Bio-inspired methods for analysis and classification of reading eye movements of dyslexic children.

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ABSTRACT: The paper describes real practical problem of analyzing diagnostic significance of dyslexic eye movements. The biologically inspired methods were used and compared with classical methods of artificial intelligence. Eye movements of 52 school children were measured using videooculographic (VOG) technique, during a reading task. There were three groups of subjects – normal readers, retarded readers and dyslexics. The main goal was to analyze the possibility of dyslexia detection only from the eye movement signal. Time and frequency domain features were extracted and subset of significant features was chosen by a simple feature selection method. The selected feature subset was visualized using a self-organizing map (SOM). Clusters were formed by the SOM proving that proposed methodology is suitable for automatic dyslexia detection. Next, the artificial neural network classifier was used for supervised learning and the performance was compared to the results obtained for nearest neighbour classifier or the Bayes classifier.

KEYWORDS: dyslexia, neural networks, eye movements, classification, self-organizing map

INTRODUCTION

This paper focuses on a medical diagnostic problem – looking for a relationship between eye movements and dyslexia. The problem has been described in several studies. However, these studies do not provide any clear unified conclusions. The approach proposed here uses artificial intelligence methods in order to contribute to a better problem understanding. First, a videooculographic measure was performed to get eye movement signal records of subjects. Signals were pre-processed and analyzed using an eye movement analysis software systems and results were saved in an analysis file. Next, an extraction procedure was performed and 58 features were obtained. The subset of significant features was selected by a simple feature selection procedure and classification experiments were performed. The neural network with back-propagation learning algorithm was compared with two conventional classifiers.

DYSLEXIA

Dyslexia (specific reading disability) is a common, cognitively and behaviorally heterogenous developmental condition, characterized primarily by severe difficulty in the mastery of reading despite average intelligence and adequate education [1]. Dyslexia is one of specific learning disabilities. Its prevalence in Czech school population is estimated to 2-3%, which is considerably less than in English speaking countries. The children with dyslexia need special educational methods for acquiring reading skills. Therefore the early diagnostic is very important [2]. An early dyslexia detection will give those people the chance of being treated by means of the most accurate and specialized intensive therapy.

EYE MOVEMENTS

There are two main kinds of eye movements - the big and the small. Saccades are rapid big eye movements which allow binocular turning or version of the eyes from one fixation point to another. During these conjugated and volitional movements, the eye is browsing a visual field. The direction and the magnitude of the saccade are influenceable by a will. Each saccade has its direction. People usually read from left to right and most of saccadic eye movements are oriented accordingly. These normal reading movements are called forward saccades. Reading movements going from right to left are called regressions.

The saccade alternates with the period of fixation made when the eyes are directed to a particular target. The fixation consists of three kinds of small eye movements - drift, microsaccades and tremor. Sequences of fixations and saccades (rapid eye movements between fixations) define scanpaths, providing a record of visual attention on a subject of interest.

In this work, the videooculographic method was used for eye movement signals measuring. The eye movements of 76 subjects were recorded using iView 3.0 videooculography system at the Department of Neurology, 2nd Medical Faculty, Charles University, Czech Republic. The subjects formed three groups – normal readers (N=20), retarded readers (N=22) and dyslexics (N=10). The measurement was executed in dark. Subject with fixated head looked at a stimulus on the screen. The screen was placed one meter from the subject. The stimulus consisted of text in Czech and the task was to read the text.

METHODS

FEATURE EXTRACTION AND SELECTION

Before feature extraction itself, the signals were pre-processed and analyzed using special software for analysis of eye movement signal. The analysis included the automatic detection and description of fixations and saccades. Next, 58 features from time and frequency domain of horizontal and vertical signal were extracted. Only five most important features are described in Table I.

Selection criterion enables to compare, whether one feature subset is better than another. In our case of two classes, we used very simple criterion based on class separability - Euclidean distance between class means. The second part of feature selection problem is search strategy. The backward elimination [3] was used as the search algorithm and a subset of 5 input variables was selected. These significant features are described in Table I.

SELF ORGANIZING MAP

The self-organizing map [4] is inspired by neurophysiological observations concerning cell properties in primary visual cortex [5]. It is essentially a combined vector quantization and vector projection algorithm. It consists of neurons organized on a regular low-dimensional grid. Each neuron is represented by a d-dimensional weight vector, where d is equal to the dimension of the input vectors. The neurons are connected to adjacent neurons by a neighborhood relation, which dictates the topology, or structure, of the map. Typically the neurons are positioned on a 2-dimensional plane in a regular rectangular or hexagonal lattice.

The SOM is trained iteratively. In each training step, one sample vector x from the input data set is chosen randomly and the distance between it and all the weight vectors of the SOM is calculated using a distance measure. The neuron whose weight vector is closest to the input vector x is called the Best-Matching Unit (BMU). After finding the BMU, the weight vectors of the SOM are updated so that the BMU moves closer to the input vector in the input space. The training is usually performed in two phases. In the first phase, relatively large initial learning rate and neighborhood radius are used. In the second phase both learning rate and neighborhood radius are small right from the beginning. This procedure corresponds to first tuning the SOM approximately to the same space as the input data and then fine-tuning the map.

CLASSIFICATION

Back-propagation network

As described above, there are three groups of subjects in examined population. However, the goal is to classify only dyslexic subjects. Therefore we understand the problem as dichotomia (two classes - dyslexic and non-dyslexic subjects). The feed-forward network is used for classification experiments considering only two classes. The Backpropagation network is one of the most frequently used models in many applications of artificial neural networks [6]. It uses a feed-forward network using error back-propagation to train. Error back-propagation learning rule is central to much current work on learning in artificial neural network.

The algorithm of back-propagation provides a computationally efficient method for changing the weights in a feed-forward network to learn a training set of input-output examples. The application of this algorithm has two phases. In the first phase, input is propagated forward to the output units where the error of the network is measured (forward propagation). In the second phase, the error is propagated backward through the network and is used for adapting connections.

Nearest neighbour classifier

Nearest-neighbour classifier uses normalized Euclidean distance to find the training instance closest to the given test instance, and predicts the same class as this training instance. If multiple instances have the same (smallest) distance to the test instance, the first one found is used.

Naive Bayes classifier

A naive Bayes classifier is a simple probabilistic classifier [7]. Naive Bayes classifiers are based on probability models that incorporate strong independence assumptions which often have no correspondence in reality, hence are (deliberately) naive. We used normality assumption for distribution of classes.

RESULTS

FEATURE SELECTION

The feature selection procedure result is in Table I. The number of five selected features was chosen with regard to the small data set. Some experiments with classification performance for various numbers of features were also performed. There are two time domain features in the selected subset. These features both describe character of directions of subject’s saccadic eye movements. It is also interesting that purely horizontal directions are involved here. The next three features are extracted from frequency domain of horizontal and vertical signal.

VISUALIZATION

The next experiment aimed to visualization of 5-dimensional data using the self-organizing map. A map with 8x6 neurons forming hexagonal grid was used. The length of first, rough training phase was 500 epochs, the length of the second one – fine-tuning training phase was 700 epochs. Gaussian neighborhood was used. The result is depicted in Figure 1:. The left upper subfigure shows how the subjects are mapped onto the grid. The patients are assigned to each neuron using color decoding. It can be seen that the SOM found in the input space two areas where dyslexic patients are concentrated. Therefore the trained map could be also used for classification. The other subfigures show values of particular features for each place of the map. This information can be used for analysis of features or feature significance examination.

Feature	Description
EAST-WEST Fixation Types Ratio	Ratio of fixations in which eye entered from the previous fixation area from the “East” direction and then the eye exited from the actual fixation area to the next one in the “West” direction. This feature corresponds to ratio of multiple regressions.
East Saccades Ratio	Ratio of saccades oriented in the “East” direction.
Horizontal Frequency Power at 6 Hz	Power of horizontal signal spectrum in the range of 5-6 Hz.
Horizontal Frequency Power at 13 Hz	Power of horizontal signal spectrum in the range of 12-13Hz.
Vertical Frequency Power at 4 Hz	Power of vertical signal spectrum in the range of 3-4 Hz.

Table I. Description of selected features

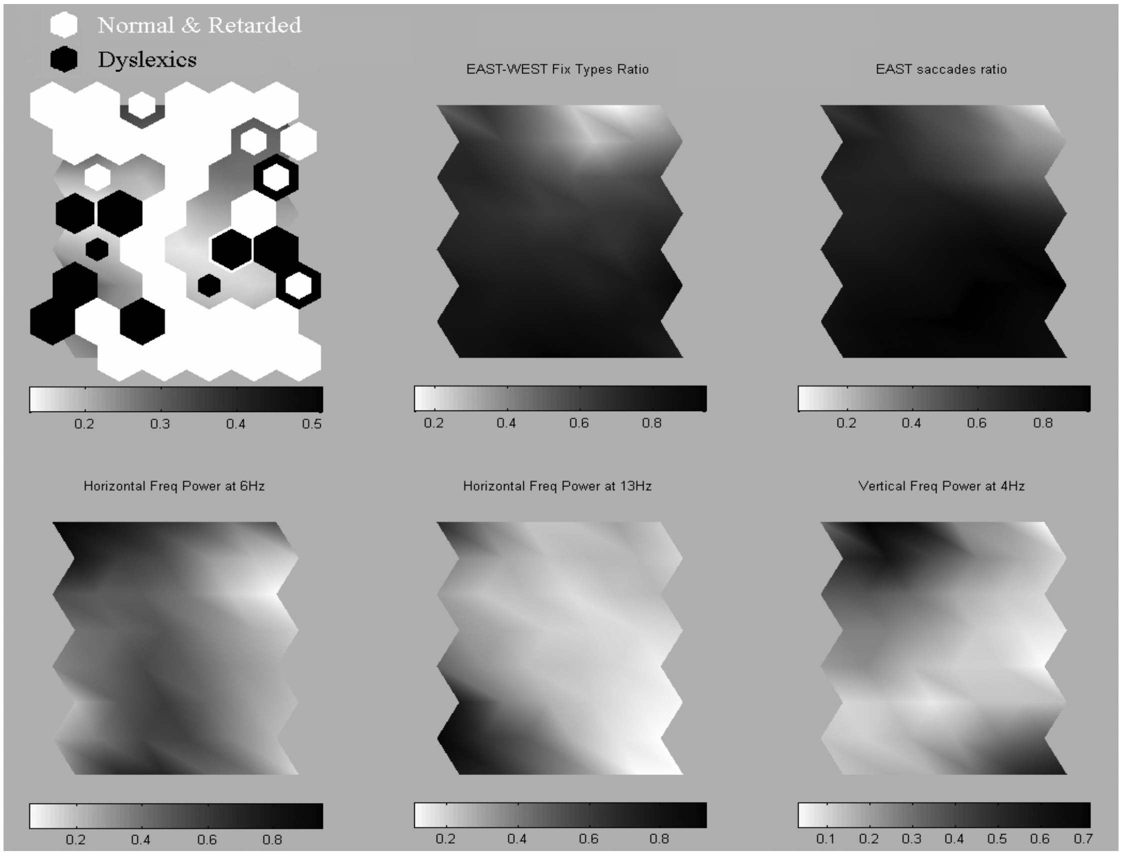

Figure 1: The self organizing map visualization.

CLASSIFICATION

During classification experiments, the neural network classifier was tested and result was compared with results for Bayes classifier and Nearest Neighbourhood classifier. The classification performance was estimated using leave-one-out cross-validation method. Three diagnostic accuracy measurements were used for comparison - the true positive fraction called sensitivity, true negative fraction called specificity and the ratio of correctly classified instances.

The neural network's topology and learning parameters were chosen experimentally. Only one hidden layer with 3 sigmoid units was used. The network was trained by back-propagation algorithm with constant momentum (M=0.2) and learning rate (LR=0.3) for 700 epochs. The results are summarized in Table II.

	Sensitivity [%]	Specificity [%]	Correctly classified [%]
Nearest neighbourhood	40	81	73.07
Bayes classifier	60	88.1	82.69
BP neural network	80	88.1	86.54

Table II. Results of classification experiments

CONCLUSIONS

We described here two biologically inspired methods for data analysis. First, the self-organisation map found two clusters of dyslexics in the 5 - dimensional space of features. The feature value plots could be also used for result interpretation. For example, we can say that the two groups of dyslexics differ in values of feature "Horizontal Frequency Power at 6 Hz".

The next experiment dealt with various classifiers comparison. It is evident, that all classifiers reached similar specificity, which is probably caused by larger amount of data for non-dyslexic subjects. Further, the classifiers differ in sensitivity. The neural network reached the best sensitivity.

Finally, a conclusion can be pronounced, that the dyslexia is detectable from reading eye movements. The results may become better and more valid if the testing population becomes larger. Especially, more dyslexic patients should be measured to get more reliable results.

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