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The Objective Method of the Evaluation of the Visual Acuity

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***Abstract*—The paper presents the use of visual evoked potentials VEP to the objective assessment of visual acuity. Methods of using visual evoked potentials (VEP) rely on the assessment of changes of the electrical action potentials generated within the cortex. To diagnose the degree of weakening eyesight a series of studies on healthy people and visually impaired ones were made. Electrophysiological studies of the eye, using noninvasive VEP examination allow a noninvasive and objective assessment of visual acuity. The use of visual evoked potentials gives the objectivity in assessment of visual acuity what may be very important in ophthalmology. This particularly may concern children examination, people with mental retardation and suspected of simulation.**

***Keywords*—electrophysiology, Visual Evoked Potentials, statistical analysis, visual acuity**

I. Introduction

THE subject of the paper concerns the methods of the objective assessment of visual acuity VA, using non-invasive measurements of visual potentials evoked VEP (called Visual Evoked Potentials). In the paper two techniques based on measurements of VEP were described and the detailed results of the study and statistical analysis for one of them, i.e. SEQ-STIMUL, were presented [1]. The attempt of scaling the obtained data allowing rapid and objective assessment of visual acuity was also made. The SEQ-STIMUL studies provide an objective assessment of visual acuity, which is described by a symbol of VA and expresses a value in the range from 0.1 to 1.0. The conventional methods of assessing visual acuity, conducted with the use of the designed tables for this, do not provide an objective assessment and must not be used in people with mental retardation or in children [2], [3]. The examinations of visual acuity providing its objective assessment are very important in ophthalmology, but most of them do not have standardized values allowing proper diagnostics.

The research enabling the assessment of visual acuity can be divided into two categories: subjective and objective. The first group includes studies using Snellen charts, while the second one the studies using electrophysiological signals of eyesight [4], [5]. The study enabling an objective assessment of visual acuity is the study Sweep VEP, which is based on the measurement of visual evoked potentials and is effectively used in ophthalmological research [6], [7]. The main disadvantage of this test is a relatively long duration, that may lead to the changes of measurement conditions, which are the source of the dispersion of results. An alternative to the test SweepVEP is the SEQ -STIMUL study introduced by Roland Consult Company. This study, in which visual evoked potentials are also used, is characterized by a comparable diagnostic effectiveness and a shorter duration at the same time. Because it is a relatively recently introduced test, it does not possess the scaled values enabling the assessment of visual acuity. In order to enable the assessment a series of tests were carried out and the attempt of their scaling was undertaken.

The main aim of the conducted study was to write new algorithms for the measurement and the analysis of visual evoked potentials performed in SEQ-STIMUL studies, using the known methods of mathematical statistics. As part of the research the analysis of acquisition methods of VEP signals was made, a series of studies was carried out and on the basis of them the standardized range of tolerance was developed. The developed set of algorithms allowed to effectively extract the maximum amount of data useful in diagnosing visual acuity proposed method. It is believed that the obtained analytical and experimental results will have a big practical importance, and further research will minimize the errors of set parameters.

II. Materials and Methods

In an objective assessment of visual acuity, using visual evoked potentials the research involving methods: Sweep VEP and SEQ-STIMUL are most frequently performed [7]. During the tests, the results of which are presented in this article, for the generation of forcing signal and the acquisition of signals VEP the specialized equipment was used which was combined with a set of computer-aided RETIsystem, produced by the German company Roland Consult [8]. Due to the lack of scaled values of the evaluated parameters is still not possible clear and objective assessment of visual acuity. The results presented by the author concern the attempts taken on scaling VEP parameters useful in this assessment. The results were obtained in a series of tests performed on two groups of 32 human subjects: of the normal and the diminished visual acuity. (median age 20 years; range 19-21 years). These both groups formed the patients with normal visual acuity, however, impaired visual acuity was achieved by appropriately selected corrective lenses. The test subjects were chosen by an ophthalmologist after earlier diagnosis of visual acuity using Snellen charts. The research followed the tenets of the Declaration of Helsinki. Informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study.

The conventional VA assessment was carried out subjectively, on the basis of ophthalmological examinations with the usage of the well-known designed charts, as well as

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objectively based on the relationships that exist between the values of specific points of curves obtained during electrophysiological studies [9], [10].

A routine eye exam generally includes a screening for glaucoma, macular degeneration and a standard subjective visual acuity test on a high-contrast letter-reading chart. VA assessment is clearly defined by the norm EN ISO 8596. A measure of VA is a numerical parameter defining the degree of impaired vision determined in the form of digits included in the range of 0.1 to 1.0. The standard measurement is carried out on the Snellen charts, so called after the name of the creator, the Dutch ophthalmologist Herman Snellen (1834-1908). These charts are provided with the so-called optotypes (such as letters, numbers, images) of the specified size (Fig.1). The Snellen chart provides a standardized test of visual acuity [11].

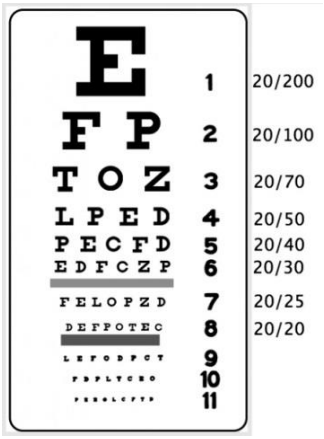

Fig. 1. The appearance of the sample charts used in the subjective Snellen visual acuity assessment.

The tested person is at a given distance from the chart (in Poland this distance equals 5 m). The size of the optotypes, which should be easily visible from this distance, is defined as 1.0. The optotype size increases gradually, while the number of describing it takes smaller values. The largest optotype is defined as 0.1. As stated Snellen, the value of VA is given by the relation 1.

$$\mathrm{VA} = \frac{D'}{D} \tag{1}$$

where: D' is the distance of testing, D is the distance from which the eye sees optotypes on the specific line of the chart.

For example, in the metric notation value of VA = 5/5 means that the tested eye can read the letter of the specified size from a distance of 5 m and it is one hundred percent of the effectiveness of vision. If the value VA <1, the visual acuity is impaired.

The test is simple, but its serious flaw is entirely subjective character and the key importance is the need to cooperate with a patient. This applies particularly to the tests performed in children, people with mental retardation and suspected of simulation and aggravation. In ophthalmology the ability to perform the objective tests using the appropriate excitation light is very important.

The VEP registration is performed by means of the surface electrodes put in the certain areas of the patient's head using a suitable conductive paste. Depending on the used excitation light (i.e. excitation stimulus), the various types of tests are known, among which Sweep VEP and SEQ-STIMUL are usually performed. During the Sweep VEP test, the eye is stimulated by a series of stimuli with black and white vertical bars of varying size. Each measuring cycle consists of a series of 13 consecutive light stimuli of decreasing the width bars in the range from 2 cm to 1 mm. In order to increase the accuracy of measurement and minimize the impact of disturbances, each test consists of 20 such cycles of measurement, the results of which are then averaged. The record of responses follows in the graphical and numerical form after each series of stimuli.

For each size of the light stimulus VEP curve is determined, and it is the characteristic parameter, which is the absolute difference between the maximum and minimum values of the curve. On the basis of the received parameters their function of changes is plotted depending on the size of the stimulus. Furthermore, for each excitation light the value of the noise is determined, which is also marked to a determined characteristic. The visual acuity assessment is carried out using a line that connects the largest value of the parameter on the characteristics with the first nearest value smaller than the noise for the size of the light stimulus. The visual acuity is determined on the basis of such specified line, according to the described guidelines [12], [13].

As suggested by the manufacturer of the equipment RETIsystem SEQ-STIMUL study, each eye was stimulated by a series of stimuli in the form of black-and-white chessboard of varying size (Fig.2). The individual measurement cycles consisted of 5 consecutive light stimuli with decreasing light squares forming a chessboard pattern. In order to increase the accuracy and minimize the impact of noises, each test sequence was repeated for the sequence of the chessboards 100 times and the results were averaged.

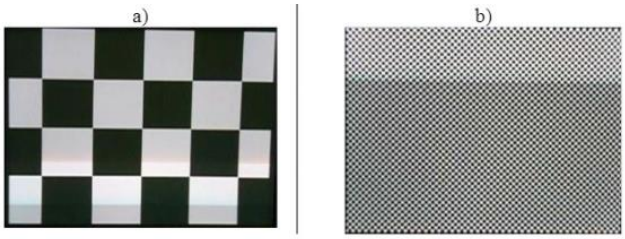

Fig. 2. The source of SEQ-STIMUL study:
a) the initial stimulus that is 1 of 5, b) final stimulus is 5.

The averaged VEP waveforms, set out for the next size of stimuli form STIMUL SEQ-curve (Fig.3) of the characteristic parameters. For the given curve the specific peak values A1, A2, A3, A4 and A5 are determined. On the basis of these values, the assessment of visual acuity can be carried out. For the initial stimulation (Fig.2a) the A1 value is minimum and increases for the next stimulations. The size of changes informs about the degree of weakening eyesight. The weakening eyesight is the greater, the smaller are the changes of the next peak value [14, [15], [16].

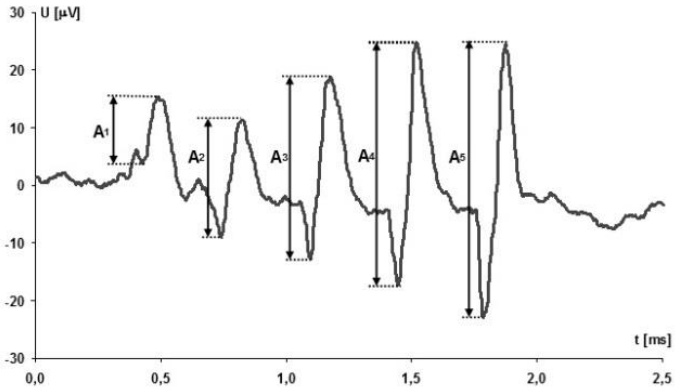

Fig. 3. The determination of the parameters of SEQ-STIMUL test.

In order to determine the tolerance ranges the series of tests were carried out, involving both healthy individuals and patients with diagnosed sight defects. The studies were conducted in the Laboratory of Electrophysiology of the Eye, using a set of non-invasive electrodes and a specialist hardware and software [1], [8]. Figure 4 shows the place of application of the electrodes, and Figure 5 presents the view of measuring stand.

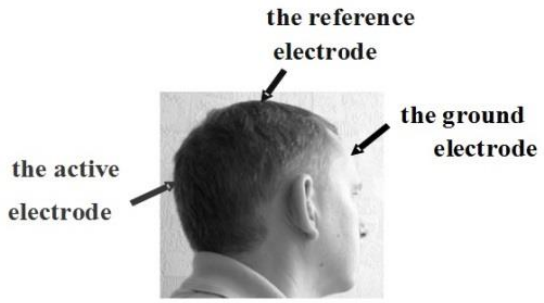

Fig. 4. The places of application of electrodes in the study of visual evoked potentials.

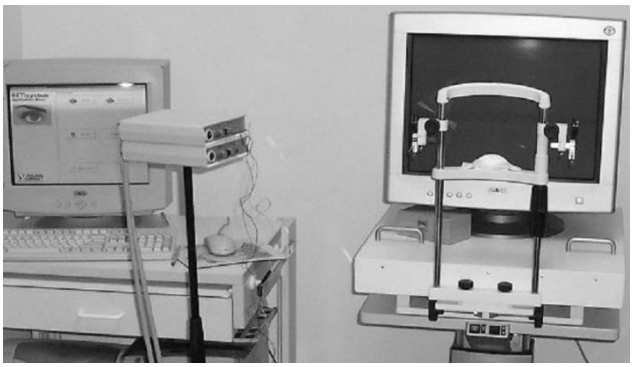

Fig. 5. The view of a measuring stand using RETIsystem.

III. Statistical Analysis

Described by the manufacturer of the RETIscan equipment SEQ-STIMUL examination has no standardized values that enable the rapid and objective assessment of visual acuity. On the basis of the data obtained during numerous experiments I have proposed a standardization process. Among many available statistical tools the algorithm determining the ranges of tolerance was chosen. The tolerance intervals are determined for the n-element sample.

The ranges of tolerance as well as the confidence ranges are random intervals which allow determining the acceptable limits of variability of the tested statistical characteristics. However, in contrast to the limits of the confidence intervals, the limits of tolerance ranges concern a fixed fraction of population rather than the parameter value, which is a significant difference [16]. The tolerance intervals are generally determined for the population having normal distributions, its boundaries are defined by a formula 2 and mean that with probability α the determined interval includes at least Q percent of the elements of the sample.

$$U_1 = \bar{x} - k(\alpha.Q) \cdot SD$$
$$U_2 = \bar{x} + k(\alpha.Q) \cdot SD \quad (2)$$

where: U_1 is the left limit of the tolerance range, U_2 is the right limit of the tolerance range, $\bar{x}$ is the arithmetic average of the sample, α is the established confidence level, Q is the percentage part of sample items, k (α, Q) is the factor to be read from the tables, SD is the standard deviation specified by the formula 3.

$$SD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \quad (3)$$

where: $\bar{x}$ is the arithmetic average, x_i is the value of the i-th element of the sample, n is the sample size.

The ranges of tolerance should be selected so that the oversize results, demonstrating the common weakness of sight, were effectively detected by the staff performing the test.

To confirm the effectiveness of the conducted studies the statistical test has been made to compare two expected values [16]. This test was used to verify the hypothesis of equality of arithmetic averages for each of VA values.

According to the assumptions, for a population with normal distribution, with unknown values σ_1 and σ_2, and samples of size n_1 and n_2, one can formulate the following hypotheses:

The null hypothesis H_0: $\mu_1=\mu_2$
The alternative hypothesis H_1: $\mu_1 \mu_2$

The statistics for the presented test depends on the sample size, for n > 30 is given by the formula 4.

$$U = \frac{\bar{x}_{n_1} - \bar{x}_{n_2}}{\sqrt{\frac{SD_1^2}{n_1} + \frac{SD_2^2}{n_2}}} \quad (4)$$

where:

$$\bar{x}_{n_k} = \frac{1}{n_k}\sum_{i=1}^{n_k} x_i \quad (5)$$

and:

$$SD_k = \sqrt{\frac{1}{n_k}\sum_{i=1}^{n_k}\left(x_i - \bar{x}_k\right)^2} \quad (6)$$

where: k is the number of sample (k = 1; 2).

The critical area determines the relationship 7.

$$R_q = \left(-\infty . \mu_{\frac{q}{2}} \right) \cup \left(\mu_{1-\frac{q}{2}} . \infty \right) \quad (7)$$

If you accept the alternative hypothesis in the form of inequality $\mu_1 < \mu_2$, the critical region is a left area, which for the statistic defined by the formula 4 accepts the limits described by the relationship 8.

$$R_q = \left(-\infty . \mu_q \right) \quad (8)$$

where: μ_q is the quantile of the normal distribution read from the tables for the assumed level of significance q.

If the determined value of the statistic U does not belong to the appropriate critical area, the presented null hypothesis is true. However, if the calculated value of statistic is in a fixed critical area, the presented hypothesis H_0 should be rejected to adopt the alternative hypothesis. The acceptation of the hypothesis H_1 means the significant changes of the expected value.

IV. Results

Obtained by means of electrodes and then processed signals SEQ-STIMUL were displayed on the screen in both the numerical and graphical forms. Among the various parameters the most relevant information provide the peak amplitudes of successive VEP curves (A1, A2, A3, A4 and A5), which values increase with the increase of the index. This growth is slower, the greater the damage of the eyesight. The assessment of visual acuity on the basis of the subsequent increase of the amplitudes proved to be inefficient because due to the physiological conditions of the tested people these values moved the fixed component. An effective solution was to appoint the following growth of peak-to-peak values towards the value A1 (A2/A1, A3/A1, A4/A1 and A5/A1). The detailed results of the analysis of the obtained research, carried out on 32 human subjects, are summarized in Table I [1].

Table I
The Ranges of Tolerance for SEQ-STIMUL Tests

	A_2/A_1				A_3/A_1				A_4/A_1				A_5/A_1			
	$\bar{x}$	SD	U_1	U_2	$\bar{x}$	SD	U_1	U_2	$\bar{x}$	SD	U_1	U_2	$\bar{x}$	SD	U_1	U_2
VA 1.0 normal VA	1.36	0.58	0.40	2.33	2.49	1.02	0.81	4.17	3.22	1.28	1.11	5.32	3.09	0.90	1.61	4.57
VA 0.7 diminished VA	1.14	0.35	0.56	1.72	1.93	0.55	1.03	2.82	2.40	0.23	2.02	2.78	2.42	0.36	1.83	3.01
VA 0.3 diminished VA	1.00	0.23	0.62	1.37	1.89	0.50	1.06	2.72	2.28	0.24	1.88	2.68	2.15	0.29	1.67	2.62
VA 0.1 diminished VA	1.11	0.37	0.50	1.72	1.60	0.62	0.58	2.63	1.79	0.54	0.91	2.67	1.63	0.48	0.84	2.41

The curves that allow scaling SEQ-STIMUL studies were plotted. The scaled curves can be represented either as real curves (Fig.6) or these curves after the linear approximation (Fig.7), and they allow a rapid and objective assessment of visual acuity. The described study was proposed by the manufacturer of the device RETIsystem and is a pioneering solution, successfully used in the Laboratory of Electrophysiology of the Eye [1].

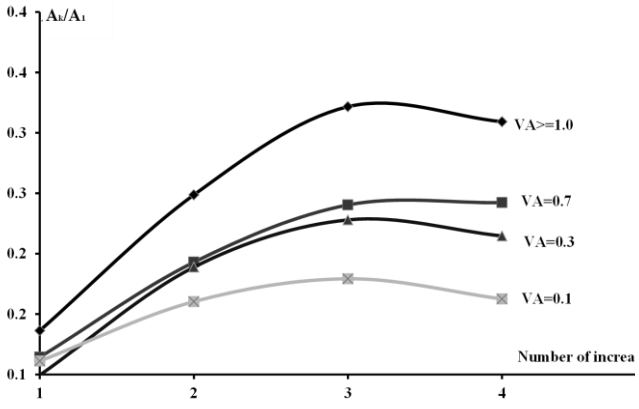

Fig. 6. The scaled curves of the parameter's growth of a SEQ-STIMUL test.

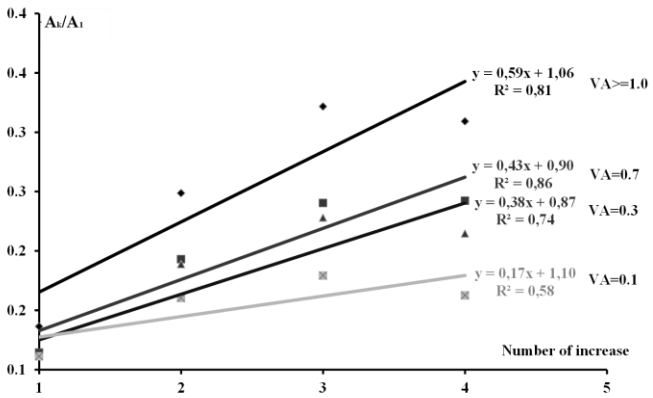

Fig. 7. The scaled approximation of the parameter's growth of a SEQ-STIMUL test.

The effectiveness of the studies was confirmed by a statistical test of comparing two expected values. In the performed analysis an alternative hypothesis was assumed that a specific increase in the average amplitude is smaller for smaller values of VA. In the calculations the normal distribution of the analyzed data of size $n > 30$ was established and the level of significance equal to q=0.01. The formulated hypothesis was also verified for the increased level of significance equal to q=0.05. The Table 2 shows the values of marked statistics U and the critical areas for two acceptable levels of significance.

TABLE II
THE SPECIFICATION OF TEST RESULTS OF SIGNIFICANCE CHANGES OF AVERAGE VALUE

Values VA	Increase in amplitudes	Statistics U	Critical range for $q = 0.01$	Critical range for $q = 0.05$
0.7 < 1.0	A2/A1	-1.8136		
	A3/A1	-2.7225		
	A4/A1	-3.5318		
	A5/A1	-3.0734		
0.3 < 0.7	A2/A1	-1.9913	$R_q = (-\infty. - 2.3263)$	$R_q = (-\infty. - 1.6449)$
	A3/A1	-0.3139		
	A4/A1	-2.0833		
	A5/A1	-2.6623		
0.1 < 0.3	A2/A1	1.5102		
	A3/A1	-2.2225		
	A4/A1	-4.6799		
	A5/A1	-4.1542		

By analyzing the results shown in Table II it was observed that in most cases the values of a statistic U are in the critical area. This property means that for these parameters. the null hypothesis should be rejected to choose the alternative hypothesis. which may tell about statistically significant differences of arithmetic averages of individual VA. The acceptance of the alternative hypothesis means that for individual VA values of arithmetic averages of the increase peak-to-peak values significantly different from each other. The acceptance of the null hypothesis is only for the first increases. which do not make the diagnostic values. These SEQ-STIMUL tests can be effectively used in the evaluation of visual acuity.

It is worth noting that the tightening of criteria of hypotheses verification consisting in an increase in the level of significance to the value of q=0.05. confirmed the test results conducted for the significance level q=0.01.

V. DISCUSSION

The electrophysiological studies of the eye. using VEP examination allow a non-invasive and objective assessment of visual acuity. Depending on the used light stimulus. various studies are carried out. among which most depend on tests on stimulation in the form of sequentially changing vertical bars. so-called SweepVEP studies. An alternative to the SweepVEP tests the SEQ-STIMUL studies are introduced by the manufacturer of device RETIsystem which are performed by the stimulation in the form of the board changing the size of its elements. An important feature of this study is the shorter duration with a comparable diagnostic efficacy. Shortening the time of the study is useful as it allows to avoid spreading of the obtained results caused by the changes in measurement conditions. These studies. however. have not scaled values. allowing unambiguous evaluation of visual acuity. One purpose of this paper was to calibrate the characteristic values of the segments of the VEP curve as a function of visual acuity. The slope of the line depicting the peak-to-peak changes of the value for the subsequent stimulating signals can objectively determine the visual acuity. The subject of further work will be aimed at improving the accuracy of determining the parameters.

VI. CONCLUSIONS

The visual acuity assessment is carried out on the basis of ophthalmic tests using. designed for this. the Snellen charts. During the test. the patient is at a fixed distance from the chart and reads located on it signs. The greatest weakness of this study is the fact that they are completely subjective and the cooperation of the patient is crucial.

The visual evoked potentials VEP provide an accurate assessment of visual acuity on the basis of registration of retina-cortical conduction in the optic nerve and optic duct. The use of visual evoked potentials gives the objectivity to the method and is important in ophthalmology. This particularly may concern children examination. people with mental retardation and suspected of simulation and agrevation. The signal recording was carried out by means of surface electrodes placed at specific sites of patient's head. and the cooperation of the patient is no longer as crucial as in conventional tests. .

VII. ACKNOWLEDGEMENTS

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