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Influence of blurring to peripheral visual acuity

MASTER THESIS

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ABSTRACT

This master thesis is written on 39 pages and it contains 24 figures, 2 tables, 2 appendixes and 19 references.

Purpose: to study distance peripheral visual acuity in different refractive conditions of the free and blurred eye.

Subjects: 7 subjects - 3 myopic, 2 emmetropic and 2 hypermetropic persons. None of subjects had any pathologies of the visual system.

Methods: subjects` central visual acuity of the dominant eye was measured and corrected. Measurement of peripheral visual acuity was done using computer-based program FrACT 3.6.3 as a source of stimulus. Subjects were placed to 6 meters from the screen and their visual acuity of the dominant eye (with correction if needed) was measured foveally and peripherally, at 5 and 10 degrees on the temporal retina. Same procedure was repeated to all subjects with „blurring“ their visual acuity with +0,50D and +1,0D lenses.

Conclusions: computer-based program FrACT 3.6.3. is suitable for using in that kind of experiment; level of peripheral visual acuity corresponds to literature; different refractive groups were influenced by blurring lenses differently.

Keywords: visual acuity, peripheral vision, eye shape.

ANOTĀCIJA

Maģistra darbs ir uzrakstīts uz 39 lappusēm, satur 24 ilustrācijas, 2 tabulas, 2 pielikumus un atsauces uz 19 literatūras avotiem.

Mērķis: izpētīt acs perifēro redzi tālumā koriģētiem emetropiem un ametropiem ar un bez papildus apmiglojuma.

Eksperimenta dalībnieki: 7 personas – trīs miopas, divas hipermetropas un divas emetropas. Nevienai no personām nebija redzes patoloģiju.

Metode: dalībnieku vadošās acis tika koriģētas līdz maksimālajam redzes asumam. Perifērās redzes noteikšanai tika izmantots speciāli konstruēts datora monitora galds un stimulu avotam tika lietota programma FrACT 3.6.3. Dalībnieki ar fiksētu zodu tika novietoti 6 metru attālumā no tangenciāli pārvietojama monitora, to redzes asums tika noteikts centrā kā arī 5 un 10 grādus temporāli. Procedūra tika atkārtota arī ar papildus izkliedējošām lēcām +0,5 un +1,0 dioptrijas.

Secinājumi: centrālās un perifērās redzes asuma mērījumi tika iegūti ar relatīvi mazu standartnovirzi; izkliedējošās lēcas degradē redzi visām dalībnieku grupām līdzvērtīgi; 5 grādu ekscentricitātē hipermetropiem tika novērots ievērojams (0,20 Logmar units) redzes asuma samazinājums; hipermetropu redzes asuma kritums pie 5 grādiem tiek skaidrots ar acs ābola formu.

Atslēgas vārdi: redzes asums, redze perifērijā, acs ābola forma.

TABLE OF CONTENTS

Introduction.....	4
1. Human eye.....	5
1.1. Shape of the eye,	5
1.2. Distribution of photoreceptors.....	8
1.3. Contrast sensitivity of the eye.....	12
2. Visual acuity.....	15
2.1. Psychophysical measurements.....	15
2.2. Central visual acuity.....	16
2.3. Peripheral visual acuity.....	17
2.4. Aberrations.....	19
3. Experimental part.....	22
3.1. Subjects and methods.....	22
3.2. Results.....	25
3.3. Discussion.....	26
4. Conclusions.....	32
5. Final remarks.....	33
References.....	34
Appendix.....	36
Appendix 1.....	36
Appendix 2.....	39

INTRODUCTION

Different areas of human retina give different results in visual acuity. Peripheral vision is less distinct due to the lower optical quality of the eye and the coarser sampling density of the retina. When doing refractions optometrists examine different visual functions in distance and near. However, practically never optometrists are involved in studying visual functions in periphery. On the other hand there are several visual tasks which can be not realized without assistance of peripheral vision. For example: shift of attention or attention as such; locomotion and correct responses on changes in surrounding; quick and adequate responses of car driver; in case of near tasks we cannot forget reading.

The aim of this study was to compare visual acuity of peripheral stimuli perception of emmetropic and full corrected ametropic persons. Peripheral visual acuity was studied in distance and blurring with plus lenses was used as an additional disturbance agent.

Hypothesis: in cases of axial refraction errors we must consider that emmetropic and ametropic eyes have different shapes. Emmetropic eye is close to spherical shape, myopic eye is close to prolate shape and hyperopic eye is more flat (oblate). In case of moderate angles myopic eye shows better (nearly the same as emmetropic) peripheral visual acuity compared to hyperopic eye.

Considering that there is no evidence of big differences in the distribution of photoreceptors in the retina of eyes with different refraction, we are able to state that peripheral visual acuity may give us information about the shape of the eye. However, it can be not true in case of true refractive ametropia. The same is true also in cases when myopic eye is spherical, but bigger than emmetropic.

Objectives: approval of different impact of blurred stimuli on peripheral visual acuity of different refractive groups; evaluation of distance visual acuity in natural conditions depending on angular distance from visual axes (0, 5 and 10 degrees); investigating peripheral visual acuity in different refractive conditions of the eye.

Tasks: to construct set up for peripheral visual acuity examination at 0, 5 and 10 degree angles with minimal bias of subjects; to explain essence of the experiment to subjects; to collect data and analyze it; to make conclusions.

Results: all subjects demonstrated relatively low visual acuity in periphery; peripheral visual acuity of hypermetropic refractive group decreased at 5° more rapidly comparing to other 2 groups.

1. HUMAN EYE

1.1. Shape of the eye

Ideal shape of the human emmetropic eyeball is spherical, which enables to the rays of light to converge on the different points of retina undependingly from the object location, giving us foveal (central) or parafoveal relatively good visual acuity. Non-spherical shape of the human eye may cause foveal and retinal defocus (axial ametropia) Fig.1.1.

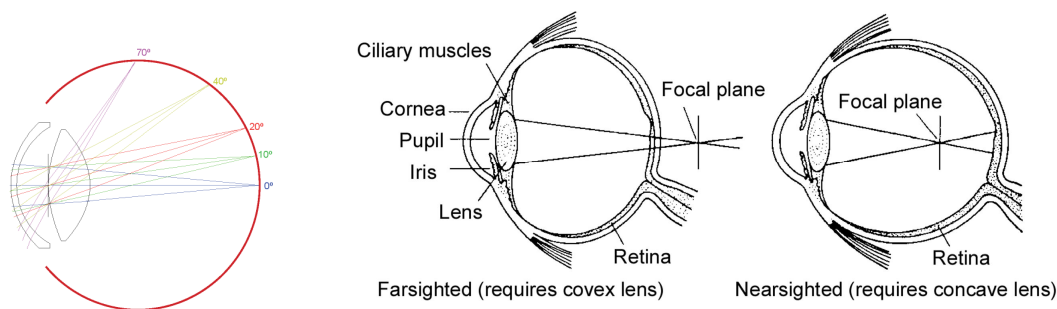


Fig.1.1 Spherical (left) model of the eye compared to hyperopic (middle) and myopic (right).

Only a few studies permit inferences about the shape of the human eye. They involved either imaging methods that directly visualise the eye or optical techniques that indirectly suggest eye shape. These studies suggest that eye shape varies between individuals and may prove an informative parameter in studying the underlying mechanisms of myopia. Three shapes are described for the human eye: spherical, prolate (or elongated along the visual axis) and oblate, or widened in the equatorial dimensions (Fig.1.2.). On balance, the literature suggests that emmetropic eyes tend to be spherical, myopic eyes tend to be prolate and hyperopic eyes tend to be oblate. Current laboratory investigations, however, suggest a need to re-examine the relationship of human eye shape and refraction [1].

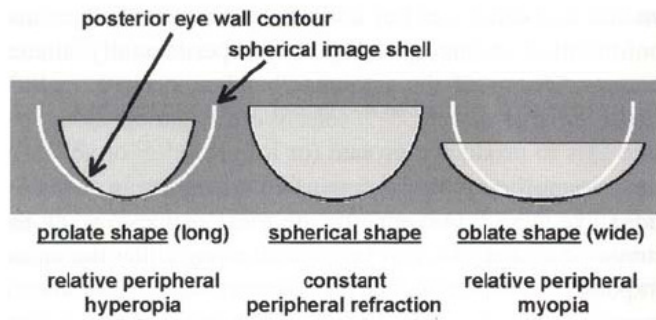


Figure 1.2. Relative peripheral refraction and posterior eye shape. The relationship between the posterior eye wall contour (black curve) and a spherical image shell (white curve) is illustrated for an emmetropic eye. The posterior eye wall and the image shell coincide for each eye shape at the posterior pole, but their relationship in the periphery varies with eye shape. For myopic eyes, the eye wall is displaced posteriorly from the image shell; for hyperopic eyes, the eyes, it is displaced anteriorly [1].

The optical role played by the ocular components once myopia has occurred is well understood; axial length exceeds the focal length formed by the refractive elements of the eye. Compared with other ocular components such as the cornea and crystalline lens, axial length is typically regarded as the primary determinant of refractive error. The correlation with refractive error is larger for axial length than for any other component (0.76). The correlation between change in axial length and progression of myopia, documented in recent bifocal clinical trials, is also quite high, between 0.77 and 0.89. Despite playing a primary role in prevalent myopia and myopic progression, the changes in axial length before and at the onset of myopia have not been documented extensively. Goss and Jackson found no differences 1 year before the onset of myopia between axial length in 24 children who became myopic compared to 56 children who remained emmetropic. However, this finding may be due to a small sample size and limited statistical power. In a study with a larger sample, Zadnik et al. have reported that children at greater risk for the onset of myopia by virtue of having two myopic parents have longer axial lengths than do other nonmyopic children with one or no myopic parents. A greater axial length in nonmyopic third-grade children was also a risk factor for the onset of myopia by the eighth grade. If an excessively long axial length in children is to be used as a predictive factor, the timing of axial elongation before myopia's onset is of particular interest [2].

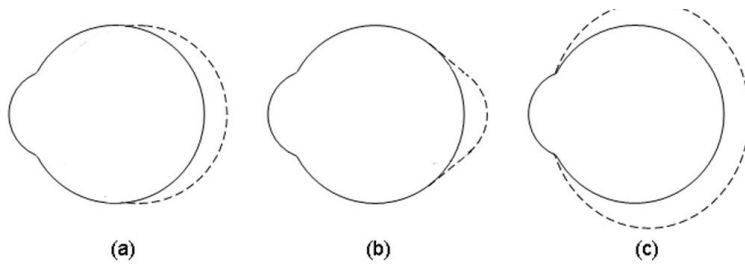


Figure 1.3. Models of myopia: (a) equatorial stretching, (b) posterior pole elongation, and (c) global expansion [3].

The rate of growth in axial length before, during, and after myopia's onset has not been documented in detail. Several patterns are possible for growth. Children at risk for the development of myopia may have an excessively long axial length before onset, but display a similar rate of increase compared with that in children who remain emmetropic. As long as axial growth outpaced the loss of diopters from the cornea and crystalline lens, myopia would be the result of a slow, steady loss of hyperopia. Another possibility is for the axial length in children who become myopic to exhibit a more rapid rate of growth than that in children who remain emmetropic. How consistent this rate may be over time is another open question. The coincidence of any acceleration in growth with respect to environmental exposures such as changing levels of near work or accommodative lag could also shed light on the mechanisms underlying the development of myopia. In addition to having excessive length, myopic eyes have been reported to have altered shapes relative to emmetropic or hyperopic eyes (i.e., the eye has grown longer axially than equatorially to become either relatively less oblate or prolate in shape) (Fig. 1.4.). This asymmetry in shape has been detected by x-ray, interferometry, and magnetic resonance scanning. A recent MRI study found that the myopic eye is typically oblate and only rarely prolate, and that the retinal contour becomes less oblate with increasing myopia. Alterations in shape also influence peripheral refractions, with myopic eyes typically having relatively more hyperopic peripheral refractive errors than do emmetropic eyes. Studies consistently have shown considerable variability and overlap in shape as a function of refractive error group. Of note, there are related meridional differences (i.e., peripheral refractive errors were more hyperopic relative to central errors in the horizontal meridian but were more myopic than central errors in the vertical meridian). This corresponds to reports of a greater vertical height than horizontal width of the globe, along with more relative oblateness vertically than horizontally, as a function of degree of myopia [2].

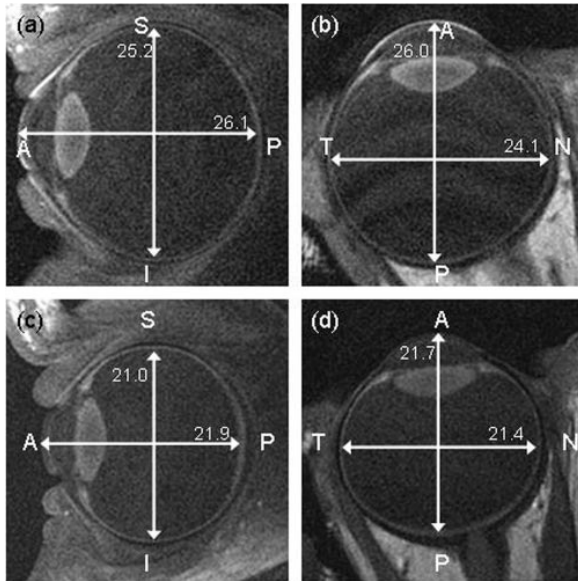


Figure 1.4. MRI slices of typical emmetropic and myopic eyes. The top images are those of a myopic eye (best sphere correction, -7.63 D) of a male participant (a, b) and the lower images of an emmetropic eye (best sphere correction, -0.13 D) of a female participant (c, d). Scans were taken in the sagittal plane (a, c) and through the axial section (b, d) of the eye. Length measures (millimeters) were taken from both the axial and sagittal sections, height from the sagittal image, and width from the axial image. In this example the greater length, height, and width of the myopic eye are easily observed. A, anterior; P, posterior; N, nasal; T, temporal; S, superior; I, inferior[3].

Although myopic eyes tend to be greater in all dimensions than emmetropic eyes, they are elongated more in the axial than the vertical dimension and are elongated much less in the horizontal dimension. We suggest this difference is most likely due to anatomic constraints of the orbital walls. Approximately a quarter of the myopic participants fitted each of the global expansion and axial elongation models exclusively, with a limitation of these models being the large variability of shape and size of emmetropic eyes [3].

1.2. Distribution of photoreceptors and visual capability in periphery

Regions of higher and lower illuminance in the retinal image are encoded into a spatial pattern of hyperpolarization in the retinal photoreceptors – that is, a neural image. Potentially, acuity can be lost during the photoreceptor encoding process if adjacent receptors are spaced further apart than the details in the retinal image. Spacing of the photoreceptors in the human fovea is well matched to the spacing of the finest details that the optics of the eye can produce in the retinal image [4].

The correspondence between photoreceptor spacing and the optical properties of the eye does not hold outside the foveal region where the spacing between adjacent cone receptors is too coarse to accurately encode all of the details in the retinal image. Neural defocus blends together gradations between the responses of neighboring photoreceptors at later processing stages. If the different signals from many photoreceptors converge onto a single neuron at a subsequent level of processing, then the neural image at this more subsequent level is, effectively, defocused. The receptive fields of ganglion cells in the peripheral retina combine (via the bipolar cells) information from a large number of photoreceptors, thereby introducing neural defocus and degrading visual acuity [4].

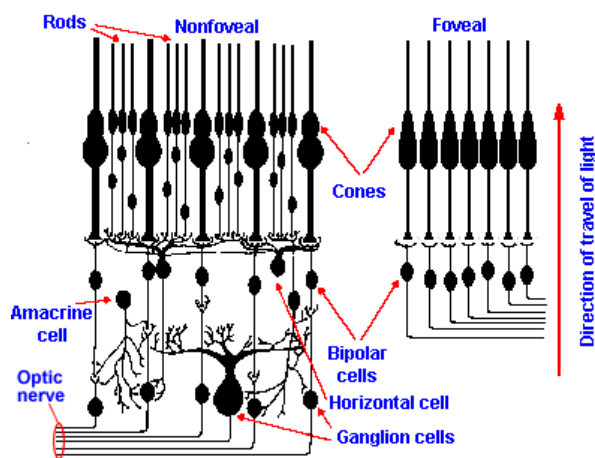


Fig. 1.5. The cellular organization of the foveal and nonfoveal retina [4].

The lower resolution of the peripheral retina is clearly seen in the lower density of photoreceptors and ganglion cells. This is also understood from the fact that only two thirds of the two million nerve fibers, from the eyes to the brain, emerges from the peripheral retina, even though the periphery makes up over 90 % of the total retinal area (Fig.1.5.). In the fovea there is at least one ganglion cell for each cone, whereas in the periphery one ganglion cell is connected to multiple photoreceptors; on average, there is one ganglion cell on 125-130 photoreceptors over the retina. This decrease in spacing of ganglion cells is often faster than the deterioration of image quality, which implies that high spatial frequencies of peripheral objects can be detected via aliasing without being resolved [5].

The most frequently quoted work is that of Wertheim, whose number for the decrease in visual acuity in the horizontal meridian is the one generally reproduced. Visual acuity is reduced to 6/12 at 2.5° and to 6/30 at 10° on the nasal side of the fovea. On the temporal side of the fovea visual acuity decreases somewhat more rapidly. Of special importance is

Wertheim's observation that it decreases more sharply below and, especially, above the fovea, so that lines connecting points of equal visual acuity are elliptic, paralleling the outer margins of the visual field. Later studies have given more detailed information about reduction in visual acuity in the region from the center to 10° from the fovea (Fig. 1.6.).

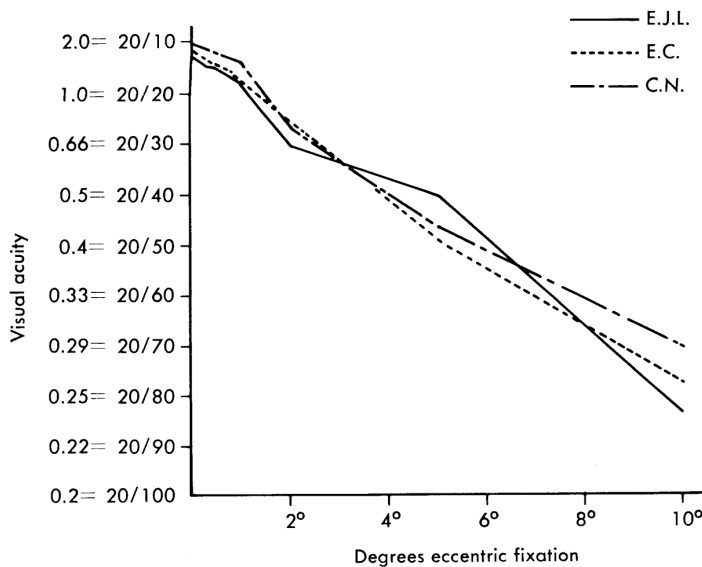


Figure 1.6. Decrease in visual acuity for three subjects from the fovea to 10° eccentrically [6].

Peripheral visual acuity declines with advancing age. A decrease in visual acuity from the center to the periphery must be related in some way to the retinal mosaic. Ludvigh's [6] data (see Fig. 1.7.) indicate that the visual acuity curve does not parallel linear or areal density of cones from center to periphery. Weymouth [6] made the intriguing and reasonable suggestion that the resolving power of a retinal area depends not on the number of cones present but on the number of perceptual units in that area. It is generally believed that the number of receptors connected by a single fiber to the brain defines the extent of a sensory unit. The ganglion cells are the cells of origin of the optic nerve fibers. Weymouth, who proposed that the density of ganglion cells rather than that of the cones should be related to the minimal angle of resolution, showed that this minimal angle of resolution, the reciprocal of visual acuity, was linearly related to the distance from the fovea. He also found a linear relationship between the density of the ganglion cells and their distance from the fovea [6].

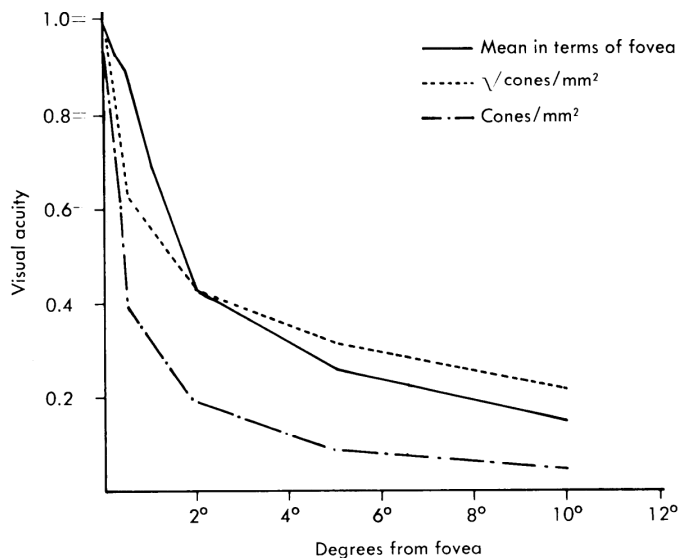


Fig. 1.7. Data indicating that the decrease in visual acuity from the fovea to 10° eccentrically (solid line) does not parallel the linear (broken line) or areal (dotted line) density of the cones [6].

Our ability to make judgments regarding visually presented stimuli varies across the visual field according to the required task. For example the detection of large, rapid-moving objects in the periphery of the visual field remains almost as good as if the objects were near central vision. On the other hand, our performance in tasks demanding precise spatial localization of objects declines rapidly on moving away from the central visual field. For many visual tasks, performance in the periphery can be made equivalent to that at the fovea simply by applying a scaling or magnification factor to the stimuli used. The direct implication of this statement is that peripheral vision is qualitatively identical to central vision, simply differing in quantitative terms. The physical process of stimulus magnification reflects the physiological observation that, at a cortical level, neural sampling declines systematically as a function of eccentricity—a relationship commonly known as cortical magnification. However, the scaling (or magnification) which stimuli require for performance to be made equivalent to that at the fovea has been found to vary dramatically (over 100-fold) and be highly dependent on visual task. In the case of the two aforementioned tasks, judgments of relative position require a dramatic increase in magnification on moving away from the fovea, while some judgments of motion require virtually no magnification at all. The neural mechanisms underlying this observation remain unclear [7].

1.3. Contrast sensitivity of the eye

Visual acuity of the eye is also affected by the contrast of stimuli. The finest limits of resolution have been determined by the ability to discriminate a thin white line against a uniform background illumination (0,5' of arc). The degree of contrast (C) is described in terms of the maximum (I_{\max}) and the minimum (I_{\min}) as follows:

$$C = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}$$

Discrimination of the grating is described as dependence of threshold from stimuli spatial frequency in cycles per degree (the grating frequency) and visual acuity is equivalent to $1/\text{grating frequency}$. Using this method it has been shown that there is a peak response in the middle range of frequencies (Fig. 1.8.) Contrast sensitivity is therefore set by the limits of the grating frequency and is affected by both the optics of the system and the direction of the grating lines, being most sensitive in vertical or horizontal directions [8].

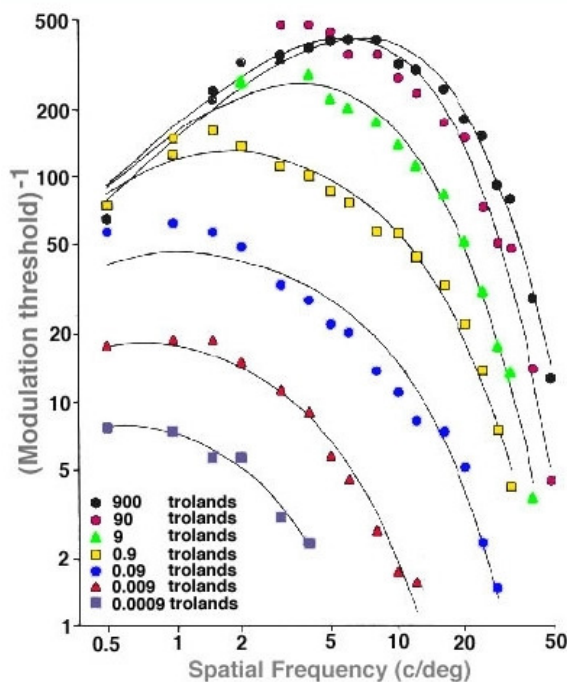


Fig 1.8. Contrast sensitivity function showing a change in shape from low pass at low luminances and bandpass at high luminances [9].

The previously given spatial contrast sensitivity model is restricted to the normal situation of the foveal vision. Outside fovea the contrast sensitivity and resolution of the eye

is much less, caused by the density variation of the cones and ganglion cells over the retina. Measurements of the density of cones and rods as a function of eccentricity have already been made in the first part of the 19th century by Østerberg. Later these measurements have been confirmed by Williams and co-workers (1988) [10].

Johnston (1987) measured the contrast sensitivity function at different eccentricities in the nasal visual field. This field corresponds with the temporal half along the horizontal meridian of retina. An emphasis was made on the high-frequency part of the contrast sensitivity curve. The test object was a vertical or horizontal sinusoidal grating pattern generated on the screen of an oscilloscope provided with blue-green P31 phosphor. Measurements and calculations are shown in Fig.1.9 [10].

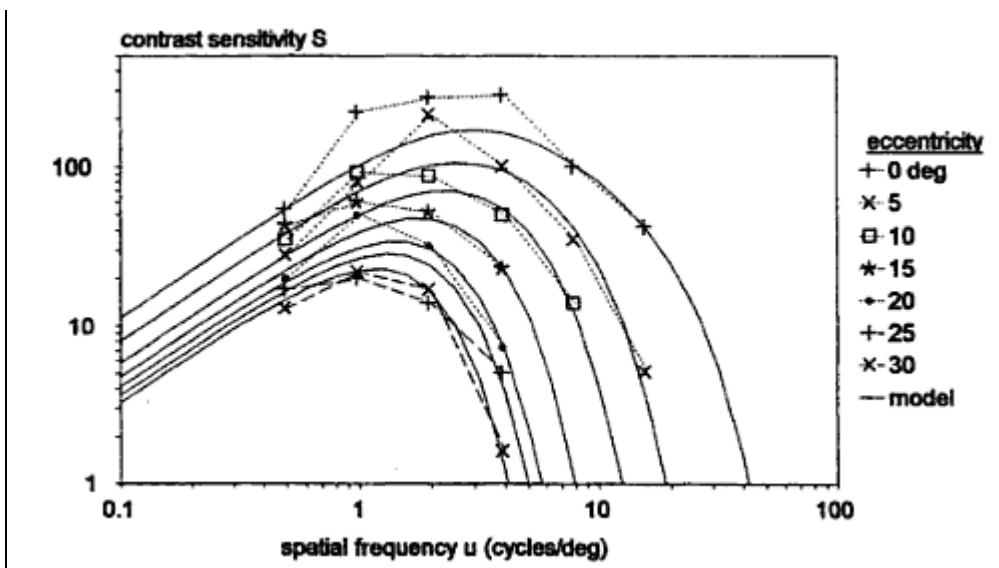


Fig. 1.9. Contrast sensitivity function measured at different eccentricities along the temporal half of the horizontal meridian of the retina. Luminance 10 cd/m². Square field with a size inversely proportional to the spatial frequency. Monocular viewing with a natural pupil [10]

Figure 1.10. shows the measured contrast sensitivity as a function of spatial frequency for first-order gratings in central and peripheral vision up to 20 deg. The foveal data reflect the descending limb of the traditional contrast sensitivity function for achromatic stimuli with sensitivity declining approximately linearly with increasing spatial frequency. In the periphery, lower spatial frequency stimuli (larger stimuli) are required to obtain sensitivity values equivalent to those at the fovea. This is reflected in the sequential leftwards shift of the functions with increasing eccentricity. The eccentricity dependence of the data can be

accounted for by applying scaling factors to the peripheral curves in order to superimpose them upon the foveal function [7].

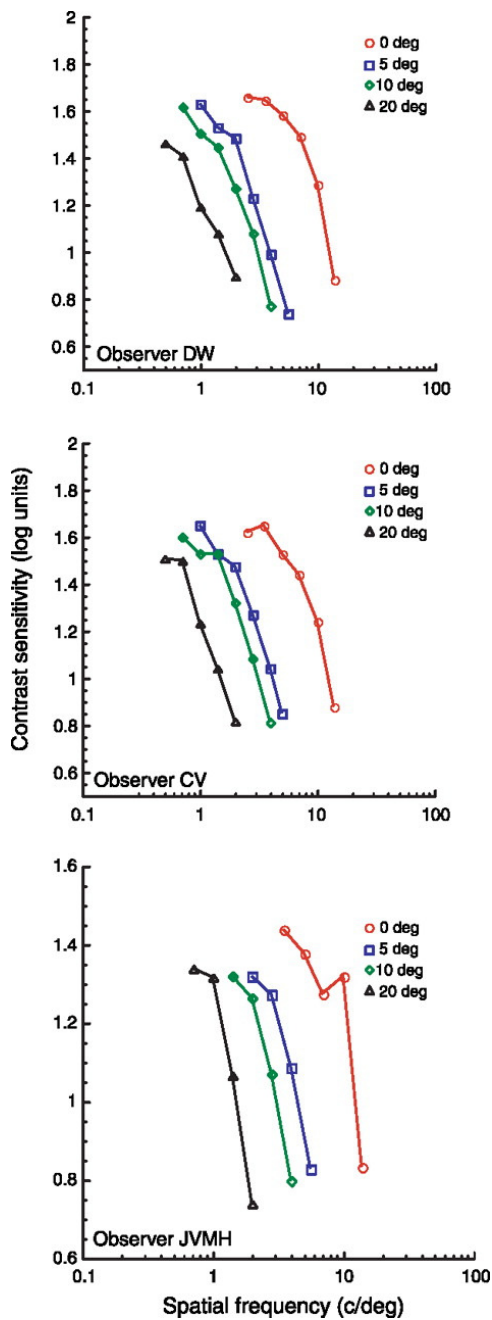


Fig. 1.10. Sensitivity as a function of spatial frequency across four different eccentricities for first-order stimuli. Data for three observers—DW (upper), CV (middle), and JVMH (lower figure). Note that progressively lower spatial frequency stimuli are required for the eccentric locations in order to reach the same level of performance as that at the fovea. Circles: 0 deg, squares: 5 deg, diamonds: 10 deg, triangles: 20 deg. [7]

2. VISUAL ACUITY

2.1. Psychophysical measurements

Any subjective examination of the eye and visual system of a subject consists of a series of psychophysical tests. The patient (subject) indicates alternations in his perceptual response when some dimension of a physical stimulus is changed. Most common psychophysical measurements are visual thresholds, which are divided by character of the experiment as absolute, difference and increment threshold.

There are three types of threshold tasks – detection task, discrimination task and recognition task. Accomplishing tasks, such as efficiently determining acuity and refractive error or locating possible visual-field losses, requires the use of procedures that give accurate, reliable results with the fewest number of stimulus presentations, without requiring sophisticated judgments on the part of the subject, and with minimal opportunities for psychological bias to affect the results. Psychophysical measurements of visual function involve presenting visual stimuli that vary along any one of a number of possible dimensions, including intensity, wavenlength, size, exposure duration, shape, relative locations of the elements of the stimulus, and cognitive meaning. In addition, the location of stimuli on the subject`s retina and the level of light adaptation of the subject`s visual system need to be controlled. In the ideal measurement procedure, all stimulus dimensions except one are fixed, and that one dimension is varied according to some pattern dictated by the psychophysical procedure that is used [11].

To construct a psychometric function, a large number of stimuli of various visibilities are presented (trials). If the experiment forces the observer to choose among two alternatives (yes/no;up/down), it is referred to as a two-alternative forced choice (2AFC) experiment (Fig.2.1.).

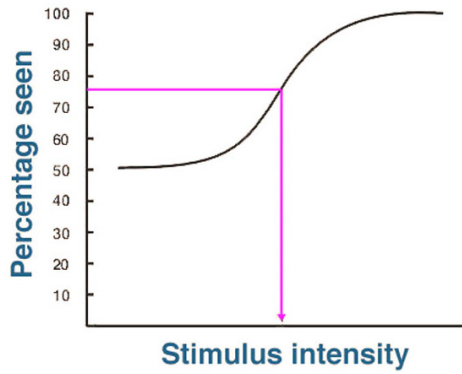


Fig.2.1. Psychometric function for 2AFC. Threshold is taken at the 75% seen level [12].

Choosing from four alternatives and six alternatives are called 4AFC and 6AFC, respectively. The percentage correct for the various stimuli intensities can be used to construct a psychometric function to determine threshold. As there is already a 50% chance of a correct response with 2AFC, threshold is commonly considered as 75% [12].

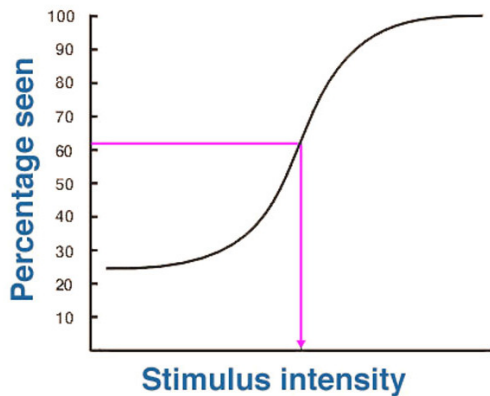


Fig. 2.2. Psychometric function for 4AFC. Threshold is taken at the 62.5% seen level [12].

The psychometric function for this experiment shows a chance level performance of 25 percent. Threshold is taken as the point midway between this chance performance and 100 percent, which is 62,5 percent. Forced choice methodology typically results in lower thresholds than other psychophysical methodologies. When observers are forced to guess, they often do remarkably well despite claims that they cannot see stimulus [12].

2.2. Central visual acuity

Spatial visual acuity is the smallest spatial detail that can be detected, discriminated or identified. The major types of spatial visual acuity are detection, localisation and resolution acuity. Resolution acuity is the smallest spatial separation between two nearby points or lines that can be discriminated – that is, the minimum angle of resolution (MAR). Although various scales are used to represent acuity results, the logMAR scale provides estimates of acuity that are probably the easiest to interpret and compare across individuals and conditions. Letter acuity becomes worse with optical defocus, reduced target luminance or contrast, and distance from the fovea. Visual acuity also is degraded for moving and for briefly presented targets. Another limitation of visual acuity can be neural defocus, which results from the convergence of spatial information onto neurons with large receptive field centers [4].

Under optimal imaging conditions, the eye's optics and the spacing of the foveal cones (center to center spacing of 20-40 μ m in the fovea) allow some subjects to resolve two points or two lines that are approximately 30-40 μ m (0,5 μ m) apart. This is called the minimum angle of resolution (MAR). Not all eyes are able to achieve a MAR of 0,5 μ m even when they are using an optimal correction for any refractive error. If the optics of the eye provides sharp enough images, a fovea with smaller cones would be expected to resolve smaller separations between images than a fovea with larger cones [4].

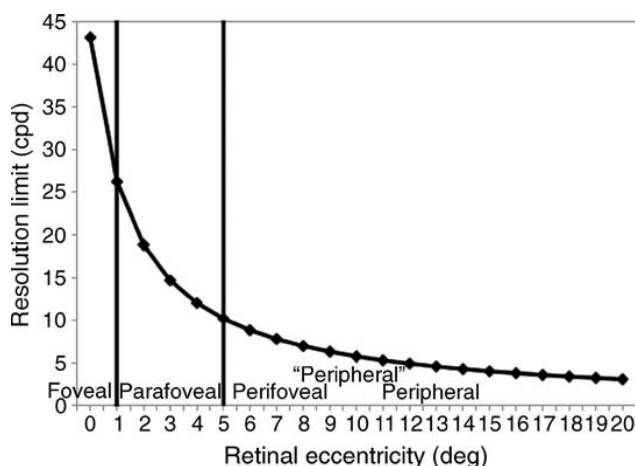


Fig. 2.3. The limits of visual resolution as a function of retinal eccentricity, with the visual field divided into three regions: Foveal, Parafoveal, and Peripheral. Resolution limits are in terms of spatial frequency cut-offs in cycles/degree (cpd) [13].

2.3. Peripheral visual acuity

The two major differences between the foveal and the peripheral parts of the eye are the performance of the optical system and the sampling density of photoreceptors on the retina. The fovea gives sharp and detailed information of what we fixate, since the optics of the eye and the retina are optimized here. Peripheral vision is normally only used for balance and orientation, which puts lower demands on image quality and retinal resolution [5].

When you fixate a stimulus, the corresponding retinal image of that stimulus falls directly upon the fovea. However, when a stimulus target is presented at a location other than the fixation point its corresponding retinal image falls outside of the fovea. Since the fovea contains the highest density of cones and is subserved by a disproportionately greater volume of cortical tissue than any other area of the retina (i.e., the so-called cortical magnification effect) it should not be surprising to learn that optimal visual acuity is observed for targets falling directly upon the fovea. Acuity for non-foveal targets is clearly suboptimal as can be seen in the special eye chart presented in Figure 2.4.[14].



Fig. 2.4. Special chart prepared to demonstrate how visual acuity decreases rapidly with target distance from the fovea. According to Anstis (1974), when the center of the chart is fixated at approximately normal reading distance, all the letters should be equally legible, since increasing target distance from the fovea is offset by a corresponding increase in letter size [15].

In daylight or at normal indoor luminance levels, visual acuity is best when targets are imaged on the center of the fovea because of the small, tightly packed cones in this region. Acuity is systematically poorer for targets presented to other retinal regions, even when the targets remain within the rod-free fovea (Weymouth et al.1928). Weymouth showed that, to a

first approximation, the change in photopic acuity is linear with retinal eccentricity when acuities are expressed as the MAR. However, the rate at which acuity worsens with distance from the fovea differs according to the acuity task. As shown in Figure 2.5. acuity worsens more rapidly for localization acuity and more slowly for grating resolution and letter identification. When expressed at MAR, letter and grating acuity worsen to twice the foveal value at eccentricities of approximately $2,0^\circ$ and $2,5^\circ$, respectively. The rate at which resolution changes with eccentricity is not the same for different retinal meridians: Acuity worsens more slowly along the horizontal than along the vertical meridian of the field and is better in the temporal than in the nasal visual field [4].

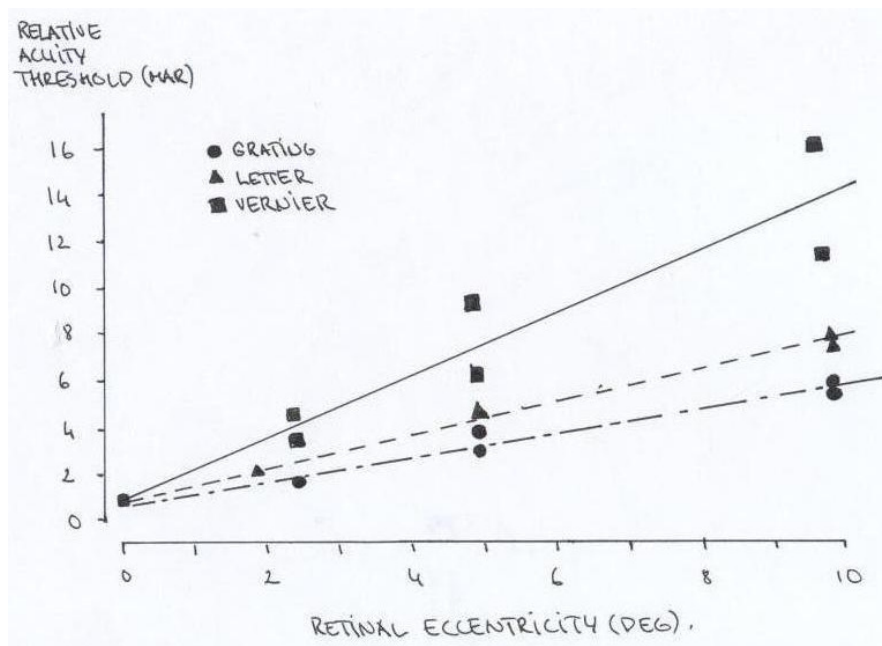


Fig. 2.4. Changes in visual acuity on different retinal locations [4].

2.4. Aberrations of the eye

Aberrations in an optical system basically mean that not all the light is focused to a diffraction-limited spot; some of the light is deviated and blurs the image. Aberrations in the eye will produce a distorted wavefront, where the different parts of the wavefront do not propagate towards the same center of curvature, and thus no distinct far point can be found. The refractive errors are sometimes considered as the lower order aberrations. Higher order aberrations are caused by errors in the refractive power of the eye, which vary over the pupil. The higher order aberrations are thus more difficult to correct, but fortunately, they usually do

not deteriorate the retinal image as much as the refractive errors do. The amount and kind of higher order aberrations varies between individuals, but a person's left and right eye often show mirror symmetry [5].

The influence of the higher order aberrations increases with the pupil size, as is shown in Fig. 2.5. The reason for this is that the off-axis optics of the eye is less optimized and thus contains more aberrations.

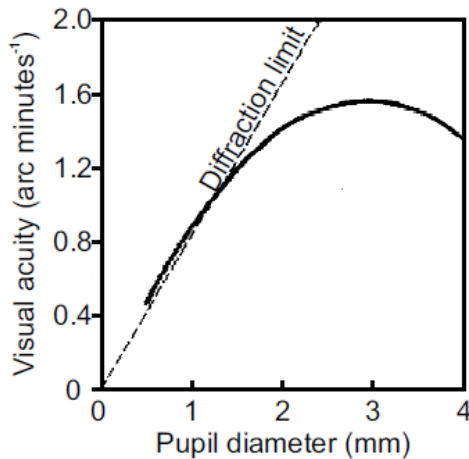


Fig. 2.5. The resolving power of the eye as a function of pupil size (solid curve), the theoretical diffraction limit is shown as a dashed line [5].

In bright daylight, when the pupil diameter is small, the foveal image quality is limited mainly by diffraction. Most eyes with their proper refractive correction are diffraction-limited at pupil diameters up to 2 mm. The optimum image quality can be found for pupil sizes around 2 - 4 mm, provided that the retinal illumination is sufficient.

Aberrations in the eye are often measured on the wavefront, which propagates out of the eye from a point on the retina (Fig. 2.6). If the eye is emmetropic and perfectly without aberrations, this wavefront should ideally be plane and the wavefront aberration, $\Phi(x; y)$, is defined as the deviation from this perfect wavefront. Quantifying the amount of higher order aberrations of an eye is simplified with a RMS-value, i.e., the root-mean-square of the wavefront aberration without the refractive errors

$$RMS = \sqrt{\frac{\iint \Phi(x, y)^2 dx dy}{\text{pupil area}}},$$

where x and y are the pupil coordinates. The RMS-value gives a rough estimate of whether the eye has large aberrations or not. At a pupil diameter of 3 mm a normal RMS-value is

around $0.04 - 0.1 \mu\text{m}$ and at 6 mm they increase to about $0.2 - 0.5 \mu\text{m}$. More accurate evaluations of the aberrations require that the PSF of the eye is calculated from the wavefront, since different aberrations influence the retinal image quality in different ways [5].

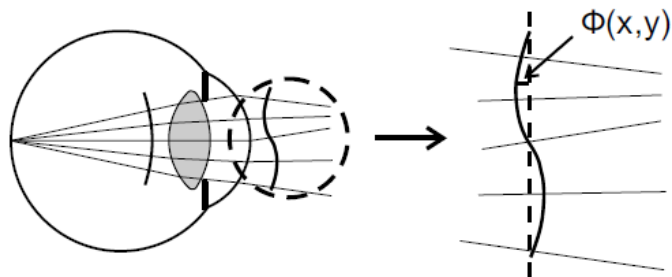


Fig. 2.6. Wavefront aberrations, $\Phi(x,y)$, shown together with a plane reference wavefront (dashed) [5].

3. EXPERIMENTAL PART

3.1. Subjects and methods

There were 7 subjects picked up for this experiment: 2 emmetropes, 2 hypermetropes and 3 myops. Refractive errors were from -4,0 D to +2,5 D. None of the subjects had any pathologies of the visual system and all of them were instructed about character of this experiment.

All subjects` (having only or not spherical ametropia) central visual acuity of the dominant eye was corrected to 1,0 decimal notation (0,0 logMAR) using trial frame Oculus with large metal-framed trial lenses. Distance of subjects to the visual acuity chart on the computer screen was real 6 meters.

Acuity is calculated as mean from then tasks each being realized by computer based program Freiburg Visual Acuity Test 3.6.3 (FrACT 3.6.3) (Fig.3.1. [16]). For the start there was performed full calibration and setup of the program, to avoid any possible flaws.

The screenshot shows the 'FrACT — Setup' window with the following settings:

- # of choices (acuity & contrast): 4
- # of trials @ 2/4/8 choices: 42, 30, 24
- 'easy trials': never
- timeouts: display 30 s, response 1 s
- optotype contrast: 100 %
- contrast-C: dia 30 arcmin, dark on li
- position x, y: 0, 0 deg
- full screen: mirrored display:
- show trial info: 2x '5' aborts:
- results → clipboard: no
- decimal-point character: dot
- auditory feedback when done:
- auditory feedback: with info
- mask on response: none
- threshold definition: psychometric
- max displayed acuity: 1.2
- crowding inducers: none
- which test on pressing '5': Acuity Landolt-C
- allow (uncertified) Sloan letters:
- allow (experimental) Face acuity:
- acuity format: decimal Snellen fraction [ft]
logMAR Snellen fraction [m]
- Snellen denominator 20 ft:
- Observer distance: 600 cm
- Length of the blue ruler: 205 mm
- [→ 1 pixel = 0.17 arcmin, max. VA = 5.96]

Buttons at the bottom: Calibration check, Luminance linearisat, Transmit Results, Help, Defaults, Ok.

Fig. 3.1. Setup form for FrACT 3.6.3. [16]

Program settings were:

1. Acuity-Landolt C with 4 choices / up, down, left, right /
2. optotype contrast 100% , black optotype, white background
3. distance of measurements was 6 meters
4. 30 trials for each measurement
5. time for response: 1 second
6. acuity format – decimal and logMAR

Subject was placed to the 6 meters from the computer screen and instructed carefully. With every subject there were completed 9 measurements (10 time each):

1. Fullcorrected central visual acuity
2. Fullcorrected peripheral visual acuity at 5° on the temporal retina (nasal visual field)
3. Fullcorrected peripheral visual acuity at 10° on the temporal retina

Measurements 4.-9. were done the same way using blurring lenses +0,50 and +1,00 diopters. Every subject resonded altogether to 2700 trials. (9x10x30).

For perifoveal measurements computer screen was moved to the left from central axes 0,51m (5°) and 1,02m (10°) and tilted from horizontal line dependingly to 5 and 10 degrees. Subject was not moving from behind the table he/she was placed (Fig. 3.2.)

To avoid head turning there was used chin rest affixed to the table. All the subjects were instructed to fixate on the fixation point on the wall, when completing phases with perifoveal visual acuity.

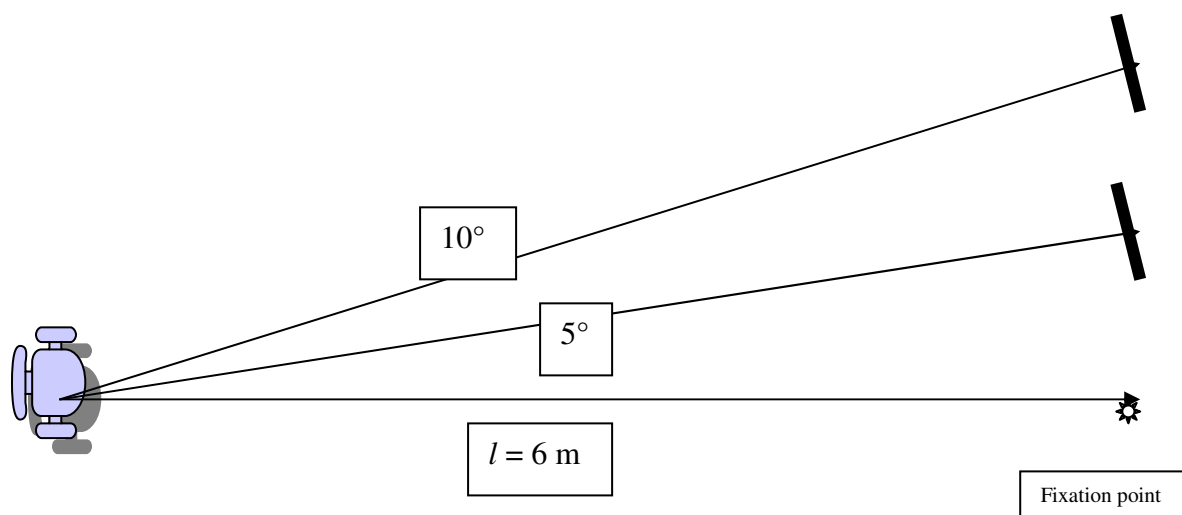


Fig.3.2. Simplified scheme of the experiment layout.

In the beginning of this experiment there were some complications to resolve. Due to relatively small peripheral visual angle there was a great possibility of beeping (saccadic eye movement towards the stimulus). All subjects were carefully instructed to fixate on the fixation point on the wall to avoid any saccadic movement of the eye during experiment. For later demonstration there was a videocamera on the tripod fixated to the subject's eye and some of the experiments were recorded. During different phases of the experiment it came to our knowledge, that uncontrollable saccadic movement of the eye was not any problem when experiment was going on with blurring lenses +0,50 and +1,00 diopters.

Computer based program was used as a stimulus during this experiment and responses about direction of the opening of the stimulus were given orally and experimentator was operating with the keyboard. Talking during the experiment caused head movement and that kind of answering was dropped. All results used in this work were registered by subjects themselves with cordless keyboard. To avoid any inadvertent incorrect responses, subjects were trained to use keyboard before the actual experiment.

3.2. Results

Alltogether 90 sets of experiments were completed with every subject and data recorded during these experiments is demonstrated in Appendix 1.

Relatively small standard deviation may be caused by the program used in this experiment as well as the subjects` training and instructions for this experiment. Depending on the correctness of the response, next an easier or more difficult to recognize optotype is presented, ultimately aiming to determine the spatial resolution limit or threshold. Average results of the experiment with standard deviations are demonstrated in Table 3.1.

Table 3.1.

Averaged results (logMAR) of subjects with standard deviations

Subject	FCC	SD	FC5°	SD	FC10°	SD
M1	0,011	0,025	0,414	0,025	0,855	0,021
M2	-0,002	0,021	0,412	0,023	0,903	0,026
M3	0,013	0,026	0,430	0,023	0,913	0,023
E1	-0,076	0,034	0,397	0,025	0,728	0,027
E2	-0,007	0,038	0,422	0,023	0,753	0,029
H1	0,008	0,023	0,626	0,020	0,894	0,025
H2	0,004	0,020	0,639	0,023	0,906	0,023
Subject	+0,5BC	SD	+0,5B5°	SD	+0,5B10°	SD
M1	0,160	0,025	0,570	0,027	0,934	0,023
M2	0,188	0,022	0,602	0,026	0,971	0,029
M3	0,182	0,024	0,579	0,030	1,053	0,030
E1	0,177	0,026	0,604	0,026	1,003	0,032
E2	0,219	0,027	0,613	0,021	1,017	0,028
H1	0,146	0,024	0,779	0,027	1,106	0,027
H2	0,159	0,026	0,775	0,029	1,084	0,045
Subject	+1,0BC	SD	+1,0B5°	SD	+1,0B10°	SD
M1	0,517	0,023	0,922	0,022	1,149	0,028
M2	0,552	0,027	0,932	0,030	1,134	0,028
M3	0,537	0,029	0,951	0,032	1,183	0,026
E1	0,496	0,021	0,786	0,026	1,035	0,041
E2	0,505	0,024	0,805	0,030	1,051	0,028
H1	0,524	0,026	0,821	0,024	1,131	0,032
H2	0,513	0,026	0,874	0,038	1,214	0,030

Legend: M-myopic, E-emmetropic, H-hypermetropic, 1,2,3- number of subject, FCC- fullcorrected central visual acuity, BC- blurred central visual acuity, FC5° /10°- fullcorrected perifoveal visual acuity, 0,5/1,0 B5°/10° - blurred perifoveal visual acuity, SD- standard deviation.

Table 3.2.

Average data of refractive groups with standard deviations

Subject	FCC	SD	FC5°	SD	FC10°	SD
M	0,007	0,024	0,419	0,024	0,890	0,023
E	-0,042	0,036	0,410	0,024	0,741	0,028
H	0,006	0,022	0,633	0,022	0,900	0,024
Subject	0,5BC	SD	0,5B5°	SD	0,5B10°	SD
M	0,177	0,024	0,584	0,028	0,986	0,027
E	0,198	0,027	0,609	0,024	1,010	0,030
H	0,153	0,025	0,777	0,028	1,095	0,036
Subject	1,0BC	SD	1,0B5°	SD	1,0B10°	SD
M	0,535	0,026	0,935	0,028	1,155	0,027
E	0,501	0,023	0,796	0,028	1,043	0,035
H	0,519	0,026	0,848	0,031	1,173	0,031

3.3. Discussion

At the first stadium of experiment, ametropias were corrected to 0,0 logMAR and central visual acuity of all subjects, including emmetropes, was measured. Afterwhat vision of the subjects` were blurred with +0,50 D and +1,0 D lenses. Results characterized changes in foveal visual acuity almost similary to all different refractive groups (Fig. 3.3.).). It is important that in all groups of subjects during changes of visual acuity from 0,0 logMAR till 0,5 logMAR SD remains unchanged.

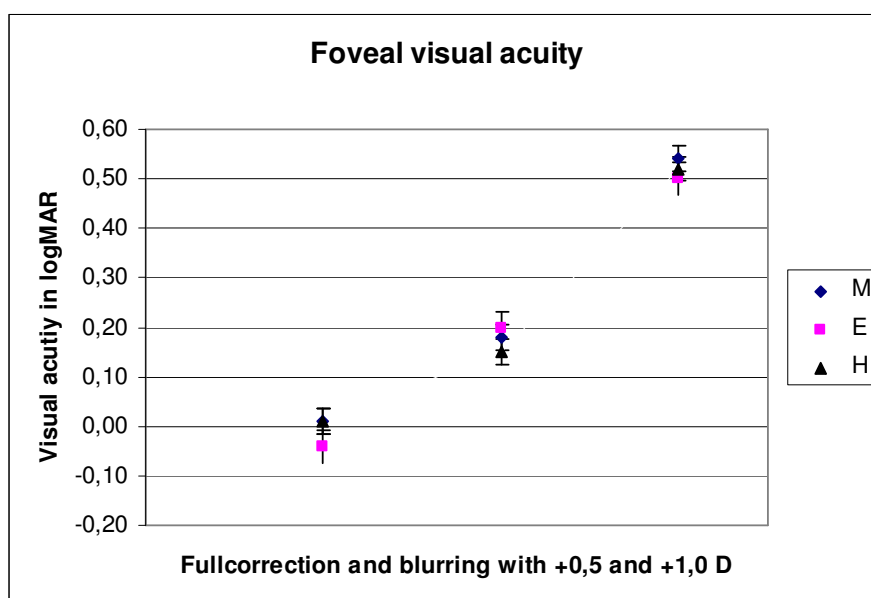


Fig. 3.3. Average foveal visual acuity of different refractive groups with and without blurring. (M-myopic, E- emmetropic and H- hypermetropic)

As the blurring of central vision caused image formation in front of the retina and made subjects myopic, all of them had even conditions in forthcoming phases of experiment. At this stage, as we focused on the foveal visual acuity, possible differences in eye shape or perifoveal influences to visual acuity had no significant role. In case of central vision we expected that response of myopic person would be most degraded by adding plus lenses. However, degradation in all groups is the same. We suppose, that myops are got accustomed to blurred stimuli more than rest of our subjects.

If we consider the shape of the eyeball ideally spherical and without influence of aberrations, which may be caused by different optical parts of the eye, we may state, that all formed images should appear at the same distance from the retina in spite of eccentricity or level of blurring. Measuring perifoveal visual acuity with fullcorrection (if needed) at 5° and 10° of eccentricity on the temporal side of eye retina, was founded that the results (Fig. 3.4.) of myopic and emmetropic refractive groups were different comparing to hypermetropic refractive group at 5° and myopic and hypermetropic groups were different comparing to emmetropic group at 10°.

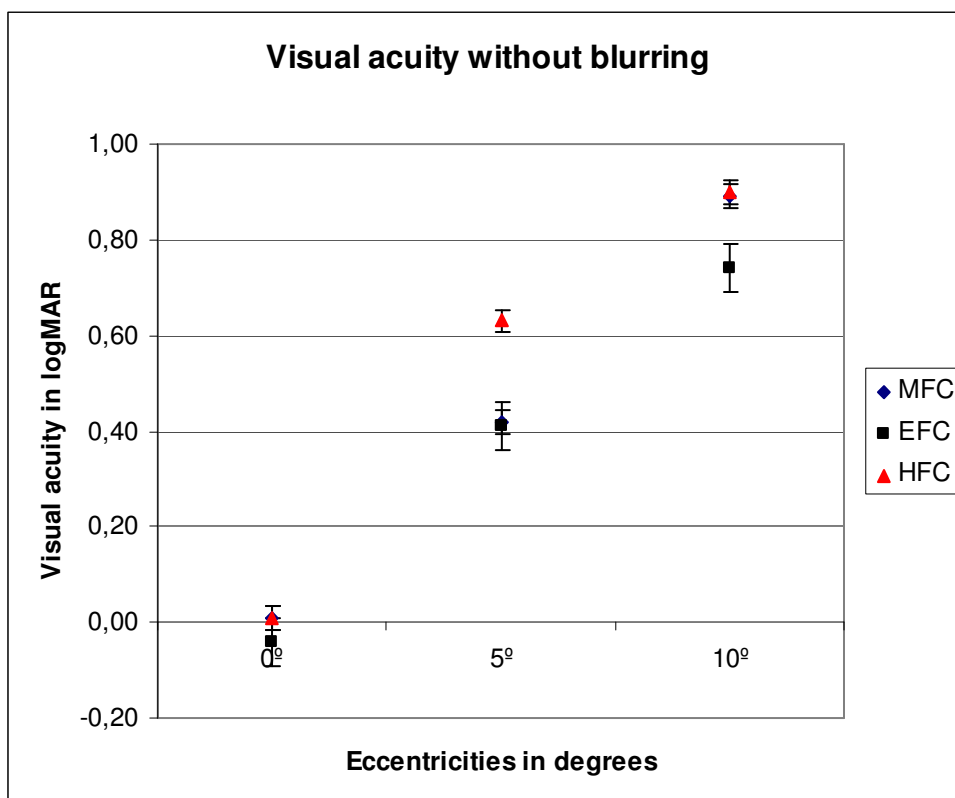


Fig. 3.4. Foveal and perifoveal (at 5 and 10 degrees) visual acuities of refractive groups without blurring.

As we can conclude from the figure above, there are no significant differences in changes of visual acuity among myopic and emmetropic refractive group, but clearly seen decrement of visual acuity in perifoveal area (at 5°) of the hypermetropic group (more than 0,20 logMAR worse). At 10° of eccentricity visual acuity of emmetropic group is better approximately 0,20 logMAR compared to hyperopic and myopic group.

Figure 1.6. at page 10 describes visual acuities of 3 emmetropic subjects measured eccentrically up to 10° on the nasal fovea. Despite of fact, that central visual acuities of these subjects are higher (up to -0,3 logMAR), decreasing of visual acuities are almost similar at 5° of eccentricity to emmetropic and myopic groups (0,4 logMAR). At 10° from the fovea visual acuities are comparable to emmetropic group of our experiment (0,70-0,75 logMAR). Myopic and hyperopic groups demonstrate at 10° significantly lower visual acuities (0,9 logMAR). Thus we are able to state that our results from this part of experiment have similarities with previous experiments.

Cheng et al [17] studied different shapes and dimensions of myopic, emmetropic and hypermetropic eyes with magnetic resonance technology. Their data showed that there is no difference in shape between emmetropic and hyperopic eyes, although the emmetropic eye tends to be slightly larger. Both types of eyes have significantly longer equatorial diameter than either the antero-posterior or the vertical diameter. Their data showed that the axial length of the myopic eye is significantly greater than that of the hyperopic eye. However, the myopic eyes did not appear at all elongated. In fact, most of them have the same shape as emmetropic/hyperopic eyes.

Llorente et al [18] compared in their study differences between hypermetropic and myopic eyes, concentrating to axial length, corneal shape and aberrations of the eye. Myopic eyes show a significantly higher axial length than hyperopic eyes. The AL/CR (axial length/corneal radius) ratio is also higher in myopic eyes, although no significant difference in corneal radius has been found between both groups. Corneal asphericity tends to be less negative in hyperopic eyes (i.e., more spherical corneal shape), and as a consequence, the corneal spherical aberration is also higher in hyperopic than in myopic eyes. Total spherical aberration is also significantly higher in hyperopic eyes, although internal spherical aberration is not significantly different between both groups.

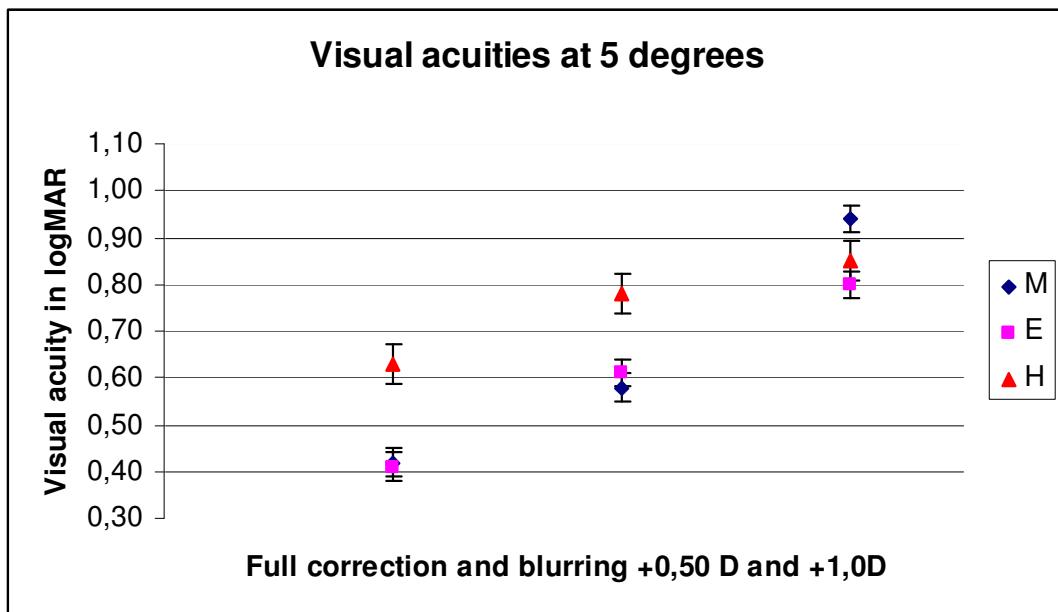


Fig. 3.5. Visual acuities of all refractive groups at 5° of eccentricity with and without blurring..

Analyzing visual acuities of all refractive groups at 5 degrees of eccentricity (Fig. 3.5.) we are able to conclude that there are no significant differences in amount of decreasing visual acuity with full correction and blurred with +0,50 D lens respectively. Difference between myopic/emmetropic refractive group vs hypermetropic group stays almost at the same level (appr.0,20 logMAR units). Blurring with +1,0 D lens equalizes the situation and decreases visual acuity of myopic group more than others. Emmetropic group is demonstrating approximately linear correlation between blurring and visual acuities.

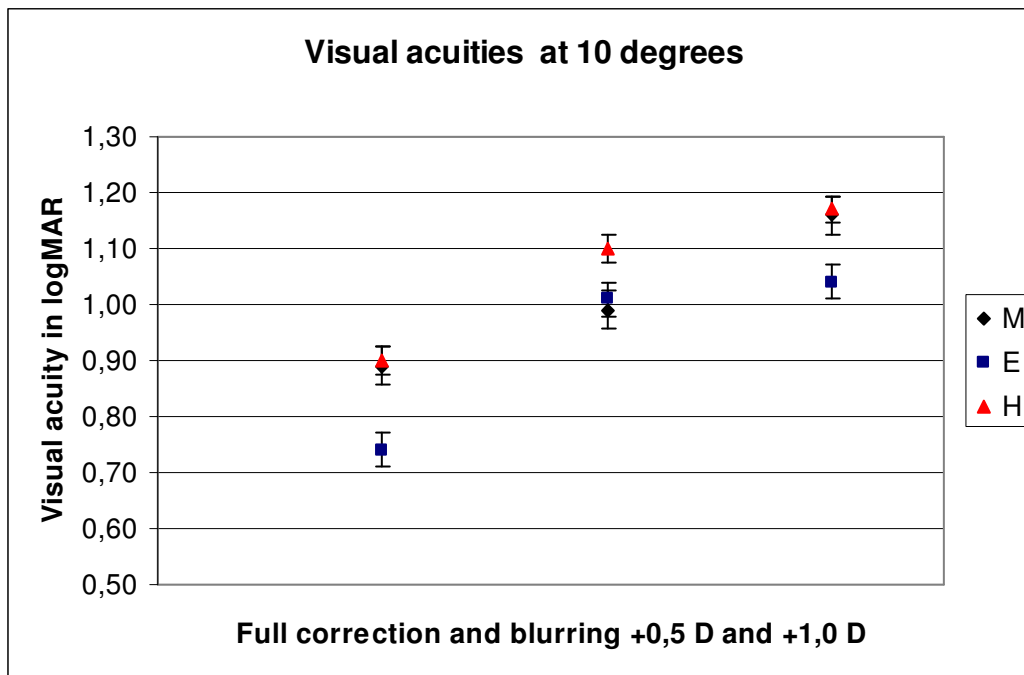


Fig. 3.6. Visual acuities of all refractive groups at 10° of eccentricity with and without blurring

Analyzing graphical data from figure 3.6. which demonstrates visual acuities of all refractive groups at 10° of eccentricity we are able to conclude that emmetropic group demonstrates relatively better visual acuities compared to hypermetropic group in all corrective conditions. Myopic group is at the same level with hyperopic group in full corrected position and blurred with +1,0 D lens. As we can see from the figure 3.5., where are demonstrated visual acuities at 5°, blurring myopic group with +0,50 D lens has less visual acuity decreasing effect than other groups, the same phenomenon took place at 10° of eccentricity. As stated above (page 27) it is may be caused by accustomizing of myops with blurred images.

If we take the general view all over the collected data, we understand that differences between visual acuities of the refractive groups under the same conditions are relatively small (up to 0,23 logMAR) and may have no significant influence in everyday life, but still, more and more reseachers all over the world study shape and peripheral visual acuity of human eye trying to find better solutions in the area of corrective optics. What could be the limitations of that process?

The optical quality of the eye is more homogeneous across visual field than that of conventional optical systems. Figure 3.7. demonstrates the different resolutions of the optical system (yellow), the sampling by the cone mosaic (light blue) and the effective retinal

resolution (red) related to the density of ganglion cells. Apparently, this is an astounding flaw of design for a foveated, highly inhomogeneous retinal sampling and cortical magnification factor. In other words, there is a good match between optical resolution and retinal resolution at the fovea, but there is a rapidly increasing mismatch towards the peripheral visual field. The reason is that the rate at which optical resolution decreases with eccentricity is low, whereas retino-cortical resolution worsens dramatically [19].

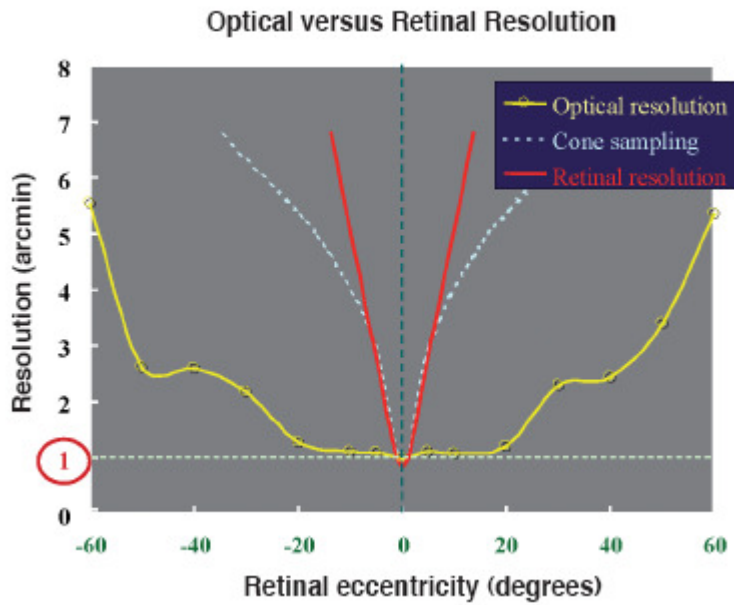


Figure 3.7. Optical resolution compared to cone sampling and retinal resolution.

4. CONCLUSIONS

It has been experimentally demonstrated that FrACT 3.6.3. software together with our experimental layout can be successively applied for peripheral distance vision acuity measurements among different refractive group subjects with high accuracy (SD is less than 5% in 5 degree eccentricity and 2,5% in 10 degree of eccentricity).

In case of blurring central vision (foveal visual acuity) with +0,5 and +1,0 lenses experimentally obtained acuity is being degraded equally in all three groups of refractive error.

Loss of visual acuity in 5 and 10 degrees of eccentricity of emmetropes and myopes corresponds with average loss of that in literature. However hyperopes exhibit higher loss by 0,2 log MAR at 5 degree of eccentricity, which can be explained by more oblate shape of the hypermetropic eye.

Blurring of peripheral vision by adding plus lenses (+0,5 and +1,0) affects ametropic persons acuity more than emmetropes by approximately 0,2 logMAR.

5. FINAL REMARKS

Peripheral visual acuity and hypothetical possibilities somehow to improve it has been object of interest through last decade. Methodology I used in my experiment with 7 subjects from different refractive groups is suitable (but quite time consuming) for bigger groups of ametropes and emmetropes also. I recommend to focus on one ametropic group instead of many. Preparing to complete experiment with subjects is essential. Explaining the character of the experiment and training is needed in most cases.

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Appendix 1.

Collected data

M1				M2				M3			
-2,25	0º	5º	10º	-3,00	0º	5º	10º	-4,00	0º	5º	10º
	0,03	0,40	0,86		0,01	0,39	0,88		0,00	0,42	0,92
	0,02	0,39	0,81		0,00	0,38	0,90		0,02	0,41	0,89
	-0,05	0,41	0,84		-0,04	0,42	0,87		0,06	0,39	0,91
	0,02	0,42	0,87		-0,02	0,40	0,91		-0,03	0,42	0,95
	0,04	0,40	0,86		0,01	0,44	0,95		0,00	0,44	0,91
	0,01	0,45	0,85		0,00	0,41	0,88		0,02	0,43	0,92
	0,01	0,43	0,89		0,02	0,39	0,88		0,05	0,47	0,87
	0,00	0,37	0,85		-0,03	0,43	0,91		0,00	0,43	0,90
	0,03	0,42	0,86		0,02	0,45	0,93		0,01	0,46	0,92
	0,00	0,45	0,86		0,01	0,41	0,92		0,00	0,43	0,94
-1,75	0,15	0,56	0,94	-2,50	0,16	0,57	0,94	-3,50	0,16	0,55	1,02
	0,17	0,57	0,94		0,21	0,61	0,97		0,21	0,59	1,07
	0,15	0,61	0,97		0,18	0,63	1,01		0,18	0,62	1,05
	0,12	0,55	0,92		0,19	0,57	0,95		0,17	0,56	1,02
	0,16	0,53	0,93		0,17	0,60	0,96		0,15	0,57	1,09
	0,14	0,57	0,94		0,23	0,64	0,98		0,19	0,60	1,04
	0,15	0,58	0,95		0,19	0,58	0,95		0,22	0,56	1,03
	0,19	0,62	0,88		0,16	0,61	0,97		0,21	0,54	1,10
	0,16	0,55	0,93		0,20	0,63	1,03		0,17	0,63	1,08
	0,21	0,56	0,94		0,19	0,58	0,95		0,16	0,57	1,03
-1,25	0,52	0,93	1,14	-2,00	0,53	0,93	1,10	-3,00	0,52	0,91	1,17
	0,50	0,89	1,15		0,57	0,92	1,11		0,49	0,93	1,21
	0,53	0,93	1,13		0,54	0,96	1,17		0,56	0,97	1,17
	0,52	0,89	1,12		0,53	0,89	1,13		0,54	0,93	1,14
	0,54	0,90	1,18		0,55	0,94	1,14		0,53	1,02	1,16
	0,48	0,95	1,13		0,52	0,94	1,18		0,57	0,94	1,19
	0,50	0,92	1,16		0,58	0,92	1,15		0,53	0,96	1,23
	0,52	0,93	1,11		0,54	0,99	1,10		0,59	0,93	1,20
	0,56	0,95	1,17		0,61	0,89	1,14		0,53	0,94	1,19
	0,50	0,93	1,20		0,55	0,94	1,12		0,51	0,98	1,17

Myopic subjects

Collected data

E1	0°	5°	10°	E2	0°	5°	10°
	-0,11	0,37	0,73		-0,05	0,41	0,76
	-0,10	0,42	0,73		0,00	0,43	0,80
	-0,08	0,40	0,77		0,03	0,44	0,75
	-0,10	0,38	0,74		0,06	0,39	0,73
	-0,10	0,42	0,72		-0,03	0,42	0,74
	0,00	0,40	0,75		0,02	0,40	0,76
	-0,06	0,39	0,68		-0,05	0,47	0,73
	-0,06	0,36	0,74		-0,03	0,41	0,75
	-0,05	0,39	0,69		0,02	0,42	0,71
	-0,10	0,44	0,73		-0,04	0,43	0,80
0,50	0,18	0,58	0,98	0,50	0,21	0,59	0,99
	0,16	0,62	1,02		0,19	0,63	1,02
	0,14	0,59	1,00		0,23	0,62	1,05
	0,17	0,60	0,97		0,18	0,59	0,98
	0,18	0,63	1,02		0,20	0,60	1,02
	0,16	0,56	0,98		0,26	0,65	1,02
	0,17	0,60	0,99		0,22	0,61	1,00
	0,21	0,59	1,08		0,21	0,62	0,99
	0,23	0,62	0,98		0,23	0,63	1,03
	0,17	0,65	1,01		0,26	0,59	1,07
1,00	0,48	0,77	0,98	1,00	0,49	0,79	1,01
	0,50	0,83	1,00		0,52	0,83	1,02
	0,47	0,80	1,03		0,55	0,81	1,07
	0,51	0,78	0,99		0,50	0,79	1,02
	0,52	0,75	1,00		0,51	0,80	1,04
	0,48	0,76	1,05		0,48	0,76	1,05
	0,53	0,82	1,10		0,53	0,79	1,10
	0,47	0,80	1,07		0,49	0,82	1,07
	0,51	0,78	1,07		0,51	0,87	1,07
	0,49	0,77	1,06		0,47	0,79	1,06

Emmetropic subjects

Collected data

H1				H2			
2,00	0°	5°	10°	2,5	0°	5°	10°
	0,02	0,59	0,86		0,02	0,61	0,92
	-0,02	0,62	0,89		0,00	0,63	0,91
	0,02	0,65	0,93		-0,01	0,67	0,89
	0,05	0,62	0,89		-0,03	0,61	0,94
	-0,01	0,65	0,90		0,03	0,64	0,92
	0,03	0,60	0,87		0,00	0,64	0,87
	-0,02	0,63	0,88		-0,02	0,63	0,93
	0,00	0,63	0,90		0,01	0,68	0,88
	-0,01	0,64	0,88		0,03	0,65	0,89
	0,02	0,63	0,94		0,01	0,63	0,91
2,50	0,12	0,78	1,08	3,00	0,16	0,75	1,12
	0,15	0,75	1,10		0,15	0,78	1,11
	0,18	0,78	1,12		0,19	0,80	1,00
	0,15	0,80	1,07		0,13	0,73	1,07
	0,12	0,77	1,08		0,15	0,75	1,09
	0,13	0,78	1,10		0,16	0,78	1,09
	0,15	0,73	1,12		0,21	0,83	1,12
	0,19	0,78	1,16		0,17	0,78	1,14
	0,13	0,83	1,10		0,13	0,76	1,02
	0,14	0,79	1,13		0,14	0,79	1,08
3,00	0,53	0,80	1,11	3,50	0,52	0,85	1,21
	0,58	0,82	1,14		0,56	0,83	1,24
	0,52	0,83	1,12		0,50	0,96	1,19
	0,51	0,79	1,16		0,49	0,87	1,17
	0,52	0,83	1,11		0,50	0,86	1,20
	0,48	0,84	1,20		0,47	0,87	1,22
	0,51	0,86	1,12		0,54	0,85	1,27
	0,52	0,78	1,15		0,52	0,92	1,19
	0,55	0,83	1,11		0,50	0,87	1,21
	0,52	0,83	1,09		0,53	0,86	1,24

Hypermetropic subjects

FrACT — Freiburg Visual Acuity and Contrast Test



Vs 3.6.3 · 2010-09-01 · F10.0

Landolt C tumbling E Sloan letters Contrast Vernier

Setup Faces About Help Exit

Response keys

press '5' to start
press '55' to abort

Key settings: 6 m distance, 4 choices, 30 trials, 1280×1024 screen.

4 directions

FrACT — Freiburg Visual Acuity and Contrast Test



Vs 3.6.3 · 2010-09-01 · F10.0

Landolt C tumbling E Sloan letters Contrast Vernier

SETUP Faces About Help Exit

Response keys

press '5' to start
press '55' to abort

Key settings: 0.6 m distance, 4 choices, 30 trials, 800×620 screen.

4 directions

dec. VA: 0.51, logMAR: 0.29

Main page and example results of FrACT 3.6.3.

Master thesis „Influence of blurring to peripheral visual acuity” is elaborated in faculty of Physics and Mathematics.

I confirm with my signature, that study is done independently, only in references mentioned sources are used and electronically submitted version of work conforms with printed version.

Author: Vootele Tamme

I recommend Master thesis for presentation

Supervisor: Dr.habil.phys. Ivars Lācis

Reviewer: Dr.phys. Gatis Ikaunieks

Master thesis is submitted in Department of Optometry and Vision Science 08.01.2011.

Secretary: Anete Paušus

Work had been evaluated in a Master's final examination commission

15.01.2011. protocol No , grade

Secretary of commission: