Model of contrast sensitivity in visual perception of motion

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Abstract - **A mathematical model expressing the function of the magnocellular subsystem, when it is activated by a motion-onset stimulation, is presented. The model outlines dependency of the amplitude and latency of the motion-onset visual evoked potentials on such stimulus parameters as contrast, spatial frequency or movement velocity. The model enables prediction of evoked responses in particular stimulus conditions.**

To describe the variability of the motion related evoked potentials a hyperbolic shape was used. That function allowed to derive and define relations between stimulus parameters and a threshold sensitivity for motion detection.

I. Introduction

The human visual system seems to consist of at least two specific subsystems. Parvocellular one is active in pattern and color processing and the magnocellular subsystem is involved in the motion detection. The subsystems are parallel and have different anatomical and functional proprieties.[1]

The magnocellular subsystem originates in the retina and troughs specific M-ganglion cells it is connected to lateral geniculate nucleus and then to the striate cortex. The final stage of the motion analysis takes place in the medio-temporal extrastriate region (MT)[2].

A selective magnocellular subsystem distortion has been reported in several neurological and neuro-ophthalmological diseases[3].

Basic functional properties of the magnocellular subsystem can be investigated via visual evoked potentials (VEP). These are measured as a response to onset of a moving pattern (M-VEPs). The evoked potentials method can also reveal important objective information about properties of this system. A high contrast sensitivity of the magnocellular subsystem was already verified with the use of M-VEPs [4]. In this study, additionally, a role of a spatial frequency or velocity of motion in the contrast sensitivity is described.

II. Methods

The M-VEPs were examined in five healthy subjects. Motion stimulus was generated on 21" PC monitor (screen size 40°x30°). A checkerboard pattern with the Michelson contrast (C) in the range from 0.3 to 96% and spatial frequency (SF) of 0.23-7.5c/deg moved at velocities between 16.3 and 0.5deg/s to keep the temporal frequency of the stimulus constant (3.75 Hz). Recording was made from three occipital leads O_Z, O_R (5cm right from O_Z) and O_L. (5cm left from O_Z) against linked earlobes.

A latency-delay of the main negative peak (N170) and its amplitude related to isoelectric line of M-VEP was determined for each recorded VEP. Obtained parameters were averaged in all five subjects. Matrices *n-by-m* dimension for latency and amplitude were achieved. The *n* rows (five) were each of different spatial frequency (velocity, respective) and the *m* columns (ten) were each of different contrast.

Every row of amplitude and latency matrices was examined by means of minimum square errors method to obtain parameters of dependency on the stimulus contrast. A relationship between these parameters and the stimulus SF was determined in the same way.

III. Results

The dependency of the M-VEP latency and amplitude changes on shift of contrast when SF is kept constant has a hyperbolic shape:

$$latency\,[ms] = a_L + b_L / C, \tag{1a}$$

$$amplitude[\mu V] = a_A - b_A / C. \tag{1b}$$

We found linear dependency on SF for the a_L and hyperbolic for the a_A coefficients. For the $b_{L,A}$ coefficients this dependency was exponential. The final form of the received two-dimensional function is:

$$latency\,[ms] = c_{L1} - c_{L2}SF + c_{L3}\exp(c_{L4} / SF) / C, \tag{2a}$$

$$amplitude\,[\mu V] = c_{A1} - c_{A2} / SF - c_{A3}\exp(c_{A4} / SF) / C. \tag{2b}$$

Since the equations (2) can give negative amplitudes for low contrast and low spatial frequency it is necessary to implant a non-linear normalisation, i.e. to define a range in which the model is reliable. This range is stated by equation (3) obtained from (2b) for amplitude equal to zero. The experiment also reveals that this zero amplitude reflect directly the threshold for the motion perception in the psychological sense.

$$C[\%] = c_{A3} \exp(c_{A4} / SF) / (c_{A1} + c_{A2} SF) \quad (3)$$

The shape of the normalised model is shown on Fig. 1. The upper graph describes the latency and the lower one the amplitude dependency. The parameters obtained from average responses of the five subjects were: cA1-4 is 12.25, 17.32, 1.46, 12,24 and cL1-4 is 189.08, 0.43, 37.52, 12.16 respectively.

This model is consistent with experimental data - the coefficient of determination (R^2) was 0.97 for amplitudes and 0.98 for latencies.

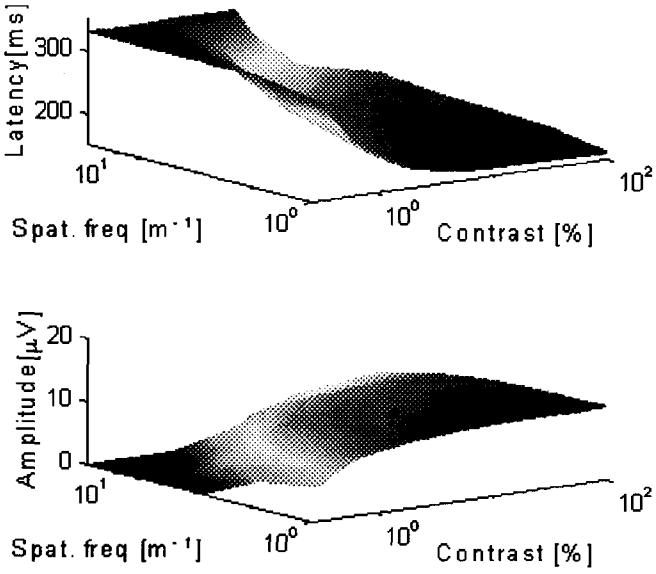

Fig.1. Model reliance of M-VEPs latency and amplitude dependency on contrast and stimulus spatial frequency.

Moreover, we obtained direct relation between amplitude and latency from this observation:

$$\frac{amplitude[\mu s] - a_A}{latency[ms] - a_L} = -\frac{b_L}{b_A}, \quad (4)$$

which can be derived from (1) and expresses identical dependency on contrast of stimuli.

IV. Discussion

The presented model depicts an approach to dynamics of the magnocellular subsystem. Frequently a logistic function is used for a description of contrast [5], however we used the hyperbolic function (1) for following reasons:

1-Though a hyperbolic function has only two parameters - a and b (logistic function has three) it accurate fits to data (R^2 falls between 0.8-0.9).

2-Logistic function do not cross a zero line for amplitude and therefore it is not appropriate for estimation of contrast sensitivity in a simple way.

The contrast sensitivity equation (3) gives a good prediction within investigated parameter space of stimuli - it means interpolation. However, in extrapolation sense there is some imprecision mainly for low spatial frequency. This is because of singularity of equation (3) in low spatial frequencies as well as high sensitivity to small changes of model parameters.

The coefficients c_A and c_L for a particular subject can be determined from M-VEPs in at least four different stimulus conditions.

V. Conclusions

1) Very high correlation between the models and N170 peak parameters strongly suggest the specificity of the N170 peak for a motion stimulation.

2) The amplitude and the latency were shown to follow contrast changes in the same way. Therefore the full contrast dependency description of the magnocellular subsystem can be based on latency variation only.

3) The models allow to predict parameters of M-VEPs in a wide range of stimulus conditions and to estimate an optimum stimulus conditions for a particular subject. This parameters can be a useful diagnostic tool for a description of the magnocellular subsystem function.

4) Due to close relationship of the M-VEPs to psychophysical values the model can determinate a perceived contrast threshold of moving pattern for different spatial frequencies it is also true even in those cases where we are not able to reach this threshold in real conditions.

Acknowledgments

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