The Optimal Fitting Model for Aging-related Receptive Field Size Curve of Macaque V1 Neurons

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Abstract—Visual function in humans degrades during the early stage of senescence beginning from middle 50s to 60s. Generally,it may derive from the general decline of cortex inhibition,which destroys the balance between excitation and inhibition system in the brain.To date, the optimal fitting model of receptive field size curve is not clear during different age groups.To address this issue, firstly,we carried out extracellular single-unit studies of the receptive field properties of cells in the primary visual cortex(v1) in young and old rhesus monkeys.By IGOR,we obtain the original data of receptive field size curve. Secondly, we use the existing models of Gaussian, DOG (subtractive) and a normalization (divisive) model to fit the data.After that,we found clear indications:The fitting goodness of DOG has a high degree during different age groups and the DOG model has better adaptability and flexibility.In addition,we can draw a conclusion:In aging process,the turning curvature of receptive field size curve of V1 cells changes obviously, and the surround suppression of the receptive field decreases clearly.

Keywords-Visual system;excitation and inhibition;receptive field ;fitting model;fitting goodness

I. INTRODUCTION

In present,the trend of aging develops rapidly.Human dysfunction followed by the aging affects people's life and work gradually.Visual function in humans degrades in the aging process.Thus,Visual system is a good model for the study.

A. Receptive field

In primary visual cortex, receptive fields are much more diverse and more complicated.It has two regions:central exciting region and surround suppression region.When presenting a visual stimulation in the surrounding of receptive field,it is capable of regulating exciting response of receptive field prohibitory.When showing a gradual increasing visual stimulation in the receptive fields of visual cells, firstly, the cells's reaction increases gradually, then it may reach a peak, finally, it decreases gradually.Thus,it forms a curve called "receptive field size curve".We use the existing models of Gaussian, DOG and Divisive models to fit the data respectively.

B. Gaussian Model

Information is integrated across the visual field to transform local features into a global percept. We used drifting sinusoidal gratings in circular and annular apertures to estimate the sizes of the receptive field's excitatory center and suppressive surround.We use combinations of stimuli inside and outside the receptive field to explore the nature of the surround influence on the receptive field center as a function of the relative and absolute contrast of stimuli in the two regions.We then develop a receptive field model based on the ratio of signals from Gaussian-shaped center and surround mechanisms.

C. DOG Model

The area-summation profiles derived from experiments done with drifting sine wave gratings in cat Visual cortex are well described by a difference of integrated Gaussians (DeAngelis et al. 1994). In this model, the center Gaussian corresponds to the excitatory or classical receptive field while the surround Gaussian corresponds to the suppressive component of the receptive field. The excitatory or classical receptive field of simple cells has been modeled by as either a Gabor filter or the difference of overlapping Gaussians.

D. Divisive Model

The DOG model proposes that excitation and inhibition interact in an additive manner. Other studies have shown that cortical inhibition might act through a divisive rather than a subtractive mechanism (Albrecht and Geisler 1991; Bonds 1989; Robson et al. 1988). A computational model by Somers et al. (1998) described the cortex as a neural network of center-surround units. Inhibition in this model was also divisive in nature. To compare these two types of interaction, we fit our summation data with the center-surround DOG model and a center-surround normalization model.

II. MATERIAL AND METHODS

A. Animals

Four young and three old male rhesus monkeys (Macaca mulatta) were used in this study.Young monkeys were 2.1–6.1 kg with a mean age of 5.5 years, and old monkeys were 5.6–9.5 kg with a mean age of 28 years. An initial ophthalmological examination was performed under ketamine (100 mg/kg i.m., Ketalar, Parke-Davis, Morris Plains, NJ, USA) anesthesia to screen for monkeys with ocular pathology.

B. Visual Stimulation

For each isolated single unit, the eye preference was determined and all subsequent stimuli were presented monocularly to the dominant eye.The receptive field of each cortical neuron was initially located using a bar of light that was optically back-projected onto a tangent screen in front of the monkey.Visual stimuli were generated on these displays by a dedicated computer that employs two high-resolution graphics boards (Imagraph).

C. Data Collection and Process

The program to generate the visual stimuli was written in MATLAB, using the extensions provided by the high-level Psychophysics Toolbox (Brainard 1997) and low-level Video Toolbox (Pelli 1997). IGOR software were used for data processing and analysis for primary visual cortex neuron unit discharge signal.Finally,we can obtain the original data of receptive field size curve.

III. DATA ANALYSIS

A. Gaussian Model

Each summation curve was fitted using the following empirical function

$$R(i) = R_i + K_i \int_{-s/2}^{s/2} e^{-(2(y-b)/a)^2} dy \qquad (1)$$

With increasing range of stimulus, there is the whole process of excitation and inhibition of the receptive field.Take Ri as the initial degree of excited response, integration as function of excitation and inhibition.Valid values of Ki, b, a are selected so that Gaussian curve and "excitation and inhibition"curve are approximate. Finally,we can get the approximating function which reflects the receptive field size curve of excited response exactly.

B. DOG Model

Each summation curve was fitted using the following empirical function

$$R(s) = R_0 + K_e \int_{-s/2}^{s/2} e^{-(2y/a)^2} dy - K_i \int_{-s/2}^{s/2} e^{-(2y/b)^2} dy \qquad (2)$$

Here, R_0 is the spontaneous rate, and each integral represents the relative contribution from putative excitatory and inhibitory components respectively (DeAngelis et al. 1994). Values of Ke, a, Ki, and b were optimized to provide the least mean squared error (MSE) to the data. Excitatory space constant measures are taken as the parameter a from the fitted curves for the first harmonic response of simple cells and the DC response of complex cells.

C. Divisive Model

A suppression index (SI) measure was also estimated from the fitted curves. This measure is the ratio of area under the inhibitory Gaussian over that of the excitatory Gaussian

$$SI = (K_i b / K_e a) \qquad (3)$$

We also considered a normalization model of the following form

$$R(s) = \left(\frac{CK_c L_c}{1 + CK_s L_s} \right)^{\beta}$$

$$L_c = \int_{-s/2}^{s/2} e^{-(2y/r_c)^2} dy, \quad L_s = \int_{-s/2}^{s/2} e^{-(2y/r_s)^2} dy \qquad (4)$$

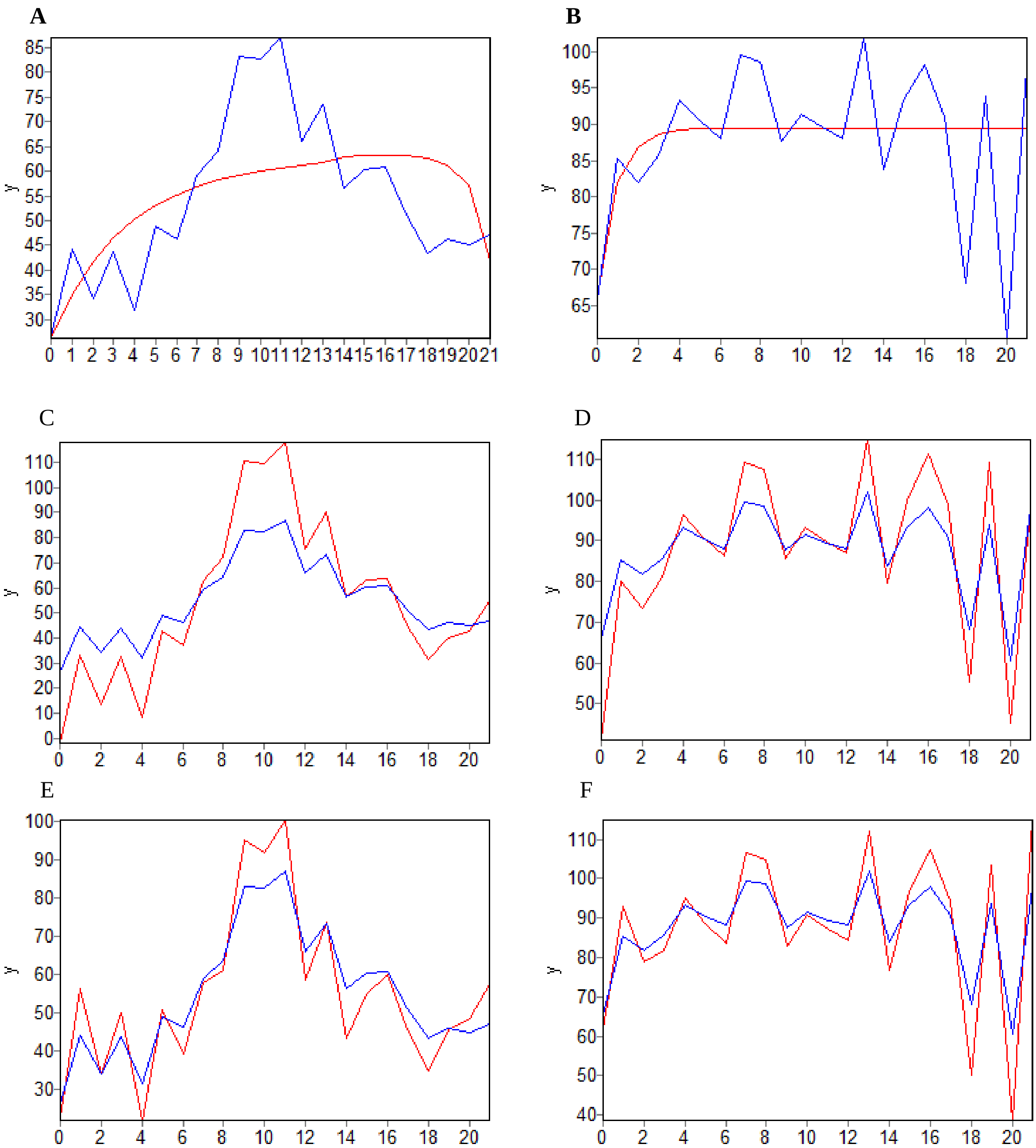
Where Lc and Ls are linear responses estimated from the integral of a Gaussian profile similar to the DOG model discussed in the preceding text. The center and surround gains are kc and ks ,respectively, C corresponds to the stimulus contrast, and β is an arbitrary exponent.

IV. RESULTS

We studied a total of 38 neurons in each young monkeys and 17 neurons in each old monkeys. In most monkeys. Neurons studied in both age groups were recorded from the same range of cortical depths to avoid laminar bias. They also had similar eccentricities of the receptive fields (less than 8 °). There was no difference in the thickness of V1 in coronal sections.

A. The Fitting Curve

All fitting procedures were done with the 1stopt (First Optimization).It have a set of integrated software packages of mathematical optimization and analysis.In the nonlinear regression ,curve fitting and so on ,it can solve complex engineering fields .No exaggeration to say that it has been in leading position.Based on the three models,we write the corresponding function,and select the appropriate fitting algorithm, for example:Levenberg-Marquardt(LM),set convergence judgment index as 1.00E-10 and maximum number of iterations as 100.Choose a group data of receptive field size of young or old randomly.Write the fitting procedure.Then we can get different kinds of chart.As shown in Fig .1:



X: Scope of simulation, Y:Response

—X-Y Line (actual value); —X-Y Line (calculated or experimental value)

Figure 1. X-Y chart of aging-related receptive field size curve of macaque V1 neurons. A:Gaussian-Young,B:Gaussian-Old,C:DOG-Young,D:DOG-Old,E :Divisive-Young ,F:Divisive-Old.

B. The Analysis of Fitting Goodness

With regard to the original data of receptive field size curve from young and old rhesus monkeys,we use 1stopt to analyze each group one by one, and they are calculated under the current three models:Gaussian, DOG and Divisive.

We can get: RMSE, SSE ,R, R2 ,DC, Chi-Square,F-Statistic respectively.Then we calculated the mean values of all.For each cell,the minimized criterion is based on the mean square error between the model's response and the experimental data.So we can easily find the intrinsic regularity from distributed data.The fitting parameters related to the fitting curve of receptive fields are shown in Table1.

TABLE I. STATISTICS OF FITTED MODELS WITH THE POPULATION MEAN R^2 VALUES AND THEIR RESPECTIVE MEAN VARIANCE

Analysis Model	**Mean variance**	**Correlation Coefficient(R)**	**Fitting Goodness (R^2)**
Gaussian_ Young	3.0028	0.7298	0.5326
Gaussian_ Old	4.7277	0.8875	0.7877
DOG_ Young	1.2549	0.9583	0.9184
DOG_Old	4.2066	0.9120	0.8317
Divisive_ Young	1.2571	0.9582	0.9181
Divisive-Old	4.4382	0.9015	0.8128

V. SUMMARY

In this study, we carried out extracellular single-unit studies of the receptive field properties of cells in the primary visual cortex (area V1) in young and old rhesus (Macaca mulatta) monkeys, and studied a total of 81 neurons from them. By IGOR,we obtain the original data of receptive field size curve. This prepared for the investigation of the optimal fitting model for aging-related receptive field size curve of primary visual cortex neurons in monkeys.

The primary finding of this study is that the functions of cells to inhibit the excitation in old monkeys exhibited significantly lower than young monkeys.We also can draw the conclusion that:In the aging process, the turning curvature of receptive field size curve of V1 cells changes obviously, and the surround suppression of the receptive field of V1 cells also decreases clearly.

Another finding of this study is as follows:

On the one hand, from the fitting curves we can see, the two models of DOG and Divisive are more mature than the Gaussian model. The two models yield quantitatively similar estimates of receptive field size. However,the normalization (divisive) model predicts weaker surround strength than the DOG model,and the fitting goodness of DOG model has a high degree during different age groups in monkeys.

On the other hand, for old monkeys, the fitting goodness is no more than 85 both under DOG and Divisive models, which also demonstrates the limitations of DOG and Divisive model. Since the two models are based on the theory of the receptive field of strong, young and active cells.This phenomenon can be explained as follows: With the loss of cell activity in the aging progress, it has great influence on the inhibitory effect of cells. In that case, the response of Gauss curve is limited. Furthermore, in order to obtain further insight into the relationship between the neuronal changes and the visual degradation in aging, put forward a new model to fit the data of receptive field size would be necessary the next step.

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