



## The fixation-related lambda response: Effects of saccade magnitude, spatial frequency, and ocular artifact removal



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### ABSTRACT

Fixation-related potentials (FRPs) enable examination of electrophysiological signatures of visual perception under naturalistic conditions, providing a neural snapshot of the fixated scene. The most prominent FRP component, commonly referred to as the lambda response, is a large deflection over occipital electrodes (O1, Oz, O2) peaking 80–100 ms post fixation, reflecting afferent input to visual cortex. The lambda response is affected by bottom-up stimulus features and the size of the preceding saccade; however, prior research has not adequately controlled for these influences in free viewing paradigms. The current experiment (N = 16, 1 female) addresses these concerns by systematically manipulating spatial frequency in a free-viewing task requiring a range of saccade sizes. Given the close temporal proximity between saccade related activity and the onset of the lambda response, we evaluate how removing independent components (IC) associated with ocular motion artifacts affects lambda response amplitude. Our results indicate that removing ocular artifact ICs based on the covariance with gaze position did not significantly affect the amplitude of this occipital potential. Moreover, the results showed that spatial frequency and saccade magnitude each produce significant effects on lambda amplitude, where amplitude decreased with increasing spatial frequency and increased as a function of saccade size for small and medium-sized saccades. The amplitude differences between spatial frequencies were maintained across all saccade magnitudes suggesting these effects are produced from distinctly different and uncorrelated mechanisms. The current results will inform future analyses of the lambda potential in natural scenes where saccade magnitudes and spatial frequencies ultimately vary.

### 1. Introduction

Electrophysiological mechanisms of visual perception are often investigated by having participants discriminate features of stimuli without moving their eyes. In these tasks the spatial and temporal properties of the stimuli are predetermined by the experimenter. A clear benefit of constraining eye gaze position to a single location is that the neural signals of interest are not masked by the large ocular artifacts evoked during eye movements. While this approach has yielded many insights into the neural mechanisms of visual perception and attention, it does not represent how we typically acquire information in our day to day interactions with the environment. That is, we actively select visual information through saccade generation rather than waiting for stimuli to appear in the fovea.

Given this, eye movements should be exploited rather than restricted to examine electrophysiological signatures of visual perception under naturalistic conditions. A growing body of literature has now demonstrated the usefulness of combining synchronous recordings of gaze position and EEG to investigate multiple stages of cortical processing in the presence of eye movements (e.g. Nikolaev et al., 2013; Nikolaev et al., 2016; Plöchl et al., 2012; Ries et al., 2016; Touryan

et al., 2017). In this framework, saccades and fixations determined from an eye tracking system provide unique time-locking events in the EEG record. Saccade and fixation-locked neural activity can be parsed and averaged to create saccade and fixation-related potentials (SRPs, FRPs) respectively. These potentials can then be used to explore the effects of exogenous (e.g. stimulus manipulations) and endogenous (e.g. behavioral goals, saccade size or fixation duration) factors on the evoked response.

The fixation-related potential (FRP) receiving the most attention over the years is the lambda complex. The lambda complex is thought to consist of multiple neural components associated with both the onset and offset of the saccade (Thickbroom et al., 1991; Yagi, 1979b). The most prominent of these components is referred to as the lambda response, or lambda potential, which is a positive deflection (when using an average mastoid reference) over occipital electrodes O1, Oz, O2 peaking 80–100 ms post fixation. The lambda response reflects the afferent input of visual information at fixation to visual cortex (Billings, 1989; Thickbroom et al., 1991; Yagi, 1979b). While the amplitude of the lambda response is positively correlated with prior saccade magnitude (Dandekar et al., 2012; Dimigen et al., 2011; Yagi, 1979b) the latency of the response is not significantly affected by saccade size,

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when time-locked to fixation onset, indicating this component primarily reflects fixation-related visual processing (Yagi, 1979b, 1979a, 1981).

Prior work indicates the lambda response is also affected by top-down mechanisms and may be used as a natural index of visual information processing related to working memory load and/or attentional allocation (e.g. Kazai and Yagi, 2003; Yagi et al., 1998; Ries et al., 2016). For example, a recent study by Ries et al., 2016 showed auditory working memory load significantly attenuated lambda response amplitude under high with respect to low load conditions. However, there are still considerable gaps in our understanding of this potential that need to be addressed. While prior research has shown the lambda response is modulated by stimulus features (at fixation) and size of the preceding saccade, prior studies have not adequately controlled for these manipulations in free viewing paradigms. In particular, an earlier study examined visual responses after saccades across different spatial frequencies (Armington and Bloom, 1974), however the limited scope of the study (i.e. no significance testing, three participants, and horizontal saccades  $< 1^\circ$  of visual angle) constrains the generalizability of the results.

Clearly, the natural visual environment consists of a complex ensemble of spatial frequencies, in addition to other low-level visual features, and free viewing visual search inevitably produces a broad distribution of saccade magnitudes and directions. Thus, quantifying how these key factors affect the lambda response is essential to our understanding of how information is processed across eye movements in everyday situations. We address this concern in the current experiment by systematically manipulating spatial frequency in a free viewing task that naturally engenders a range of saccade sizes.

Addressing this research question requires a careful and unbiased quantification and correction of the ocular artifacts, produced during saccades, in the EEG record. Independent component analysis (ICA) has been most frequently used to identify and remove these ocular artifacts. Commonly, independent components (ICs) corresponding to ocular artifacts have been selected and removed using subjective criteria; however, a recent approach gaining in popularity, uses an objective algorithm to reject ICs based on their covariance with simultaneously recorded eye-tracking data (Plöchl et al., 2012). While this algorithm has been used in prior FRP investigations to remove ocular artifact (Ehinger et al., 2015; Ries et al., 2016; Simola et al., 2015), it is unclear whether this approach also removes some of the cortical processing indexed by the lambda response. It is therefore necessary to evaluate the impact of this algorithm on the lambda response given the close temporal proximity between perisaccadic activity and the onset of this potential.

The following study addresses the concerns above by focusing on three specific aims: 1) quantifying the influence of spatial frequency on lambda response amplitude, 2) replicating and expanding upon prior research demonstrating the relationship between saccade size and lambda response amplitude and 3) evaluating lambda response amplitude before and after removing ICs that co-vary with saccade activity. Given the close association between the lambda response and the P1 ERP we hypothesize an inverse relationship between lambda response amplitude and spatial frequency (e.g. Hansen et al., 2016). Likewise, we expect to observe a positive relationship between prior saccade magnitude and lambda amplitude, as has been previously reported (e.g. Nikolaev et al., 2016; Yagi, 1979b). Finally, if removing ICs identified by the approach described above removes only ocular artifacts related to eye and eyelid movements, then the amplitude of the lambda potential should not be significantly altered.

## 2. Methods

### 2.1. Participants

Eighteen civilians (3 female) from the Army Research Laboratory

performed a free-viewing search task in a dimly lit, sound attenuated chamber. Data from two participants were removed due insufficient trial numbers available for averaging (see Data Processing below). Therefore, all analyses were performed on a sample size of 16 participants. Of the 16 participants all had normal or corrected to normal vision (based on demographic questionnaire responses), 1 was female and the average age was 34.75 years. This study was conducted in accordance with the declaration of Helsinki and the U.S. Army Research Laboratory's IRB requirements (32 CFR 219 and DoDI 3216.02). The voluntary, fully informed consent of research participants was obtained in written form. The study was reviewed and approved by the U.S. Army Research Laboratory's IRB before the study began. Participants were recruited through informational fliers posted in a work environment as well as through an email sent to all Human Research and Engineering employees at the U.S. Army Research Laboratory. Participants were chosen in the order they replied until we reached our a priori designated sample size. To our knowledge there is no literature demonstrating gender differences in FRP amplitude or latency, however, the low number of female participants in the present study may limit the generalizability of the results.

### 2.2. Stimuli and procedure

The task was implemented in MATLAB (Mathworks, Natick, MA) using the Psychophysics toolbox (Brainard, 1997) and presented on a gamma corrected  $2560 \times 1440$  Acer XB271HU monitor with a 120 Hz refresh (Windows 7 64-bit, Nvidia GeForce GTX 660 video card, Intel i7-4770 K 4-core 3.5 GHz CPU, 16 GB RAM). Participants were comfortably seated 98 cm from the monitor using a chinrest to minimize head movement. Each trial began with a blue '+' sign randomly located in one of the four corners of the display. After fixating this location for 1.6 s, a search display was presented containing two of each 1.5, 3, 6, and 12 cycles per degree (cpd) spatial frequency Gabor stimuli. Each stimulus subtended  $2^\circ$  visual angle on a medium gray background (RGB 128,128,128) Fig. 1. To control for potential luminance contrast effects, each Gabor was presented at 60% Michelson contrast. Inter-stimulus distance was manipulated to ensure a range of saccade sizes with the

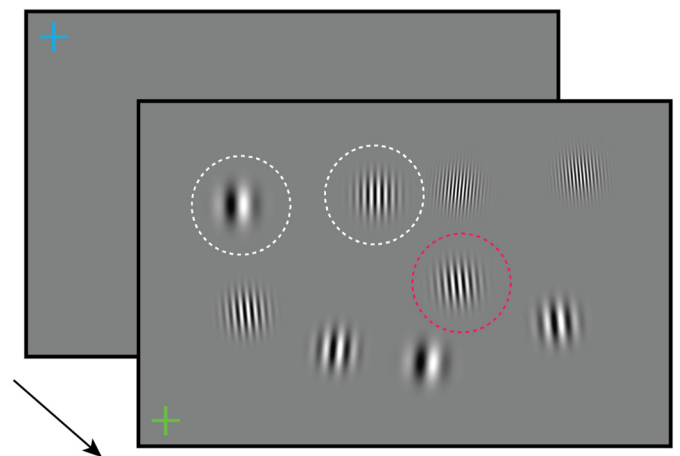


Fig. 1. Free-viewing paradigm. Participants initiated each trial by fixating the blue cross randomly located in one of four corners of the screen. Next, an array of static Gabor patterns appeared at various positions. Participants were instructed to fixate each pattern and make a button press when a target (vertically oriented pattern) was detected. Target stimuli are indicated by the dashed white circles. A subset of trials contained an additional transient Gabor stimulus indicated by the dashed red circle. Circles are used for illustrative purposes only and were not present during the experiment. After fixating each stimulus, the participant ended the trial by fixating the green cross randomly located in one of the four corners of the screen. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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