in experimental condition. In our opinion it is equally, if not more, informative to study the change in the relative occurence in time of these components. Therefore in this paper, we study ERPs from the presentation of visual stimulus using the average activity from LO. Instead of focusing on the amplitude of ERP components, we will focus on the time interval between these components to characterise the duration of the early response.

Another interesting direction in the research on visual perception is that of noise-assisted detection of weaker stimulus. *Coherence resonance (CR)* can be defined as the phenomenon whereby addition of certain amount of noise in an excitatory

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system makes the oscillatory response of the system most coherent. Andreev, Makarov, Runnova, Pisarchik and Hramov [10] studied coherence resonance phenomenon in a network of globally coupled Rulkov neural oscillators with randomly distributed coupling strengths under the influence of intrinsic noise. A subpopulation of variable size that was coupled all-to-all with the rest of the network was stimulated and the coherence of the macroscopic response for the whole network was measured. They found that there exists an optimal size of stimulated neuronal network, or optimal amount of noise as each added neuron brings its own noise to the system, for which the coherence of the larger global network was maximum. Subsequently, Pisarchik et al. [11] found experimental evidence of such coherence resonance in their electroencephalography (EEG) experiments based on visual stimulation in human subjects.

Frequency-tagged stimuli can be used to elicit brain response at particular frequencies in the visual cortex and other areas [12]. This corresponds to the global network discussed above. There would be a smaller subpopulation that first receives the stimulus signal and then transmits it to the rest of the network. The early response in the LO showing the ERP components would reflect properties of this smaller subpopulation. Using such an experiment, we present our findings on the relation between the response of the two populations and test the hypothesis that detection of visual stimuli is driven by CR.

## II. Materials and methods

MEG experiments were performed on twelve healthy subjects (6 males; 17-64 years) with normal or corrected-to-normal vision using frequency-tagged stimulus to study both the early and the steady-state response of the brain. All subjects signed a written informed consent before the commencement of the experiment. The experiments were performed in accordance with the Declaration of Helsinki.

### A. Experimental setup

Neurophysiological data were recorded with a whole-head Vectorview Elekta AB MEG system with 306 channels. The machine is placed inside a magnetically shielded space at the Laboratory of Cognitive and Computational Neuroscience, Center for Biomedical Technology, Technical University of Madrid, Spain. Polhemus fastrak digitizers were used to obtain the three-dimensional head shape of each subject using approximately 300 points on the scalp which could be later used to warp the subject's anatomy on a default MRI. Four head position indicator (HPI) coils were attached to the subject's head to compensate for head movements inside the machine. Additionally, three fiducial points, namely, nasion, left- and right-preauricular were acquired for co-registration of all channels and HPI coils. A vertical electrooculogram was placed on the left eye to capture blinks. A single empty room recording of more than two-minutes duration was performed on each day of the experiment (Day-1: 4 subjects; Day-2: 5 subjects; Day-3: 3 subjects). Data were sampled at 1000 Hz with an online anti-alias bandpass filter between 0.1 Hz and 330 Hz.

### B. Stimuli

An image of a grey bistable Necker cube was presented on a grey background using a projected image from a personal computer with 60 Hz monitor frame rate. The image was projected onto a translucent screen located 150 cm away from the subject. The pixels' brightness of the left and right cube faces was modulated using a sinusoidal signal with 60/9 and 60/7 Hz frequencies, respectively. The particular two frequencies were chosen as they showed the strongest frequency tags in the visual cortex among twelve trial frequencies in a previous study [12]. The modulation depth was 100% with respect to the medium greyscale level of the background. The edges of the cube remained white and thus clearly visible at all times. A parallel port channel was used to mark important events directly in the MEG recordings. Due to uncontrollable delays inside the computer and the projector, there was a delay between the triggers and the actual presentation of stimulus. This delay was later calculated using a photodiode and it came out to be about 56 ms. This delay was later fixed while analysing the data.

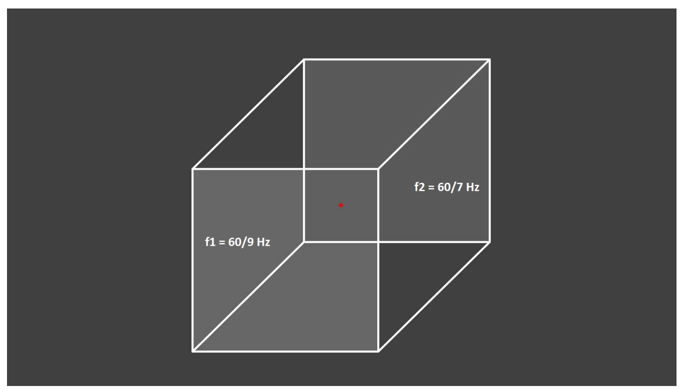


Fig. 1. A snapshot of flickering stimulus.

### C. Task

The subjects were sat in a comfortable reclining chair with their legs straight and arms resting on an armrest in front or on their laps. The participants were asked to remove any metallic items above their waist like jewelry, belts, and brassieres, along with their shoes before the experiment. The experiment began with the recording of a two-minute background activity while the subject was focusing on a red dot at the middle of a stationary (non-flickering) cube image. This MEG trial acted as a background reference for further measurements.

After a 30-s rest and an instructional visual message, the flickering Necker cube with two frequencies was presented 24 times on the screen. Each of the 24 trials lasted for 5-s with a 5-s rest in between. For the first 12 trials, the participants were informed through the visual message to interpret the cube as either left- or right-oriented. After a 30-s rest and another instructional visual message, the participants were requested to interpret the next 12 cubes in the opposite orientation to before.

### D. Evoked and induced response

Data analysis was performed with Brainstorm [13], which is documented and freely available for download online under the GNU general public license (http://neuroimage.usc.edu/brainstorm).

For calculating the evoked response, all 24 trials were averaged. We modeled the brain using a mesh of about 15000 points on the cortical surface. The mapping of measured magnetic activity from 306 channels to 15000 sources was done using the minimum norm approach. The normalisation of depth-dependent sensitivity and spatial resolution was done using the standardized Low-Resolution Electromagnetic Tomography (sLORETA) method. The obtained source activity was then averaged over the sources corresponding to the LO.

For the induced or steady-state response which is not time-locked uniformly to the start of stimulation for all trials, we dealt with each trial separately. After projecting the MEG channel activity to the source space with 15000 sources, we averaged the activity over the cortical sources corresponding to the visual areas V1 and V2. The coherence of this visual network was computed as described in [14]. The general idea is that while focusing on the left-oriented cube, the spectral energy of the left face frequency (f1) should be higher than the right face frequency (f2), and vice versa. The larger the difference between the spectral energies, the more coherent the brain activity in the given network. This coherence will be denoted by $\mu$. It is also important to note that this coherence is a reflection of the participant's performance in attending to the designated cube orientation for the entire trial period.

The cortical sources associated with the LO, and visual areas V1 and V2 on the modelled cortical mesh were found using the Desikan-Killany and Brodmann atlases in Brainstorm, respectively.

## III. Results and Discussion

The ERP in LO showed 3 prominent components, namely, P200, N250, N400. Fig.2 shows the global average of the ERPs of all subjects.

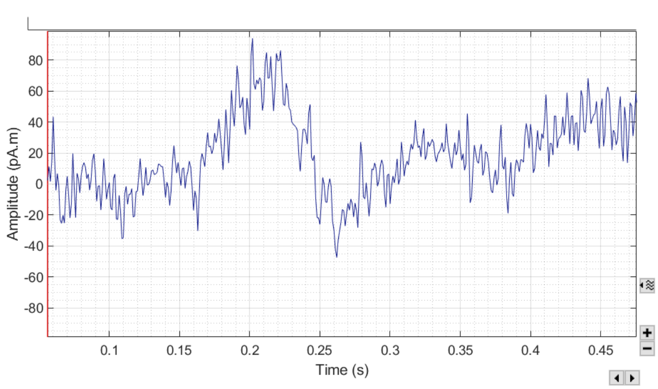


Fig. 2. Evoked response in LO averaged over all subjects.

Table I shows the exact latencies of these components for all the subjects in seconds. As we can see in the table, these peaks for all subjects take a wide variety of values centred around 200-, 250- and 400-ms.

TABLE I
ERP component latencies (in seconds)

| Subject | P200 | N250 | N400 |
|---|---|---|---|
| A | 0.197 | 0.264 | 0.462 |
| B | 0.193 | 0.257 | 0.400 |
| C | 0.192 | 0.267 | 0.385 |
| D | 0.233 | 0.357 | 0.559 |
| E | 0.187 | 0.305 | 0.534 |
| F | 0.156 | 0.235 | 0.478 |
| G | 0.216 | 0.265 | 0.447 |
| H | 0.225 | 0.282 | 0.370 |
| I | 0.214 | 0.254 | 0.385 |
| J | 0.177 | 0.243 | 0.317 |
| K | 0.216 | 0.256 | 0.411 |
| L | 0.167 | 0.211 | 0.400 |

Normalised histograms of the 3 latencies for all the subjects were obtained as shown in Fig. 3. Normalisation was done by subtracting the mean value for all subjects and subsequently dividing by the standard deviation of the same. The sharpness of unimodal distributions such as this one is often characterised using Kurtosis (K) which happens to take the value of $K = 3$ for Gaussian distribution. The N250 latency was found to be the most regular across all subjects with $K = 4.4$. Whereas, the $K$ for the P200 and N400 latencies were even lower than Gaussian distribution and equal to 2.0 and 2.5, respectively.

For some subjects the evoked response lasted shorter than 200-ms ($400 - 200 = 200$), i.e. the time interval between P200 and N400 was shorter. While for some other subjects, it lasted longer. We call this time interval as *early-response time duration (ERTD)*.

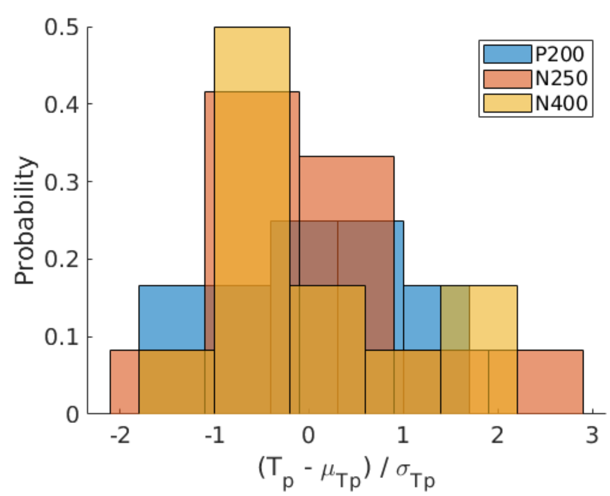


Fig. 3. Histogram of the P200, N250 and N400 latencies for all subjects.

We found that the coherence ($\mu$) of the visual cortex of the subjects over the entire 5 seconds reached a maximum for an optimal value of ERTD which also happens to be close to the ideal case of 200-ms as can be seen in Fig. 4. Note that the data point corresponding to subject-G was removed from this figure as the subject reported claustrophobia and subsequent distraction during the experiment.

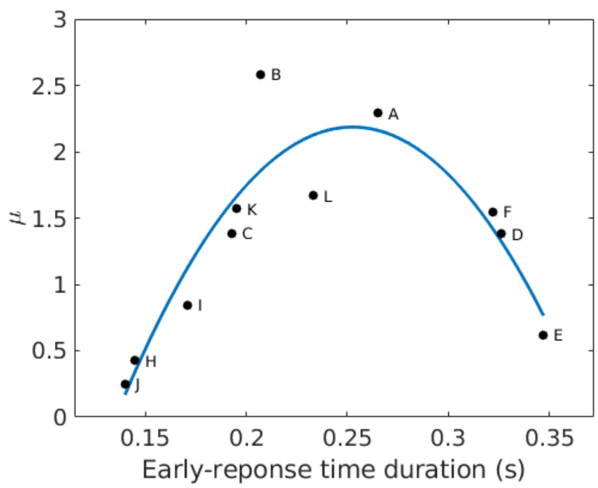


Fig. 4. Coherence ($\mu$) versus early-response time duration.

The brain is known to dynamically adjust its functional neuronal network structure to enhance the sensory processing efficiency. We have chosen to study brain response in two overlapping regions, LO and visual areas V1 and V2 (V12). LO is a smaller subnetwork that receives the input from the eyes first and then transmits to the larger visual network V12. The ERP component latencies and the time duration in which they begin and end (ERTD) must depend upon the size of active neurons in the LO as each participating neuron adds delay to the collective response of the LO subpopulation. Finding that there is an optimal value of ERTD, corresponding to a certain intermediate size of the LO subnetwork, at which there is maximum coherence in the overall activity of the larger global network V12 supports the CR driven stimulus detection hypothesis.

## IV. Conclusions

Flickering Necker cube experiments using MEG were performed on 12 participants. Evoked and steady-state responses in the visual cortex were calculated and compared in overlapping neuronal networks. We found an optimal response time in the evoked response that leads to better attentional performance seen through the steady-state response. Our results also support the hypothesis that detection of stimulus in brain is driven by coherence resonance.

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