REGULARITY OF DYNAMIC VISUAL ACUITY CHANGE IN THE TRAINING RESULTS

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ABSTRACT

There is the issue of evaluation of dynamic visual acuity, which is an important indicator of visual capacity of individuals associated with the perception of moving objects. A new method of evaluation of dynamic visual acuity (DVA), based on the using of high-speed video recording of eye movements during the recognition of moving optotype (Landolt ring), which impose on the screen, was developed.
An approach to the definition of DVA, based on the measurement of time of pupil movement through a grid chart, was implemented. The average value of DVA (subjects in the age 23-35 years) is equal to 272 ms. Operation of the unit and the calculations was carried out by the author's programs. Statistical hypothesis that the distribution of the experimental data corresponds to the Weibull distribution law with parameters: scale A=9,221 and form B=1,044, confirmed by the Kolmogorov-Smirnov test. Regression analysis of the data revealed the dependence of DVA from training.

Index Terms – Dynamic visual acuity, static visual acuity, high-speed video recording of eye, Weibull distribution law, regression analysis, simulation modeling, Student's *t*-test.

1. INTRODUCTION

Visual efficiency (VE) – the ability to perform visual work and maintain a high degree of mobilization of visual function over the time. Visual efficiency affects on productivity and quality of work. Determination of parameters of visual efficiency is a very actual problem in professional selection.

Static visual acuity (SVA) – a spatial threshold of view, the ability to discern small or distant immobile objects.

Dynamic visual acuity (DVA) – an ability to determine the speed and direction of moving of the object and the ability to hold a picture of the subject on time enough to see it details; the ability to estimate the speed and direction of movement of the object; ability to visually "grab and hold" the image of the subject for a time enough to recognize its details.[1]

One of the measure of DVA – units of minimum object's presentation time, at which the subject is able to distinguish its elements (ms).

DVA – one of the measure of visual capacity.

There is the issue of evaluation of dynamic visual acuity, which is an important indicator of visual capacity of individuals associated with the perception of moving objects. Development of DVA estimation methods are necessary to assess the professional suitability, the reaction rate and adaptation abilities of human, vision correction, optimization of visual work under terms of active development of technology.

Widespread application of DVA assessment is restricted by the following factors: standardized methods and special equipment does not declare, standard values of DVA is not approved; and other causes. Brain mechanisms that are responsible for DVA, not fully investigated.

It is known that DVA is depends on: the static visual acuity, oculomotor function (smoothness of eye movements), age, speed of the observed object, physical exertion, presence of fatigue or insomnia [2].

Objectives of work: development of a new method of DVA assessment and unit for its execution; measurement of the DVA in the group of adults with various physical state; statistical and regression analysis of the data, identifying dependence of DVA from training.

2. REVIEW OF EXISTING DVA EVALUATION METHODS

Active scientific work in the field of DVA assessment began in the late 1940s. Prestrude (1987) noted that of approximately 250 published papers on DVA, foveal DVA was studied more often than peripheral DVA [3]. Currently there are more than 350 works devoted to DVA: Bhansali, Stockwell & Bojard (1993); Herdman, Schubert & Tusa (2001); Herdman, Tusa, Blatt, Suzuki, Venuto & Roberts (1998); Hillman, Bloomberg, McDonald & Cohen (1999); Lee, Durnford, Crowley & Rupert (1997); Longridge & Mallinson (1984), etc. [3, 6].

Table 1. Review of methods of evaluation of dynamic visual acuity.

Author	Mean	Method	Disadvantages
Hoogerheide (1964)	minimum discern band width for DVA is 25% wider than for SVA	Determination of the difference between the square and the two bands separated by a dark background ($S_{band} = S_{sq}$). Same luminosity of objects. Rotation on the dark display screen at rate of 2 rev/min.	obligatory observance of light conditions, the risk of guessing
Herdman (1998)	2.4 - 2.7 the number of missed optotypes regarding SVA	Computerized system. Speed sensor is located on the subject's forehead. Horizontal movement of the head at rate of 120-180 deg/s. Recognition of E on the screen till the error.	medical contraindications
Hillman (1999)	discerned line is on 2 position higher than for SVA	Recognition of objects while walking on a treadmill. Close to life conditions.	medical contraindications
Tian, Demer (2001)	75 ms	Recognition of E orientation, that randomly moving around the screen. Distance equal to 6 m. Full rotation of the body with a variable or fixed rate.	medical contraindications
Kohmura, Yoshigi, Sakuraba (2007)	30 m	Recognition of Landolt ring, forthcoming from a distance of 50 m. Speed equal 30 km/h. Determination of the distance at which the defect visually blurred.	no movement in the plane of view
	270 ms.	Two luminous objects appear on the screen almost synchronously. Task: to determine which earlier.	risk of guessing
Julia Bark (2008)	2-2.5 lines worse then SVA	Reading the Snellen test card while the head oscillation with a frequency of 2 Hz and 60 Hz vibration from a distance of 10 ft. Reading Lines from large to small.	medical contraindications, there is a numerical estimate
A. Kubarko, I.Lukashevich (2005)	90 ms	Computer-based method (Landolt ring moving on the screen). Electrooculogram record of eye movements. 107 people in age 18-25 years was examined.	obligatory observance of light conditions
	92 ms	The minimum time interval of distinguishing of appearance of two objects on the screen.	
Iuliia Rottc (2010)	22.03 ms	Method based on the presentation to the subject continuously moving optotypes, which are plot on the outer surface of the rotating cylinder. Measurement of maximum rate in which optotypes are distinguishable. Calculation of optotypes recognition time. [4, 5]	based on confidence in the subject answers

Geography of studies presented by researchers from the U.S., UK, Japan, Belarus, Russia (known for his work in Russia Saenko). Most well-known methods of estimating DVA grouped in the table 1, that shows information about the average dose values obtained by the authors of methods, highlighted the main identified disadvantages of methods.

Known mechanical devices designed for training DVA and not focused on its numerical evaluation. Most often in professional selection DVA assessment is carried out not as an independent research, but as a part of the research of assessment the vestibular apparatus condition, for example: the selection and training of astronauts and fighter pilots. [7] Therefore, usually it is not evaluated numerically.

3. METHOD BASED ON VIDEO RECORDING OF EYE MOVEMENTS

3.1. Membership of test groups of people

The test group consisted of persons who have no psychological or neurological diseases, and of subjects not observed symptoms of vestibular abnormalities. Among the subjects were people with normal SVA and with it deviations (nearsightedness, age farsightedness). Moreover, the test was carried out for people with disabilities in terms of natural vision and in the correction of vision through the lens.

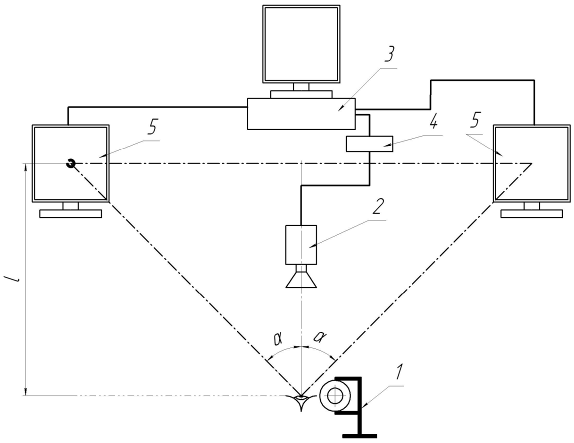

Fig. 1. Measuring unit

Professions of majority subjects were associated with prolonged use of the PC. Among the subjects were people involved in sports, in particular riders. DVA was measured for 9 subjects (10 measurement for each person). Age of group was 23-35 years old, the average age 26 years and 6 months (SD = 4.6).

3.2. Design and principle of unit operation

Block diagram of the measuring unit for the implementation of the new method is shown (Fig. 1).

The measuring unit includes a template for non-contact measurements 1, 2 high-speed camera connected to the computer 3 through frame grabber 4, 2 monitors on both sides of optical axis of camera for showing of optotypes 5, the information processing device – computer whith MATLAB software package and image processing program Osprey (development of TU Ilmenau [8, 9]) 3.

The method is carried out as follows. The subject sits in front of high-speed camcorder 1, thus visual axis of eye coincides with the optical axis of the camera. His head is placed in a specific position on a fixed stand. Template for non-contact measurement 5 is placed near the subject's eye. Focusing of camera on a sharp image of the pupil, which is visually monitored on the PC screen 2, are performed.

Subjects were asked to perform a task: fix gaze on the camera objective 1 without blinking; after the start signal to move the gaze from its initial position on the optotype [10, 11], which is shown on the screen of one of the two monitors 4 synchronously with the start signal; recognize the optotype as quickly as possible; look back to the initial position.

Beginning of the record is synchronized with the start of the test.

After the task the correctness of optotype recognition is analyzed. If the subject correctly identifies the optotype, the series of received frames is liable to further processing.

According to the results of measurements an array of coordinates of the center of the pupil, while moving on the test specified path, formed.

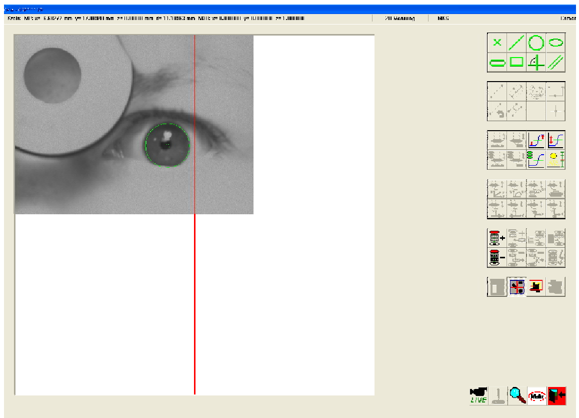

Fig. 2. Example of image processing

3.3. The experimental conditions

The first measurement was carried out with each subject, without prior training. Before repeated measurements made once a day, the subjects were asked to perform exercises to improve DVA (for example, reading signs while walking, or reading a scrolling text). Measurements were repeated during 10 days. Mainly, each subsequent measurement showed the best DVA results in comparison with previous.

Distance from the eye to the camera lens =300 mm.
Initial gaze direction – the camera lens.
Distance from eye to the optotype on the screen L = 1,118 m.
Template's internal hole size = 14 mm.
Persons head fixed in immobilizer.
The room is well lit.
Recording duration = 1 s.
All calculations in MATLAB.
Image processing by program Osprey [12].
Frames scaling through templates image measuring.
High-speed camera with shooting 90 f/s.
Minimum image resolution: 1280×1024.

4. PROCESSING OF RESULTS

4.1. Algorithm of mathematical data processing

During frame-by-frame processing of video sequence (Fig. 2), that characterizes the trajectory of the center of the pupil, in case of correct optotype identification, the coordinate of the center of the template is measured.

Coordinate of the template center on the frame is taken as the point of origin. The diameter of the template is measured in a frame to implement a calculations in units of length. Then the scale factor is calculated by the formula (1):

$$k = \frac{d_r}{d_f}, \qquad (1)$$

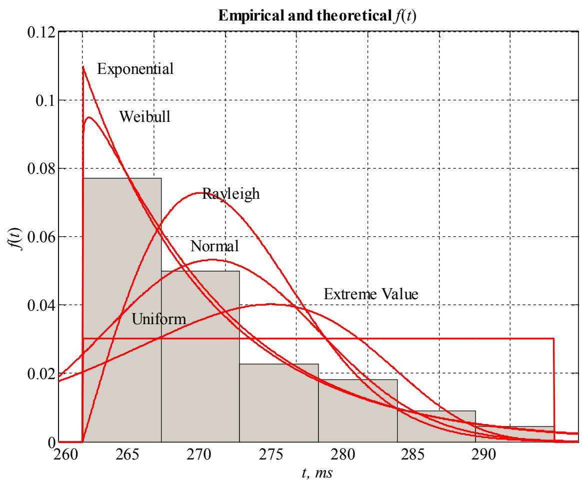

Fig. 3. Histogram of experimental data distribution

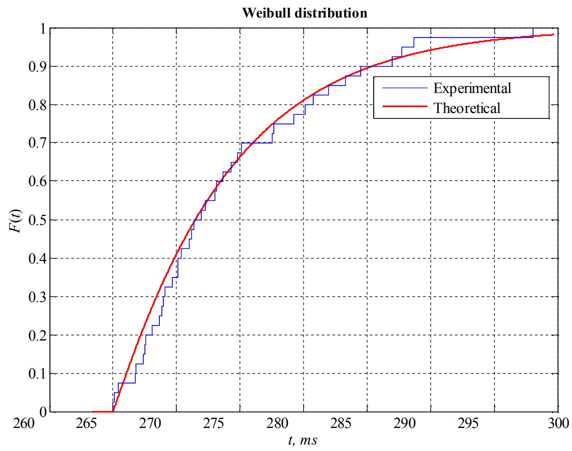

Fig. 4. Correspondence of experimental data distribution to Weibull low.

where k – scale factor, d_r – the actual diameter of the template, d_f – diameter of the template on the frame. The obtained value of scale factor k= 1,24.

Coordinate of position of the pupil in each frame relative to the point of origin is measured; an array X of the pupil center coordinates on each frame is formed; deviation of the pupil center coordinates for each frame relative to the first frame Δx_n calculated by the formula (2):

$$\Delta x_n = k \cdot (x_0 + (x_n - x_1)), \qquad (2)$$

where k – scale factor, x_0 – the point of origin, x_1 – coordinate of the pupil in the first frame, x_n – coordinate of the pupil in each subsequent frame, n=1,2 ... – number of each subsequent frame.

Thus, an array of coordinates of the pupil center position, while moving on the test specified path has been, formed. As additional information an arrays of the iris radius, form deviations and other were obtained.

Further, the maximum displacement of the pupil center, which corresponds to a maximum element of the array position pupil deviations ΔX, measured. An area of the initial position and maximum deviation of pupil center ε is calculated by formula (3):

$$\varepsilon = x_1 + \left| \frac{5 \cdot \Delta x_{\max}}{100} \right|. \qquad (3)$$

Obtained ε=100 micrometers.

The movement time of the pupil center to the coordinate, measured on each frame is estimated. A time values array T, each element of which has a corresponding to element of the array X is formed. By pupil position deviation array ΔX the number of element n_ε, belonging to the array X, is determined. Element n_ε correspond to the last frame in which the pupil position deviation Δx is located in the area of ε Δx_{max}: $\Delta x \geq | \Delta x_{max}$-ε |.

A mean value of n_ε=16. A correspondence with this element of the array X to element of array T is set. This element is the value of time spent on moving the center of the pupil from the initial coordinates to optotype and back, and optotype recognition. This time corresponds to the DVA.

The number of frames before the first gaze motion: 4-5 frames (65 ms). Number of eye movements frames (to optotype and back) – characteristic oculomotor function: 4-6 frames (32-50 ms). Hold of gaze at optotype – visual information processing speed: 13 frames (175 ms). DVA – the amount of the time before the first gaze motion, eye movements time and the time of gaze hold at optotype [8, 9, 13]:

$$\Delta t = t_0 + t_{mov} + t_{hold} = 65 + 32 + 272 \text{ ms}. \qquad (4)$$

4.2. Processing of measurement results in MATLAB

Program in MATLAB, developed by the authors of work, allows to calculate the number of frames that are relevant to each stage of the task, and presents a numbers of the corresponding frames. Time of frame recording relative to the start of the task determines by its number in the video sequence. The value of DVA accepts as the time, corresponding to the returning of the pupil center to the initial coordinates after the optotype recognition task.

As noted, the average value DVA obtained by using video recording of eye movements for 9 people equals 272 ms. The results of experimental data processing in MATLAB has shown below. Graphically, the processed data are presented as histograms of DVA values with imposition of envelopes, of the most common statistical laws, that built on the principle maximum likelihood estimation (Fig. 3). Additionally, the imposition of the distribution function of the experimental data on the empirical function presented on Fig. 4.

Calculation of data distribution parameters:
x_{min}=263,392, x_{max}=296,468;
Mean of sample: Mx=272,483;
Dispersion: Dx=57,693;
Standard deviation: Sx=7,595;

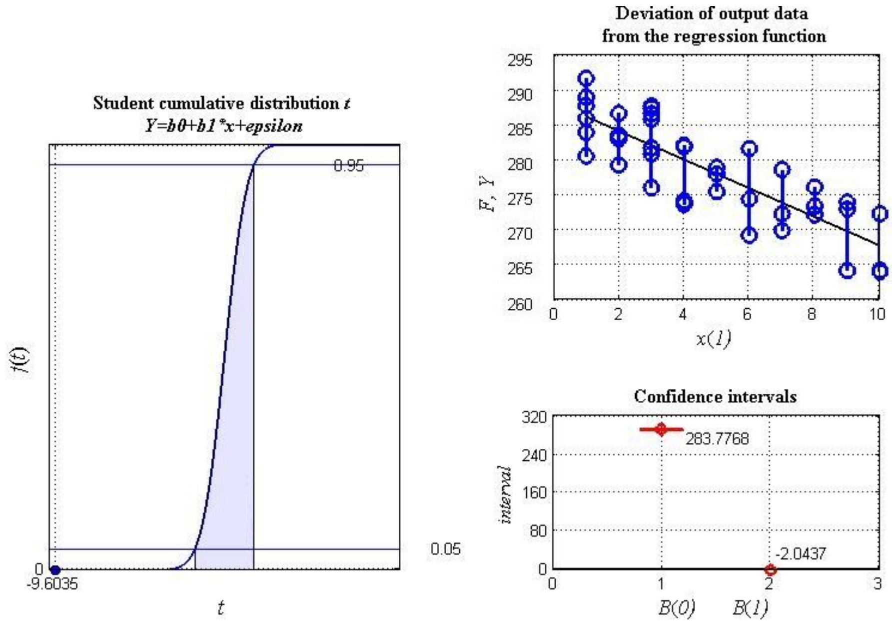

Fig. 5. Estimate of regression coefficients: Cumulative Student distribution; Deviations of output data from the regression function; Confidence intervals

Asymmetry: *Ax*=1,218;
Excess: *Ex*=1,258;
Quantity of intervals: *k*=6;
Width of the interval: *h*=5,512;
Parameters of distribution by Maximum Likelihood Estimation:
Extrem value distribution: μ=13,201; σ= 9,154;
Exponential distribution: μ=9,09;
Normal distribution: μ=9,09; σ=7,500;
Uniform distribution: a=0,001; b=33,075;
Rayleigh distribution: *A*=8,333;
Weibull distribution: *A*=9,221; *B*=1,044;

In accordance with the Kolmogorov criterion the Weibull distribution (A=9,221; B=1,044;) optimally fit for experimental data approximation. Critical significance level for it equal 0,847.

The laws of data distribution obtained by the authors and data published by the Belarusian medical researchers A. Kubarko, I. Lukashevich are in qualitative agreement (Weibull distribution). Taking as a reference value of DVA a A. Kubarko, I. Lukashevich data, that equal to 90 ms [2], the authors were able to introduce a correction factor to convert the measurement results obtained by different methods (k_{dva}=3,02):

$$k_{dva} = \frac{DVA_{autor}}{DVA_{Kubarko}}, \text{ ms.} \qquad (4)$$

5. REGRESSION ANALYSIS OF DATA

DVA values express in units of the object examining time enough the subject is able to distinguish its elements.

These units may lie only in the positive range of values. For modeling of distributions of these units can be used Weibull law or its particular cases: the exponential distribution (with constant coefficient of variation *V*=1) and the Rayleigh distribution (with *V*=0,523). The one-parameter distributions has only one parameter – the scale, as their form parameter *b*=const (for Rayleigh *b*=2, for exponential *b*=1).

Hypothesis that DVA distributed according to the Weibull law, validated by the Kolmogorov-Smirnov test of obtained data samples.

As large-scale experiments can not be made, the effective way to assessing DVA is simulation [8, 9, 12]. For calculation and simulation was used MATLAB tools.

The statistical parameters of the distributions DVA values were calculated. To validate the obtained data, a linear regression model was used for regression analysis of one-dimensional simulation systems (linear regression models) by the Ordinary Least Squares method (OLS). [13] Estimates of the coefficients of the approximation polynomial (regression coefficients) were calculated:

$$Y = \beta_0 + \beta_1 x_1 + \varepsilon(\mu, \sigma), \qquad (5)$$

here *Y* – the simulated value of DVA, *x* – influencing factor, ε – random component, σ – standard deviation and μ – the average of distribution of the simulated noise which calculated over the experimental data .

Dependence of the DVA from training was chosen for regression analysis. The regression coefficients are: β_0=281.86 and β_1=-1.99 (negative regression coefficient β_1 shows the corresponding slope of the approximation line, Fig. 5):

$$Y = 281{,}86 - 1{,}99 \cdot x_1 + \varepsilon(\mu = 272; \sigma = 7{,}5). \qquad (6)$$

Calculations of statistical estimates of the parameters with a significance level α=0,1, based on simulated data. After calculation of the values of $P(\beta\geq 0)$ and $p(\beta\leq 0)$, the value of p-values and confidence intervals of the coefficients an analysis of statistical significance of the coefficients carried out.[13, 14]

Verification that the regression coefficients are not contradict output data carried out on the basis of Student's t-test.

The results of verifications for the simulated experiments are shown in Fig. 5.

Value of a random variable $t = \frac{b_1 - \beta_1}{s_{y1}}$ with probability 0,9 lie in the interval $-1{,}684 \leq \frac{b_1 - \beta_1}{s_{y1}} \leq 1{,}684$.

Solution of these inequalities leads to the confidence interval, which covers the found estimate of coefficient b_1. Therefore the estimate b_1 taken as significant with a 10 percent level. In terms of the hypotheses, the verification that the regression coefficients are not contradict output data has the following wording.

Two hypotheses are tested: H_0: $\beta_1=0$, and its alternative H_1: $\beta_1\neq 0$. The fact that the confidence interval factor β_1 with probability 0,9 does not include zero, is the reason to reject the hypothesis H_0: $\beta_1=0$ and accept the hypothesis H_1: $\beta_1\neq 0$ at 10% significance level.

Numerical estimates are confirmed by graphical construction of confidence intervals (lower-right window).

The left window represents the Student's cumulate with symbols on it specified levels of 0.05 and 0.95 quantiles, t_{Stat} statistics and probability $P(t\leq t_{Stat})\equiv P(\beta\geq t)>0{,}95$, which also confirm previous findings about the statistical significance of estimate β_1 [14].

In the upper right window of Fig. 5 shows the regression function, which is defined as a linear function of one variable. Obtained coefficient b_1 determines the slope of the regression model, that simulate a linear depentanizer with a tangent of slope angle equal to b_1. The lines that connect the regression function with the experimental data represents the deviation output data X from the regression function Y, or so-called residuals.

Models are stable. In accordance with the above estimates can be argued that measuring of DVA correspond to the precision at 10% significance level [13].

6. AREAS OF POTENTIAL APPLICATION OF RESEARCH RESULTS

As DVA can be a valuable indicator of qualifications of individuals associated with the perception of moving objects, the results of research can be used in educational institutions for training of previously mentioned personnel, both military and civilian (pilots, astronauts, drivers, operational staff).

In the sports industry – professional selection, training of athletes.

Since the state of sensory functions of vision and eye movements depend on the functional state of a several brain structures, the evaluation of sensorimotor functions of the visual system and DVA determining used for the diagnosis of neurological and psychiatric disorders. In accordance with this, the study is of interest in the field of practical medicine (diagnosis of diseases, dose adjustment). Even development may be useful to medical research institutes (the study of the mechanisms of the visual system).

Evaluation of DVA is possible to assess human own capabilities in personal interests.

The results of research have already been applied in Ltd "Biotelemehanika" to development systems for collecting and processing information about the human condition (the results were used to estimate the dynamic visual acuity of athletes).

7. CONCLUSIONS

A new method of evaluation of dynamic visual acuity (DVA), based on the using of high-speed video recording of eye movements during the recognition of moving optotype (Landolt ring), which impose on the screen, was developed.

Operation of the unit and the calculations was carried out by the author's programs.

The average value of measured dynamic visual acuity (subjects in the age 23-35 years) is equal to 272 ms.

DVA level for people involved in sports, significantly better than for others. This is admittedly due to the regular trainings. However, can not be excluded an inverse relationship: people with good DVA shows some achievements in sport.

A statistical analysis in MATLAB showed that the distribution of the experimental data corresponds to the Weibull distribution law with parameters: scale A=9,221 and form B=1,044.

The statistical hypothesis confirmed by the Kolmogorov-Smirnov test.

It allows to simulate DVA distribution by Weibull and correctly carry out its assessment.

Improvement in DVA as a result of training were identified. The regression analysis of the data confirmed this fact.

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