Lambda response as an index of visual perception research

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On the basis of the result that the lambda response was associated with the offset of the saccade, EEGs were averaged at the offsets of saccades to obtain the lambda responses under the following four conditions: in the dark, looking at a white paper, looking at a map, and searching on the map. Six subjects were permitted to move their eyes freely. It was found that the lambda response showed the tendency similar to the visual evoked potential. The offset averages enabled more accurate detection of the responses than did the onset averages in earlier studies. It was therefore discussed that the lambda response might be applicable as a new index of research on visual activity with free eye movements.

Key words: electroencephalogram (EEG), lambda responses, lambda waves, eye movements, saccades, visual perception, visual information processing.

Lambda responses are obtained with averaging EEGs time-locked to saccades. In early works (see Barlow & Ciganek, 1969), the lambda response was interpreted as a cortical response to retinal stimulation that results from shifting of the image across the retina as the fixation point of gaze is shifted. According to the interpretation, the lambda response should be associated with onset of the saccade. EEGs have been practically time-locked to onset of saccades (Barlow & Ciganek, 1969; Scott & Bickford, 1969; Ohtani & Yagi, 1972; Lesèvre & Rémond, 1973). During the saccade, however, the subject does not have a perception of blur nor shift of an image of the background due to saccadic suppression.

Recently, Yagi (1979a, b) found that the lambda response is associated with offset of the saccade but not with onset. The duration of the saccade is not constant when the subject observes the stimulus object freely (Yarbus, 1967). Therefore, EEGs should be time-locked to offset of saccades in order to obtain the accurate lambda responses. Since the moment of offset of the saccade is the beginning of the next fixation, the lambda response could be considered as the response evoked by the afferent inflow beginning at the fixation pause.

In studies on the relationship between visual perception and the visual evoked potential (VEP), the movements of eyes are usually very restricted. The situation where the subject have to keep fixation to a given point for a long period is very abnormal in daily life. On the other hand, eye movements allow detection of lambda responses. Therefore, the lambda response may be applied as an index of the visual activity with eye movements.

The VEP varies not only with physical properties of the stimulus but also with psychological factors. If the lambda response is equivalent to the VEP, the lambda response should also change with such effects. We developed a system averaging EEGs at offset of saccades in order to obtain accurate lambda responses (Yagi, 1980). The purposes of
the present experiment are to obtain the lambda responses time-locked to offset of saccades in several free eye movement situations and examine the application of the lambda responses to the research on perception.

Methods

Subjects

Subjects were six normal adults aged 26 to 30 years old. They were ignorant of the purpose of the experiment.

Procedure

After electrode placement, each subject was seated in the sound proof shielded room. The experimental conditions are as follows:

Dark. The room was kept dark. The subject was instructed to open his eyes and to move them freely even though he could see nothing.

White paper. The light was turned on. He faced 110 × 60 cm sheet of white paper placed about 50 cm in front of his eyes. The subject was instructed to look at the white paper and to change his eye position freely. The average luminance level of the white paper was 44.6 cd/m².

Map. The subject was instructed to look at 60 × 45 cm topographical map (Geographical Survey Institute, 1967) which was placed on the white paper and to change his eye position freely.

Searching. A name of a small village on the map was given through an intercom. The subject was instructed to locate the place and to report when he had found it, then another name was immediately given.

The order of the experimental conditions was randomized for each subject. The recording time of each condition was four minutes. Intervals between each condition were about three minutes. During the intervals, the light was turned on except the interval just before the dark condition.

Recording

EEG was recorded from Oz referred to the right mastoid. The ground lead was attached to the left mastoid. The signal was amplified with a bio-amplifier (Nihonkoden, RM-5) at a low frequency time constant of 0.3 s and a high frequency cutoff at 50 Hz. Eye movements were recorded by means of electro-oculography (EOG). A pair of Ag-AgCl electrodes (Beckman) was placed at the outer canthi of two eyes for horizontal movements. Another pair was placed above and below the right eye for vertical movements and eye blink potentials. EOGs were amplified with high gain DC amplifiers (Nihonkoden, RUD-5) set for 100 Hz upper limit. EEG and EOGs were recorded on a magnetic tape (Yasek, CD-100).

Analysis of Data

EEGs time-locked to offset of saccades were averaged in order to obtain lambda responses. Data were processed with the tape run backwards in order to detect offset of saccades. The horizontal and vertical EOGs were differentiated with differentiators at time constant of 0.02 s. Both potentials were fed to inputs of a vector module (Teledyne-Philbrick, 4352) to obtain the absolute value of the saccade. Whenever the output of the module exceeded a given level (2°), a trigger pulse was delivered to a computer (DEC, PDP 11/10). The positive high spike (more than 200 µV) in the vertical EOG, which was defined as a blink potentials, was also transformed into the pulse. EEG, the vector of EOGs and the blink pulse were digitized every three ms with separate A-D converters and were stored temporarily in buffer memories of the computer. When eye blinks or the next saccades occurred during EEG sampling, buffer memories were erased. Thus, EEGs from 60 ms before to 300 ms after
offset of saccades were obtained without artifacts and averaged 100 times with the computer (see Yagi, 1980). After running average of the five points, the results were recorded on a XY plotter for each subject. The responses for each condition were further averaged across six subjects in order to obtain the grand averaged lambda responses.

Results and Discussion

Figure 1 shows the grand averaged potentials for six subjects in four conditions. In the dark condition, however, two subjects were excluded from grand averages because of predominant appearance of the alpha wave in the EEG.

When occipital EEGs were averaged on the basis of offset of saccades, lambda responses were not observed in the dark condition. The results coincided with the report that no lambda response obtained in the dark when EEGs were time-locked to onset of saccades (Kurtzberg & Vaughan, 1977). These results indicated that the light was required for appearance of the lambda response.

In the white paper condition, four of the six subjects showed three small components: the negative which coincided with offset of the saccade (NO), the positive with latency of about 100 ms (the lambda response), and the negative with latency of about 180 ms (N180). In all cases, the time from offset of the saccade to the peak of the component was referred to as latency. The other two showed no definite components. It would be expected that responses would be small because the VEPs were evoked by contrast and that the contrast on the white paper was low. Our finding that the lambda response is linked to the offset of the saccade allows precise averaging, and such small responses can be seen. Triggering at the saccade onset would possibly smear the responses, so that they would be invisible, as reported by Scott, Groethuysen, and Bickford (1967).

In the map condition, three components appeared more definitely for all subjects. The lambda response was quantified by measuring the peak-to-peak amplitudes except in the dark condition. When the component did not appear definitely, a maximal peak and a minimal with an equivalent latency were measured. Table 1 shows the mean peak-to-peak amplitudes and the mean saccade sizes across six subjects. Amplitudes of the lambda responses were larger in the map than in the white paper condition. Therefore, not only light but also a patterned stimulus was required for appearance of lambda responses. The amplitude of VEP is heightened to the patterned stimulus more than to the simple blank stimuli (Spehlmann, 1965). The result also supports the assumption that the lambda response
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Table 1
The means and the standard deviations of peak-to-peak amplitudes of the lambda response and the saccade size

<table>
<thead>
<tr>
<th></th>
<th>D</th>
<th>W</th>
<th>M</th>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
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<tr>
<td>Lambda Amplitude</td>
<td>N0-P100</td>
<td>4.64±2.87</td>
<td>6.99±3.68</td>
<td>7.51±4.54</td>
</tr>
<tr>
<td>(µV)</td>
<td>P100-N180</td>
<td>3.42±2.48</td>
<td>6.82±5.26</td>
<td>8.78±5.98</td>
</tr>
<tr>
<td>Saccade size (µV)</td>
<td>49.2±8.4</td>
<td>59.2±11.3</td>
<td>45.8±10.6</td>
<td>47.5±12.5</td>
</tr>
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Note: D: Dark, W: White paper, M: Map, S: Search.

response is equivalent to the VEP.

The shape of the lambda responses time-locked to offset of saccades in the present experiment was similar to those time-locked to onset of saccades in earlier literatures (e.g. Scott & Bickford, 1969). When the subject observes a patterned figure, the potential has sometimes so large amplitude that can be observed as a spike-like potential in the EEG. The potential is referred to as the lambda wave (Evans, 1952). Therefore, the lambda responses could be obtained in their patterned figure conditions even when EEGs time-locked to onset of the saccade.

The amplitude of VEP is increased with information processing load to the stimuli (Harter & Salmon, 1972; Harter & Previc, 1978; Van Voorhis & Hillyard, 1977). If the lambda response is a kind of VEPs, the amplitude of the lambda response also might be increased with information processing load.

In the search condition, three major components like in the map appeared clearly. The amplitudes of the grand averaged lambda responses in the search condition appeared to be larger than in the map. Only four of the six subjects, however, showed larger amplitudes in the search condition than in the map. We have reported that the lambda response changes with attention (Yagi, 1977). Although the results in the present experiment also showed the similar tendency, the effect of information processing load was not so definite that we could draw a conclusion. The instruction given by the experimenter might be inadequate to setting up the difference between two conditions.

Mean sizes of saccades to which EEGs were time-locked are shown in the lowest row on the Table 1. Some eye movements in the dark condition were very large in amplitudes. Since their velocities however were very low, the computer was not triggered by the large eye movements. The differences in sizes of saccades to which EEGs were time-locked, however, were so little between conditions (statistically no significant differences2) that the differences of the lambda response could not be attributed to differences in the saccade size.

The small positive component preceding the saccade (Becker, Hoehne, Iwase, & Kornhuber, 1972; Kurtzberg & Vaughan, 1973) was not obtained in the present experiment. The component, which might be associated with onset of saccades, would be cancelled by scoring average because EEGs were time-locked to offset of saccades in the present experiment.

As mentioned above, when EEGs were averaged on the basis of offset of saccade, the characteristic lambda response was obtained in each condition. In most of early literatures, EEGs have been time-locked to onset of saccades. If an ANOVA \( \left( F = 1.591, df = 3/15, p > .10 \right) \).
vindual lambda wave has a large amplitude and each saccade size is small or consistent, we can obtain lambda responses even with onset averages. When the saccade sizes however vary, there is a possibility that the lambda responses might be distorted or be missed with onset averages. Consequently, EEGs should be time-locked to offset of saccades in order to detect the accurate lambda responses in free eye movements. In that case, the lambda response will be applicable as a new index to research on perception.

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