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Measurement of Dynamic Visual Acuity with Augmenting Landolt Rings

Master Thesis submitted for the degree
Master of Science M.Sc.

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Preface

Starting the Master course in Vision Science and Business (Optometry), at Hochschule Aalen, Baden-Würtenberg, Germany in 2013. I wasn't aware of how much knowledge I would have acquired and how would have these last two years influenced my everyday practice and gave me the opportunity to enter a totally new professional level.

Despite being far from home and family during the courses, I felt at ease because of the special way of relationship created between lecturers and students.

Master thesis is the final part of this voyage into knowledge about vision, and should be starting point in connecting the various dots into the whole picture, by using everything I have learned to answer the upcoming questions.

Writing this master thesis was much easier because I could understand the problems much better thanks to the knowledge that was given to me during this course. I have been able to deal with various challenges that come onto me like the topic I have chosen for my thesis. The gathered knowledge is of enormous value to my everyday practice as well.

Acknowledgments

I would like to begin by thanking those who have been directly involved in this work. First my supervisors, Dr. Bernd Dörband who's leadership introduced me to the scientific research world by sharing his experience and wisdom and shaping this study in completely new direction that made it one of the kind; M.Sc. Matjaž Mihelčič who had such a strong influence on my professional development, and introduced me to the topic of „dynamic visual acuity“.

Prof. Dr. Anna Nagl and Prof. Dr. h. c. Dietmar Kümmel, for their help and support during study and encouraged me to complete this master thesis, immediately after finishing courses.

I am extremely grateful to Đuro Zec whose skills in graphic design and animation were of immense help in creating tests for this study that I would never have achieved otherwise!

Finally I would like to thank my husband Vjeran and our son Karlo, for their love and support, which was the fuel for me during this journey into knowledge. Last but not least, our nanny Ljubica without whose collaboration the whole thing would have been nearly impossible.

Contents

1 Abstract

Purpose

The purpose of this study was to investigate the correlation of measured visual acuity (VA) both static and dynamic obtained with static and dynamic measuring tests, as well as, response time to visual stimulus and analysis of its influence on dynamic visual acuity. The aim was to compare the results gathered for the three age groups and analyze the possible differences.

Methods

The test groups consisted of 75 subjects between 10 and 60 years old, categorized in three age groups. The measurements of static and dynamic visual acuity and reaction time were conducted. The set of nine tests (five with radial magnification speed and four simulating driving condition at 72 km/h and 130 km/h) was designed in order to measure dynamic visual acuity and the set of two tests for reaction time measurement.

Results

Compared to static visual acuity in both tests, the results obtained with measurements of dynamic visual acuity resulted in lower values depending on Landolt ring size and magnification speed of animation. In average, the dynamic visual acuities in tests with different magnification speeds were lower than static by 0.4 visual acuity units, or 31% and the average of dynamic visual acuity after subtracting motoric component (reaction time) was for 0.2 visual acuity worse than static or 15%. In the second test simulating driving conditions at 72 km/h the average drop in dynamic visual acuity was 33% while at 130 km/h average drop for younger and middle age groups was 37% and for older group was 44% and after subtracting motor component values for 72 km/h speed simulation average drop in visual acuity values was 23% for all three groups; for 130 km/h speed simulation younger and middle aged group average drop of visual acuity was 20% and with older group it was 24%.

Conclusion

The tests used in this study were simple and fast and revealed significant difference between static and dynamic visual acuity and influence of reaction time on dynamic

visual acuity values. It is hoped that this thesis will be a positive contribution in testing and training of dynamic visual and sensory response skill with drivers, sportsmen and people with visual-motor dysfunction.

Keywords: Dynamic visual acuity (DVA), static visual acuity (SVA), reaction time (RT), motoric component, dynamic visual acuity test, reaction time test, radial increase in size

1 Introduction

The most information for the majority of everyday tasks is gathered via the visual system and this visual input tends to override information from other sensory sources.

Dynamic visual acuity and its difference from static visual acuity have been of great interest in scientific area in medicine, in connection with brain injury, or everyday situations such as sports, driving, walking, etc. The studies usually measured dynamic visual acuity with tangential rotation of signs on the screens at one constant velocity or tried to find connection between vestibule ocular reflex and dynamic visual acuity.[1] Dynamic acuity is used in situations when we look at moving objects (or details), when we move and the observed object does not as well as in cases when both observer and the observed objects are in motion.

The aim of this study is to investigate the correlation of measured visual acuity (VA) obtained with static and dynamic measuring tests, as well as to compare the results gathered for three age groups. In everyday life, we are constantly in motion (playing sports, while driving, etc.) or we encounter moving objects, which is why it seems very interesting and important to research the correlation between dynamic (DVA) and static (SVA) visual acuity and how the dynamics of objects influence our ability to see. Static acuity is used mostly when observing static objects, or their details.

Examining static acuity implies the study performed while the subjects are not moving. Measuring static acuity in this study was conducted with the standard method, using Landolt ring optotypes projected on the screen. As opposed to that of static acuity, measurement of dynamic acuity is not standardized. A special test was developed for this purpose, and its results were sorted by the age of the test participants.

The radial increase in size of Landolt ring with different magnification speed at 20%, 40%, 60%, 80% and 100% per second as well as another test simulation of movement at velocities respectively of 72 km/h and 130 km/h was used in this study.

In addition to dynamic visual acuity, response time to visual stimulus was also measured and analysis of its influence on dynamic visual acuity values was investigated. Both tests were constructed for well-lit and dim-lit condition to investigate

another issue which is the mesopic vision especially with night time driving, where 27% of night time drivers share the same deviation from physiological response.[2]

In first chapters of the thesis, some physiological and psychological factors in processing of visual stimulus, retinal perception and visual-motor reaction are described. In the following chapters the tests are described and the findings are discussed in regard to reaction time influence on dynamic visual acuity. Due to awareness of the complexity of the measurements the focus was kept on the difference between static and dynamic visual acuity and the influence of reaction time on it, in three age groups.

2 Physiological aspect of visual processing

2.1 Overview of visual processing

In everyday practice optometrists are faced with clinical issue that require understanding of vision and visual information processing. The visual system is compound of three areas, which are used in clinical evaluation: visual acuity, vision efficiency, and visual information processing.[3] These three processes are in interaction and works together.

2.1.1 Visual acuity

Visual acuity (VA) commonly refers to the clarity of central vision. Visual acuity is dependent on optical and neural factors, i.e., the sharpness of the retinal focus within the eye, the health and functioning of the retina, and the sensitivity of the interpretative faculty of the brain. A common cause of low visual acuity is refractive error (ametropia). Visual acuity is an ability to distinguish details and shapes of objects.[4]

2.1.2 Visual resolution

Visual resolution is the ability to resolve detail. Visual resolution depends of visual acuity value. Static visual acuity (SVA) is measured when there is no movement between the observer and the test. Dynamic visual acuity (DVA) is measured when the movement between the observer and the test present.[5] DVA depends on resolving visual stimulus, resolving power of retina, target luminance, velocity, time exposure and contrast of test as well as physiological function that can affect DVA value and interpretation of visual information.

2.2 Vision efficiency

Vision efficiency is directly linked with attention and cognitive processing. The connection between DVA and vision efficiency is vergence and pursuit eye movements.[3]

2.2.1 Vergence

Vergence function is responsible for ocular alignment and has a direct impact to depth perception and tracing of trajectory objects. Direction of the vergence change is typically appropriate for the change in target distance and maintain accurate bifoveal fixation. The binocular sensory component of the vergence system relies on retinal image disparity for stereopsis, which contributes to better depth perception.[3,4]

2.2.2 Pursuit eye movements

Pursuit eye movements maintain continuous clear vision during fixation of a rapidly moving object or moving object with varying velocities. This type of fixation changes direction when tracking object with a predictable motion path depending on object velocity.[3,4]

2.2.2.1 Depth perception

Estimation of distance and spatial localization information are important for visual performance and response to it when either the visual information or the observer is in motion. Depth perception is the visual ability to perceive the world in three dimensions (3D) and the distance of an object. Depth perception arises from a variety of depth cues. These are typically classified into binocular cues that are based on the receipt of sensory information in three dimensions from both eyes and monocular cues that can be represented in just two dimensions and observed with just one eye. Monocular cues include: size, distant objects separated with smaller visual angles than near objects, grain, size, and motion parallax.[6] Stereopsis and vergence function, which are responsible for ocular alignment and have a direct impact to depth perception and tracing of trajectory objects are also connected with dynamic visual acuity.

2.3 Visual information processing

Visual information processing is also an important category in understanding dynamic visual acuity because this information causes an appropriate motor response. It is connected with visual-spatial, visual-analysis and visual-motor characteristics of vision.

Visual-spatial characteristic is connect with understanding the directionality like up and down, left and right. Visual-analysis characteristic is the ability to recognise, recall and manipulate with visual information, for example comparison. Visual-motor characteristic coordinates visual information and motor response.

Visual information processing is a connection with visual cognitive skills that are used in separating and organizing visual information from the environment and connecting this information with other sensory parts in body. The selection of information depends on motivation, experience and development and what generates the visual stimuli. Visual stimuli are signals sent to the muscles in the body causing a response. Vision provides information on where and when something is located in the environment. Visual processing information delays can't be compensated with other skills.[3] Accurate information processing is connected with quick interpretation, decision and an appropriate motor response. Demand for visual processing is greater if no static tasks are processed because visual information in motion cause constant processing of changes in the visual information versus static tasks where stationary information have to be processed.[7] The resolving power of retina, target luminance, velocity, time exposure and contrast of test and physiological function can affect DVA value and interpretation of visual information.

2.4 Visual motion in the brain and optic flow

The visual cortex of the brain is the part of the cerebral cortex responsible for processing visual information. It is the simplest, earliest cortical visual area. It is highly specialized for processing information about static and moving objects and is excellent in pattern recognition.[3,4]

The medial superior temporal (MST) area is a part of the cerebral cortex, which lies in the dorsal stream of the visual area of the brain. The MST receives most of its inputs from the middle temporal (MT) area, which is involved primarily in the detection of motion. The MST uses the incoming information to compute things such as optic flow.[6]

MST neurons have very large receptive fields; respond selectively to complex optical flow fields: expansion, contraction and rotation. It is believed that MST is involved in 3D

motion perception, inferring 3D motion of objects/observer from optical flow.[8] Neurons in MT are selective for motion direction. Neural responses in MT are correlated with the perception of motion. Well-defined pathway of brain areas underlying motion specialization in MT. There is one further piece of evidence concerning the significance of motion and area MT. The direction-selectivity of neurons within area MT is laid out in an organized fashion. Nearby neurons tend to be selective for motion in the same direction.[9] This is analogous to the retinotopic organization evident in cortical areas V1 and V2. Taken together, the evidence argues that area MT plays an important role in motion perception.[10]

MT neurons receive inputs from direction-selective neurons in primary visual cortex (V1). MT neurons are velocity selective, each responds best to a preferred velocity (speed and direction) within its receptive field, pretty much independent of stimulus pattern. By contrast, a direction-selective V1 neuron confounds motion with pattern. A typical V1 neuron responds to a particular orientation moving in a particular direction. The response of the V1 neuron also increases with contrast. A typical MT neuron, on the other hand, responds to almost any pattern with almost any contrast, as long as it moves with the right velocity (Figure2-1). The optic flow then provides information about the observer's heading and the relative distance to each surface in the world.[11]

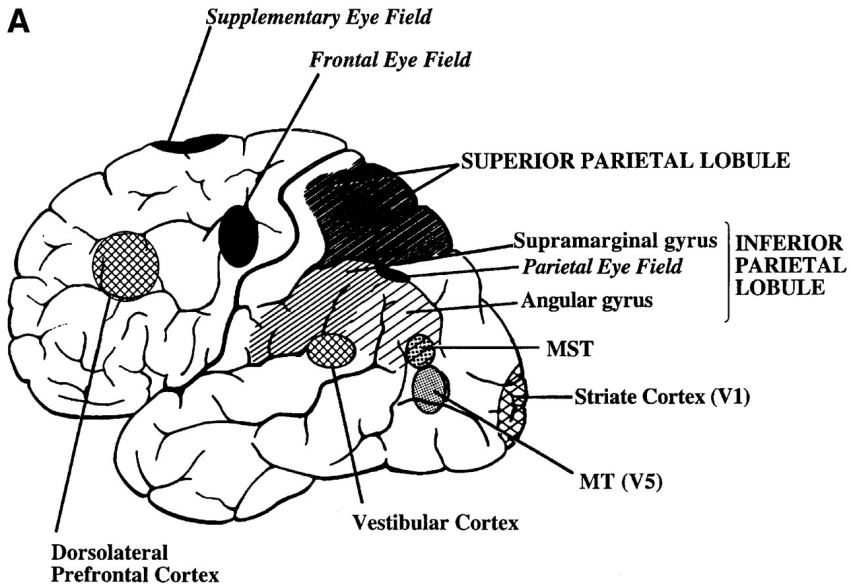

Figure 2-1 MT, MST and V1 area in the brain

2.5 Motion perception

Motion perception is the process of inferring the speed and direction of objects in a scene based on visual, vestibular and proprioceptive inputs. Secondary visual cortex (V2), also called prestriate cortex, is the second major area in the visual cortex, and the first region within the visual association area. It receives strong feed forward connections from V1. Together, these four regions provide a complete map of the visual world (Figure 2-2).[12]

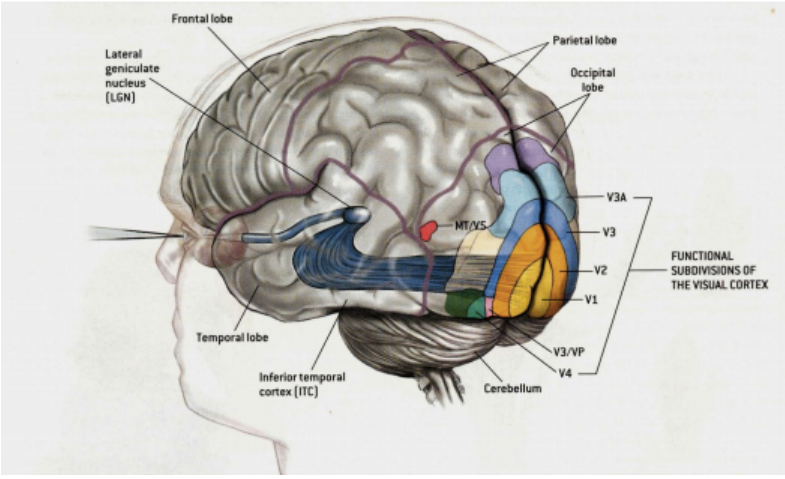

Figure 2-2 Primary (V1) and Secondary (V2) visual cortex in brain

In terms of anatomy, V2 is split into four quadrants, a dorsal and ventral representation in the left and the right hemispheres. The dorsal stream originates from a common source in visual cortex and it is responsible for detection of location and motion (Figure2-3).

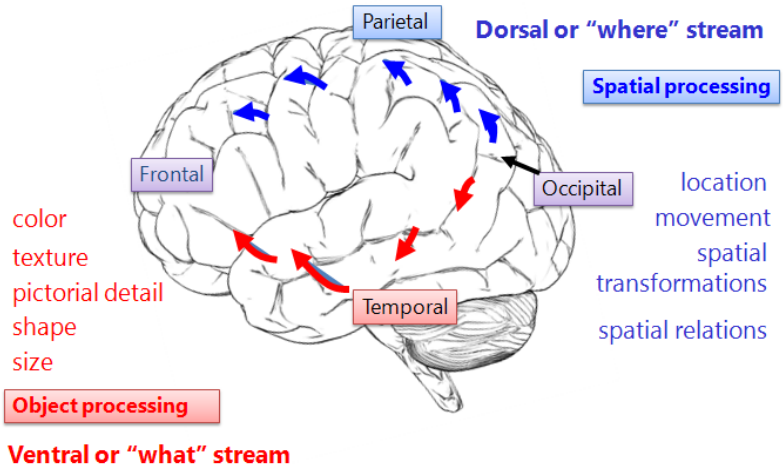

Figure 2-3 The dorsal stream

More recently, Goodale and Milner extended these ideas and suggested that the ventral stream is critical for visual perception whereas the dorsal stream mediates the visual control of skilled actions.[13]

2.6 Retina and perception of motion

The visual system discerns motion from the changing pattern of light in the retinal image. This adaptation is local in the retina. The neurons are sensitive to motion and selective for the direction of motion, they adapt to the stimulus, simply detecting that something is moving. A small, close object moving slowly creates the identical retinal images over time same as large, distant object moving quickly. Two different kinds of events can cause visual motion. When an observer moves through an otherwise stationary environment, the entire retinal image changes over time as discussed above.[14] When an object moves toward the observer, the retinal projection of an object expands over a period of time, which leads to the perception of movement in a line toward the observer. The dynamic stimulus change enables the observer not only to see the object as moving, but also to perceive the distance of the moving object.

It was found evidence for psychophysical information-processing channels that handle motion in depth forming a stereoscopic system for motion.[8,15] On this basis, it is tentatively suggested that, in the human visual pathway, there are binocularly driven neurons responsive to changing disparity and sensitive to the direction of motion in depth.

2.6.1 Perception of object size

The perception of the size of an object is as basic a component of our perception of that object as is its shape, colour, or location in three-dimension space. How does our visual system create this feature of our visual experience of an object? One obvious cue to the size of an object is the size of the retinal image projected onto the retina when we look at the object. In general, the bigger an object, the bigger its retinal image size. Visual system creates the perception of the size of an object based, in part, on retinal image size information. Retinal image size varies not only as a function of the size of an object,

but also as a function of the distance of the object from the viewer. The only possibility way to achieved size constancy is that size perception system must utilize two cues when creating the perception of size: retinal image size information distance information.[14,16]

2.6.2 Expansion of an object image on retina and looming detectors

When an object moves toward the observer its retinal image expends. The detection of looming, the motion of objects in depth, underlies many behavioural tasks, including the perception of self-motion and time-to-collision.[15,17] Adaptation to a stimulus that changes size produces the after-effect of motion in depth. These results suggest that the looming mechanisms detect not only the optical flow of the whole retinal image while in self-forward motion but also the retinal area of the moving object in depth; moreover, these mechanisms process the inside of the receptive field of the object. The rate of expansion of an object image on retina is not a correlate of the time to collision.[12]
For example, large object and smaller object, which are move to the observer at the constant speed, retinal image of the larger object will expand at greater rate than retinal image of smaller object. Looming detectors on retina has a property to discriminate between isotropic and non-isotropic expansion of the retinal image because they are sensitive on time to collision. When retinal image expansion is not-isotropic motion in depth perception can be weak or even absent.[15,17,18]

3 Physiological aspect of Reaction

3.1 Reaction and its components

From a purely biomechanical perspective, it might be helpful to think of reactions as of stimulated movements of neural clockwork. Each neuron is like a gear that affects others in chains and networks. At the start of one set of chains light is altering the motion - brain is always active. The reaction of the mind/body is in the whole change of state. The reaction of a visual stimulus changes the state of the brain and that causes changes in muscles and internal organs. These changes are measurable reactions of stimulus.

Anatomical studies lead us to believe that there are two directions of flow in sensory systems; feed-forward, and feed-back, also referred to as bottom-up and bottom-down.[19] In the visual system, the bottom up-stream goes from the retina in the eye, to the lateral geniculate nucleus in the thalamus, to the primary visual cortex (Figure 3-1).

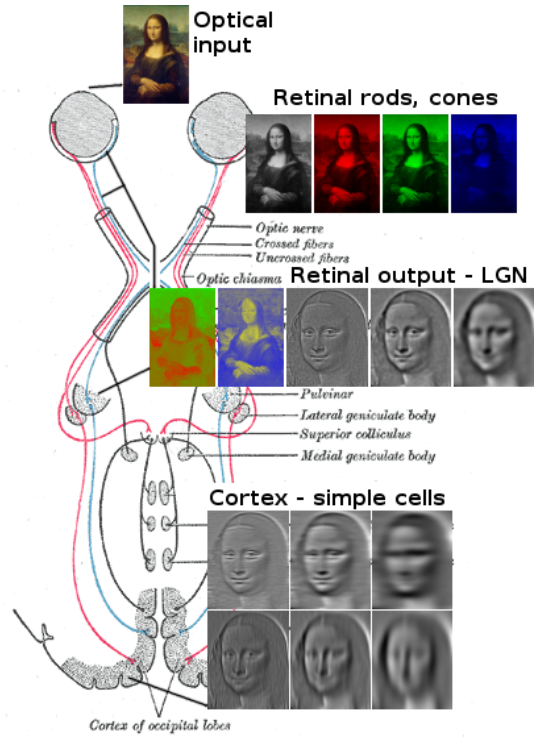

Figure 3-1 Human visual system

From primary visual cortex, visual signals diverge and travel to multiple higher visual cortical areas and then to "multimodal" higher areas that tie together perception, action, self-assessment, attention and decision-making. As you move up the hierarchy of brain areas, the ways neurons process the signals they receive changes moving from narrow local representations of image falling on the retina to more global and complex representations of objects. The top-down stream goes from cortical areas back to thalamus and eventually even to the retina.[19,20]

The final stage in a (conscious) reaction chain is typically assumed to involve signals going from prefrontal cortex to motor cortex, which controls muscle movements. Reflexes or unconscious reactions may bypass prefrontal cortical processing, meaning that visual signals can in some cases go straight to motor areas. This is of course an oversimplification of the concept of "reaction", which can also involve emotional and visceral processes and changes in the automatic nerve system (Figure 3-2).[21]

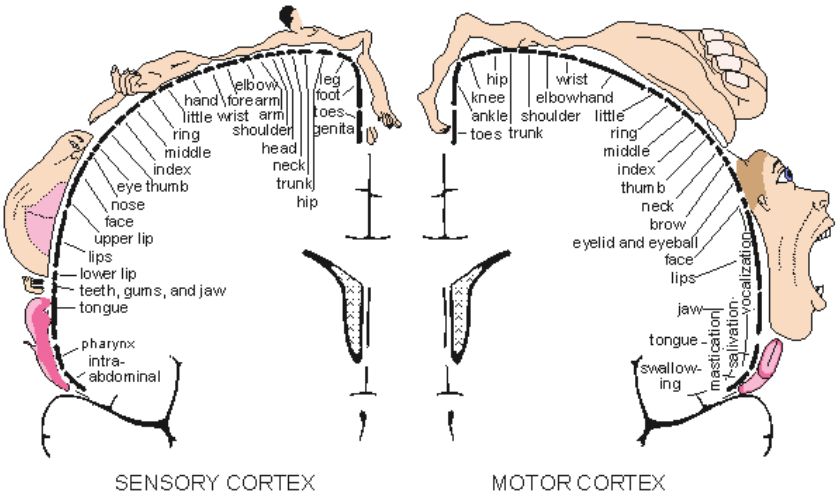

Figure 3-2 The division of sensory (left) and motor (right) functions in the cerebral cortex

This study was deployed in order to accentuate, while measuring dynamic visual acuity where the test was in axial motion, the time of subjects' reaction while the visual stimulus approaches.

In this study, we are interested in sensory properties of the subjects' stimulus, that is, the abilities when subject is focused on receiving stimulus and muscular ability of the stimulus, when subject's attention is focused on performing the move. More precisely, the time of the willing reaction is structured from the time when the receptor forms the impulse (stimulus information), the time it takes for impulse to transmit to cerebral cortex, the time it takes for stimulus content to be processed, the time it takes to constitute response order for stimulus, the time of transmitting impulse to effectors, and finally the time necessary to develop effectors response.[19,22]

Starting point was the time of simple sensorimotor reaction, where the subject performs a particular movement (presses a key) with maximum speed as a response to a signal known in advance. That is time of every reaction that includes only one signal, known in advance, and only one predetermined response.

The basis of every reaction is a reflex arch consisting of 4 components:

1. Afferent neuron transmitting incurring stimulus from the receptor to the synapse in the form of an impulse moving at speed of 100 m/s;
2. A synapse or a reflex nerve system transmitting the signal between the afferent and efferent neuron;

3. Efferent neuron is a motor neuron transmitting signals from the synapse to the effector;
4. Effector is a muscle or some other organ.[14,21]

3.2 Reaction time

Potential action of the motor board spreads through the muscle cells and conditions contraction mechanism activation. Reflex time is the time of transmission from the stimulus to the response. It includes:

1. Time of receptor stimulus latency,
2. Time of impulse transmission between receptor and synapse (afferent conduction),
3. Time of synaptic transmission,
4. Time of impulse conduct from the synapse to the effector,
5. Time of stimulus effector latency (Figure 3-3).[19,23]

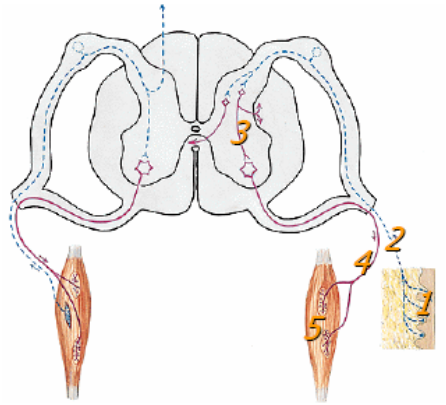

Figure 3-3 The pathway of stimulus and impulse

Considering the type of stimulus, the speed of reaction to visual, auditory and tactile stimulus can be differentiated.[20]

Reaction time is different for different stimulus: for example, visual signal reaction lasts longer than acoustic signal reaction because of different length of time necessary for the signal to turn into nerve impulses. Regarding a simple reaction, only 10-20% improvement is possible, 30% when it comes to reaction of choice. The reaction of time difference between less complex and more complex mental activities. There are

however still not enough realizations about the relation between reaction times and individual mental efficiency.[20,22,23]

4 Methods

4.1 Pilot study

The purpose of the pilot study made prior to the testing was to clarify, whether the used instrumentation and test setup could provide reliable and reproducible results. The first test was designed for reaction time measurement. The other tests were designed to show if there exist difference between static visual acuity (SVA) and dynamic visual acuity (DVA). The group consisted of 20 subjects age 18.

Results of pilot study:

Reaction time test results were in average 440 milliseconds. Difference between static and dynamic visual acuity showed the results for test with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60% 80% and 100% per second between 0.1 VA and 0.6 VA units in average, depending on sign animation speed, and with subtracted motoric component (subtracted reaction time) the results were between 0.05 VA and 0.4 VA units.

The pilot study showed that there was difference between static and dynamic visual acuity and the influence of motoric component (reaction time) on the results was present. The additional tests were designed and different lighting condition was added for real study.

4.2 Subjects of the main study and the criteria

The measurements were done at the Optika RA-VU in Rijeka, Croatia. The groups consisted of 75 subjects between 10 and 60 years old. They were categorized in three age groups:

1) younger group (10-20 years old, 15 female 10 male),

2) middle-aged group (30-40 years old, 13 female, 12 male) and

3) older group (50-60 years old 11 female, 15 male).

For minors under 18 years old, the individual agreement with parents was made allowing the participation in the study.

Subjects participating in this study had good visual acuity. Monocular no less than 1.0 visual acuity, no difference between two eyes in visual acuity and binocular visual acuity was not less than 1.0. Best visual acuity measured was 2.0. No participant had eyesight problems, thanks to which consistent results were obtained. Those who didn't meet the criteria of age range or visual acuity or eyesight condition were excluded from the study. Prior to the study the appropriate assessment of habitual correction was made. Every subject was tested with full optometry exam and best refractive correction was used.

4.3 Test instructions for the subjects

Every subject has got detailed instructions for each test on how to use equipment, and which measurements were made. All the subjects were wearing their corrective glasses or contact lenses if they needed one.

For the measurement of reaction time the subjects were instructed to look at the distant screen and they were instructed to press keyboard spacebar immediately on spotting the Landolt ring on the empty screen, which caused the animation to stop. The elapsed time needed for subject's reaction was then displayed at the bottom of the LCD screen. They were instructed to hover their finger over a spacebar and to be as fast as possible in pressing the spacebar once they see Landolt ring on the screen.

For the tests with radial increase of Landolt ring size with magnification speed at 20%, 40%, 60% 80% and 100% per second and the test with simulation of driving at 72 km/h and 130 km/h they also got keyboard and were instructed to press the spacebar the very moment when they recognized the position of the Landolt ring opening, pressing the spacebar caused the animation to stop. The corresponding value of visual acuity was then displayed at the bottom of the LCD screen. They were instructed to be as accurate as they can.

4.4 Measurements conditions control

The measurement distance was constant at 6 meters. The screens were positioned at same vertical angle. The same contrast adjustment (white, black) was done on both screens. There were no unusual objects in the field or sounds to avoid distractions. The measurements in lit condition were done with the constant bright illumination of 1300 lux. The measurements in dim condition were done after 20 minutes of adaptation. The dim condition was the simulation of a night light, between 12 and 9 lux. The illumination was measured with spectrophotometer instrument (Konica Minolta CL-500A). There were only one subject and the tester in the room at the time.

4.5 Instrumentation

For measurement of static and dynamic visual acuity Landolt ring sign was used. Static visual acuity was measured on polarized screen with battery of test for refraction that is used in everyday practice and finally evaluation of static visual acuity was done on the Landolt ring sign. For all dynamic tests Landolt ring sign was also used which was constructed in different sizes.

The measurement of dynamic acuity was conducted with the help of a computer program constructed in Adobe Flash Player. The test sign that was presented on a LCD screen consisted of a Landolt ring construction (Figure 4-1) shown in eight different positions and in the size corresponding the visual acuity of VA=3.1 to VA=0.1.

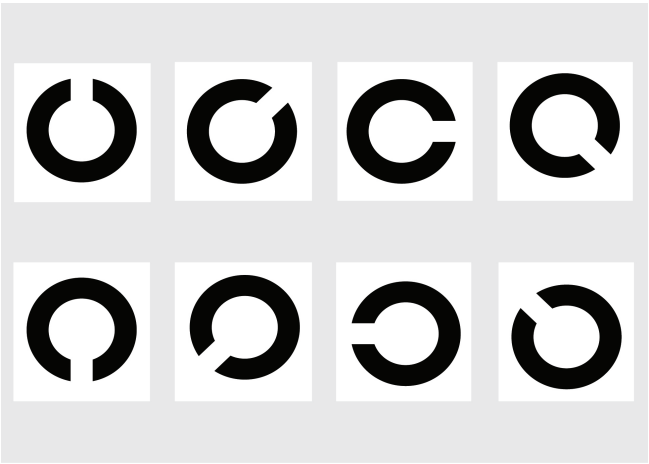

Figure 4-1 Landolt ring in eight positions

The Landolt ring construction was created with the use of Formula 1, (Figure4-2) for calculating the width of the Landolt ring opening (d), as well as its total height and width (D), individually for every height of acuity, Formula 2, (Figure 4-3), was used for calculating the angle of the Landolt ring opening (ε) for every individual distance from which the ring is viewed. By incorporating that result into Formula 3,(Figure 4-4.), the height of acuity (V) was calculated.

$$d = \tan \varepsilon \times a \; [m]$$

$$D = 5 \times d \; [m]$$

(1) Formula

for which it sands:

d – height of the Landolt ring opening

ε – opening angle of the Landolt ring for a specific acuity height

D – height and width of the Landolt ring

Figure 4-2 Figure 2 Formula for construction of the Landolt ring

$$\tan \varepsilon = \frac{d[m]}{a[m]} \times 60'$$

(2) Formula

for which it stands:

d – width of the Landolt ring opening

a – distance from which the Landolt ring is observed

ε – opening angle of the Landolt ring for a specific acuity height

Figure 4-3 Formula for calculating the angle of the Landolt ring opening

$$V = \frac{1}{\varepsilon}$$

(3) Formula

for which it stands:

V – acuity value

ε – opening angle of the Landolt ring for a specific acuity height

Figure 4-4 Formula for calculating the acuity value (VA)

The figure 4-5 shows the scheme for the Landolt ring construction.

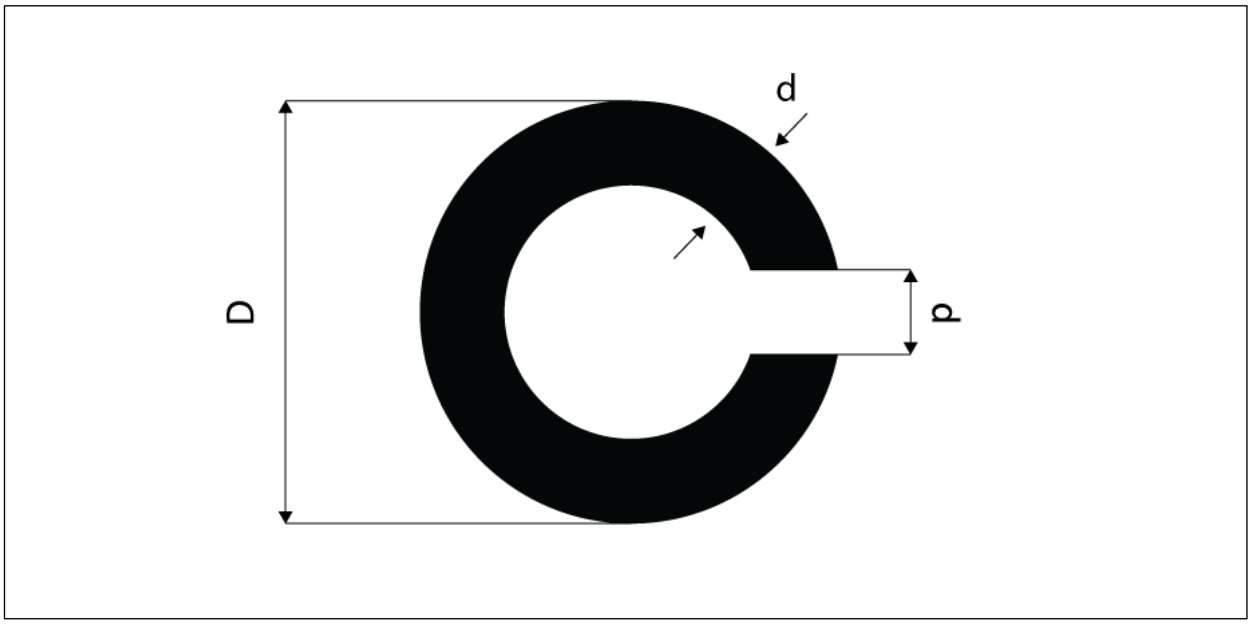

Figure 4-5 Landolt ring scheme

The control of tests through the measurement was done with wireless keyboard. The spacebar was used for stopping the animation and left arrow key was used for control results of visual acuities, combination of Ctrl key and letter “r” key was used for restarting the animation.

4.6 Tests

4.7 Reaction time tests

For the needs of this study, reaction speed was measured. The set of 2 different tests were designed for reaction time measurement.

The measurements of reaction were done in lit and dim environment. The sign used in lit condition was black sign on white background and the sign used in dim condition was red sign on black background. The aim was to determine if there were differences in subject’s reaction time in lit and dim conditions.

For this purpose a test was constructed in way that white or black screen appeared, depending in which condition the measurements were taken, after 10 seconds a big Landolt ring sign size of 0.1 VA appeared on screen.

Subjects were seated in front of the screen on which an empty screen with respectively white or black background was displayed for certain amount of time, after which a Landolt ring sign would appear respectively of black or red colour (Figure 4-6; 4-7).

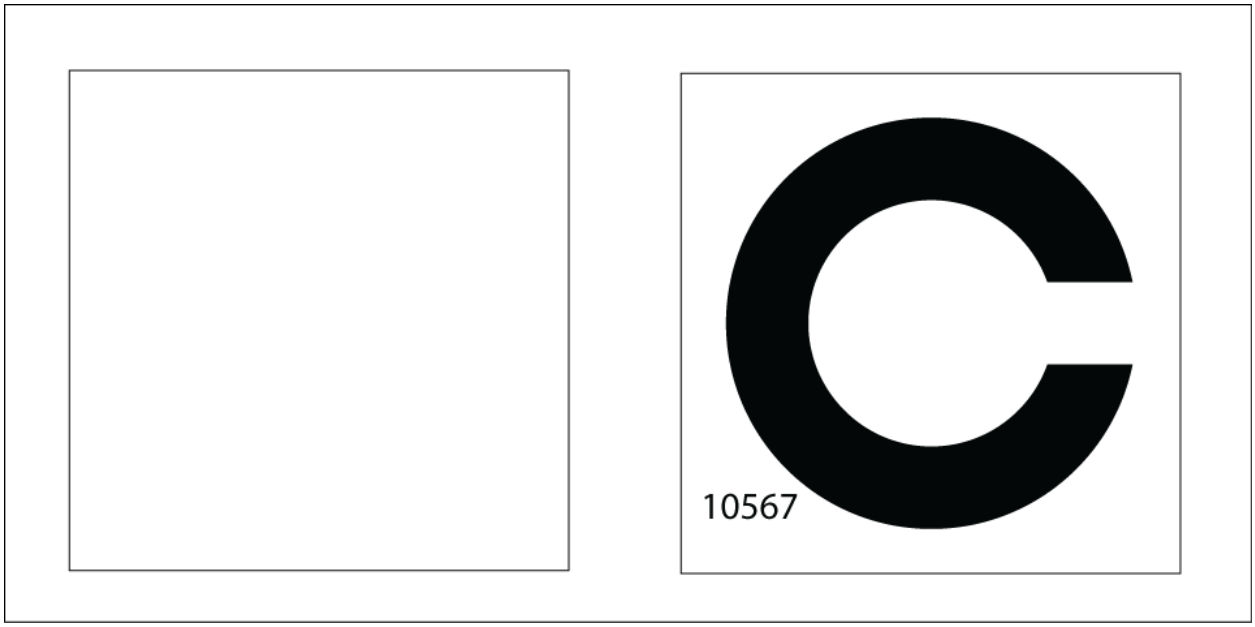

Figure 4-6 Reaction time test with black Landolt ring on white background

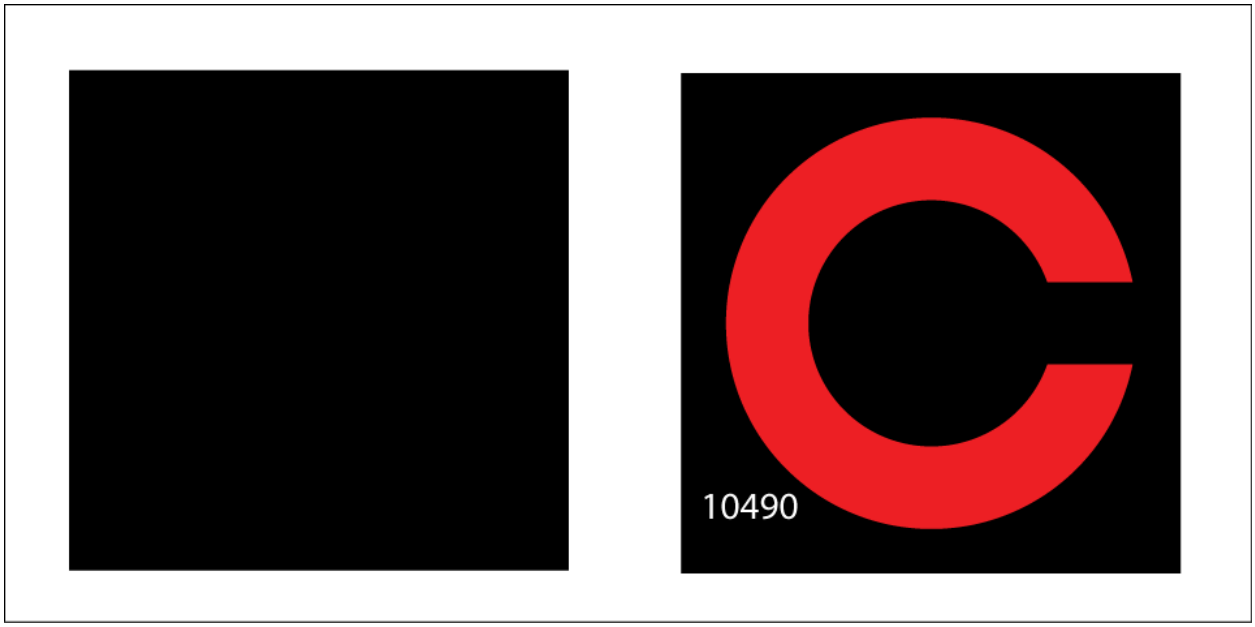

Figure 4-7 Reaction time test with red Landolt ring on black background

The subject was instructed to press the spacebar on the keyboard the very moment he/she saw the Landolt ring sign. Pressing the key software stops counting elapsed time. These results were later used for calculation of dynamic visual acuity values, as

explained in Chapter 3.9. The result was displayed in milliseconds, the so called "idle" time, i.e. the time during which white or black background were displayed prior to Landolt ring sign appearance on the screen was subtracted from the obtained result, the difference between those two values was actual time needed for subject's reaction. Reaction time was measured 5 times in lit condition and 5 times in dim condition.

4.8 Tests for dynamic visual acuity with radial increase of Landolt ring size with magnification speed at 20%, 40%, 60% 80% and 100% per second

As previously mentioned, calculations of the opening (d) and width (D) values of Landolt ring were necessary for the construction of Landolt ring, and were calculated for every distance and every magnification speed per millisecond. Five tests were designed for each radial increase in size of sign animation magnification speed at 20%, 40%, 60% 80% and 100% per second.

These tests were designed to see what happened with dynamic visual acuity when a known radial increase in size of Landolt ring with a given magnification speed was present in every second. The approach in this test was a general relationship between magnification speed and its influence on visual acuity. The starting point was at visual acuity 3.1, and each of 5 tests had different magnification speed of Landolt ring (20%, 40%, 60% 80% and 100% per second). The fact that the measurements were done at the 6 meters distance was taken into consideration during Landolt ring construction calculation. For the test simulations dynamic augmentation of the Landolt ring for a screen distance of 6 m had to be provided. The shortened calculation in 500 milliseconds steps are shown in Table 4-1.

Landolt ring sizes calculation for DVA test - speed magnification at 20%, 40%, 60%, 80% and 100% per second

Distance to screen	Object width	Driving speed	Driving speed	Time interval in table
z0 [m]	l0 [m]	v0 [km/h]	v0 [m/s]	Dt [s]
6	0,01745	72	20,0	0,010

t [s]	Distance to car in front	Object width on screen 20% Magnification speed	SVA for resolved object	Distance to car in front	Object width on screen 40% Magnification speed	SVA for resolved object	Distance to car in front	Object width on screen 60% Magnification speed	SVA for resolved object	Distance to car in front	Object width on screen 80% Magnification speed	SVA for resolved object	Distance to car in front	Object width on screen 100% Magnification speed	SVA for resolved object
	z [m]	l [mm]	VA [1/']	z [m]	l [mm]	VA [1/']	z [m]	l [mm]	VA [1/']	z [m]	l [mm]	VA [1/']	z [m]	l [mm]	VA [1/']
0	186	0,563	3,10	186	0,563	3,10	186	0,563	3,10	186	0,563	3,10	186	0,56	3,10
0,500	176	0,617	2,83	157	0,666	2,62	147	0,712	2,45	139	0,755	2,31	131	0,80	2,19
1,000	166	0,676	2,58	133	0,788	2,21	116	0,901	1,94	103	1,013	1,72	93	1,126	1,55
1,500	156	0,740	2,36	112	0,933	1,87	92	1,139	1,53	77	1,360	1,28	66	1,592	1,10
2,000	146	0,811	2,15	95	1,103	1,58	73	1,441	1,21	57	1,824	0,96	46	2,252	0,78
2,500	136	0,888	1,97	80	1,306	1,34	57	1,823	0,96	43	2,447	0,71	33	3,185	0,55
3,000	126	0,973	1,79	68	1,545	1,13	45	2,306	0,76	32	3,283	0,53	23	4,504	0,39
3,500	116	1,066	1,64	57	1,828	0,95	36	2,917	0,60	24	4,405	0,40	16	6,370	0,27
4,000	106	1,167	1,50	48	2,163	0,81	28	3,690	0,47	18	5,910	0,30	12	9,008	0,19
4,500	96	1,279	1,36	41	2,559	0,68	22	4,667	0,37	13	7,929	0,22	8	12,739	0,14
5,000	86	1,401	1,25	35	3,028	0,58	18	5,903	0,30	10	10,638	0,16	6	18,016	0,10

Table 4-1 Landolt ring construction calculation first 5 seconds for tests with radial increase of Landolt ring size with magnification speed at 20%, 40%, 60% 80% and 100% per second

For all tests with radial magnification of Landolt ring signs was calculated, the opening of ring (d) and height and width (D) for construction the magnification and dynamic of increase in Landolt rings size, bigger the magnification faster the change rate. This test was done only in lit condition.

At the moment when the subject recognized the direction of the Landolt ring opening, he/she would press the keyboard spacebar, which caused the animation to stop and screen was covered with black rectangle. The frame number was then displayed at the bottom of the LCD screen (Figure 4-8). For every frame the corresponding visual acuity value was known. The subject then had to state the correct orientation of the Landolt ring opening. The test was repeated five times (only correct answers were taken into account). Results were compared to the static visual acuities measured by the same Landolt test displayed on the LCD screen. After that the reaction time was subtracted from result to see how motoric component interact with dynamic visual acuity.

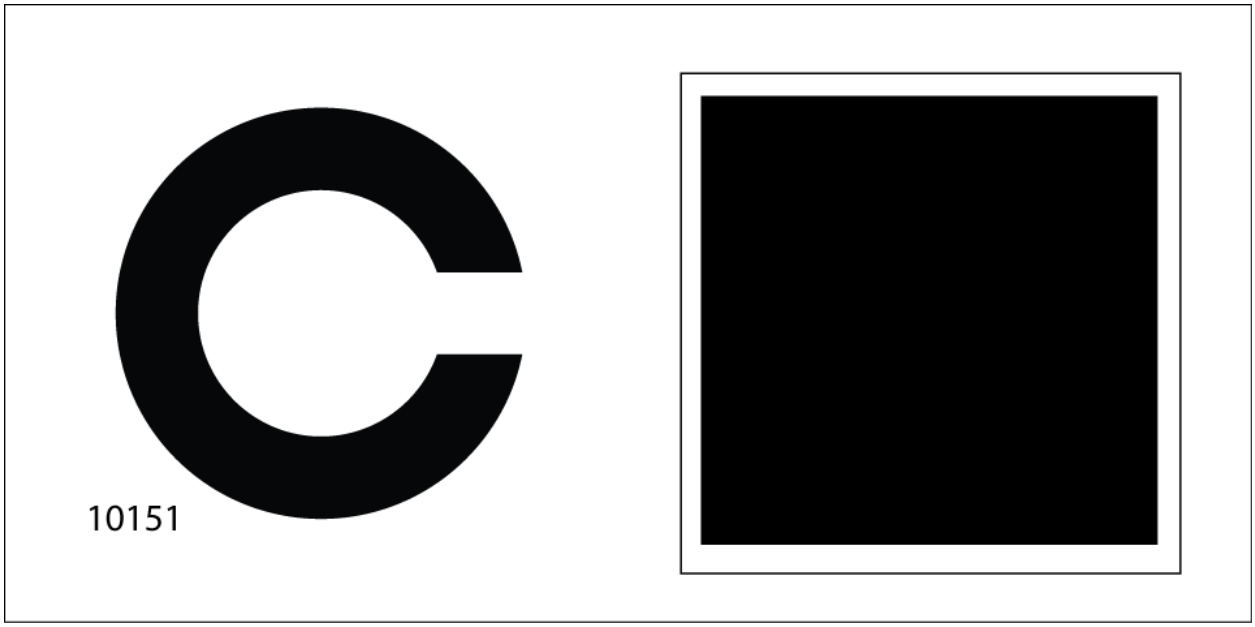

Figure 4-8 Screenshot of the test with radial increase of Landolt ring size with magnification speed

4.9 Subtraction of reaction time from dynamic visual acuity values

The tests were constructed in a way that for every fraction of time dynamic visual acuity value unit was known, subtracting reaction time obtained with previously described reaction time test, provided value of dynamic visual acuity without motoric component.

For example if reaction time was 500 milliseconds and dynamic visual acuity was 0.8 VA units, it was known that the sign would appear in 4166th millisecond, when reaction time was subtracted, the result was 3666 milliseconds, from test layout it was known that this was equivalent to 1.1 VA units.

4.10 Test for simulation of driving condition at the speed of 72 km/h

This test was done in two variants black Landolt ring on white background and red sign on black background (Figure 4-9). Test with black sign on white background was done in lit condition; test with red sign on black background was done in dim condition. For these tests the idea behind Landolt ring construction was the fact that if we move at a

constant speed of, for example, 72 km/h, and the magnification speed of the object changes with the object distance.

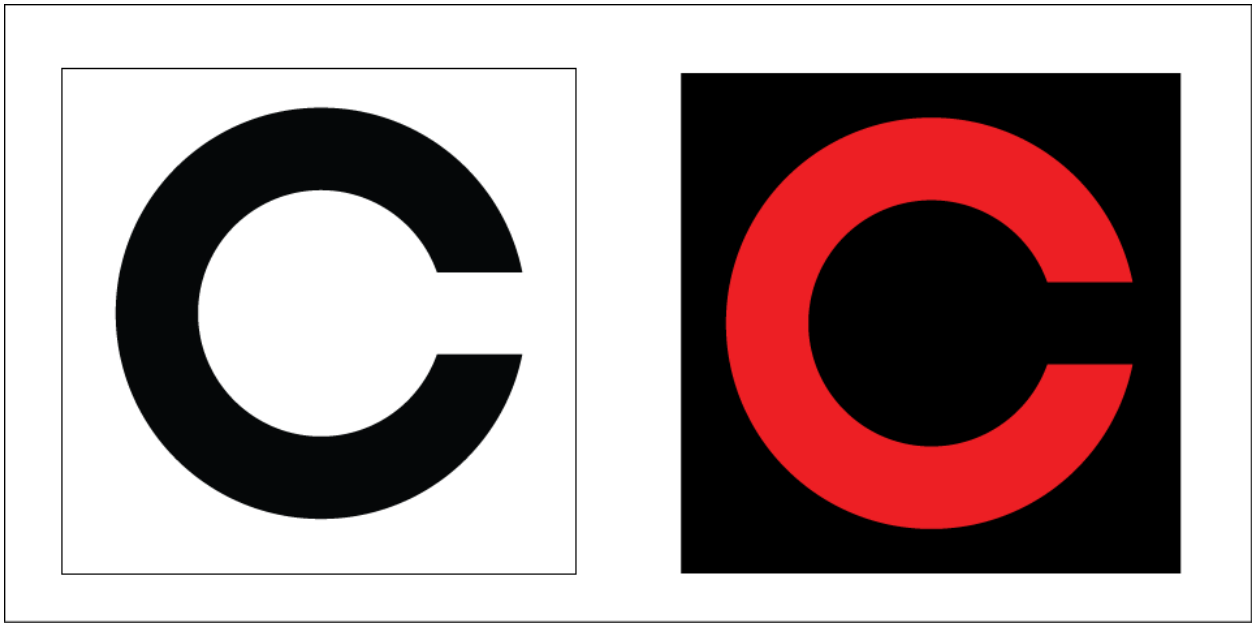

Figure 4-9 Screenshot of the test simulating driving speed condition

For the test simulations dynamic enlargement of the Landolt ring for a screen distance of 6m had to be provided. The shortened calculation in 500 milliseconds steps with magnification speed for the Landolt sign are shown in Table 4-2.

Landolt ring size calculation for simulation of driving speed at 72 km/h

Distance to screen	Object width	Driving speed	Driving speed	Time interval in table
z0 [m]	l0 [m]	v0 [km/h]	v0 [m/s]	Δt [s]
6	0,01745	72	20,0	0,5

t [s]	Distance to car in front	Object width on screen	SVA for resolved object	Magnification speed on screen	Relative magnification speed on screen
	z [m]	l [mm]	VA [1/']	Δl [mm/s]	[%/s]
0	186	0,562	3,100		
0,500	176	0,594	2,905	0,064	10,8%
1,000	166	0,630	2,740	0,072	11,4%
1,500	156	0,671	2,575	0,081	12,0%
2,000	146	0,717	2,410	0,092	12,8%
2,500	136	0,769	2,245	0,105	13,7%
3,000	126	0,831	2,080	0,122	14,7%
3,500	116	0,902	1,915	0,143	15,9%
4,000	106	0,987	1,750	0,170	17,2%
4,500	96	1,090	1,585	0,206	18,9%
5,000	86	1,217	1,420	0,254	20,8%
5,500	76	1,377	1,255	0,320	23,3%
6,000	66	1,586	1,090	0,417	26,3%
6,500	56	1,869	0,925	0,567	30,3%
7,000	46	2,276	0,760	0,813	35,7%
7,500	36	2,908	0,595	1,264	43,5%
8,000	26	4,026	0,430	2,237	55,6%
8,500	16	6,543	0,265	5,034	76,9%
9,000	6	17,450	0,100	21,813	125,0%
9,500	-4	-26,175	-0,065	Crash	Crash

Table 4-2 Landolt ring size calculation for test simulating driving speed at 72 km/h and magnification speed calculation

The Landolt ring dynamically increased simulating approaching velocity of 72 km/h. Every measurement started with the size of Landolt ring corresponding the visual acuity VA=3.1, and its size increased with the same orientation of the opening to visual acuity VA=0.1. At the moment when the subject recognized the direction of the Landolt ring opening, he/she would press the keyboard spacebar; this action caused the animation

to stop. The frame number was then displayed at the bottom of the LCD screen. For every frame the corresponding visual acuity value was known (Figure 4-10).

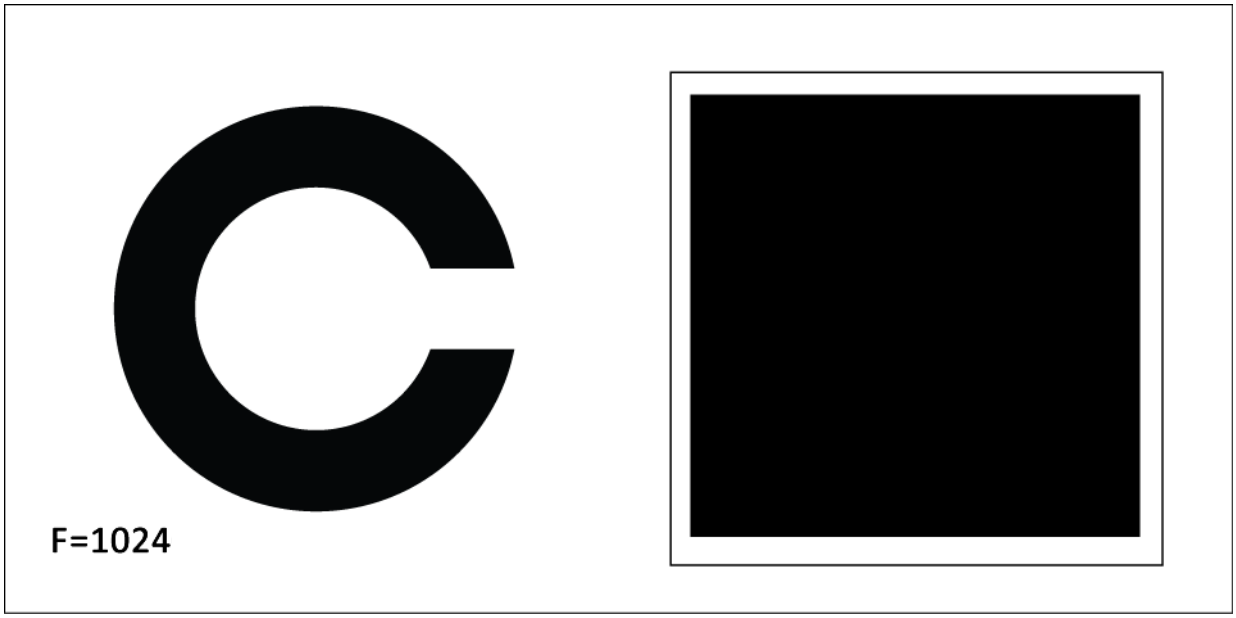

Figure 4-10 Screenshot of the test simulating driving speed condition with black sign on white background

The subject then had to state the correct orientation of the Landolt ring opening. The test was repeated five times (only correct answers were taken into account) for binocular vision. Results were compared to the static visual acuities measured by the same Landolt test displayed on the LCD screen.

Same principal of measurement were used for the test with red sign on black background (Figure 4-11).

Figure 4-11 Screenshot of the test simulating driving speed condition with red sign on black background

This test was created for measurement in dim condition. Every subject spent 20 minutes in dim environment before measurement; the illumination values were between 6 and 9 lux, which simulates night driving. The aim was to determinate if there were some differences between dynamic visual acuity in lit and dim conditions.

4.11 Test for simulation of driving condition at the speed of 130 km/h

Like the test simulating driving condition at the speed of 72 km/h this test was also done in two colours, black Landolt ring on white background and red sign on black background. Test with black sign on white background was performed in lit condition; test red sign on black background was performed in dim condition.

For the test simulations dynamic enlargement of the Landolt ring for a screen distance of 6m had to be provided. The shortened calculation in 500 milliseconds steps with magnification speed for the Landolt sign are shown in Table 4-3.

Landolt ring size calculation for simulation of driving speed at 130 km/h

Distance to screen	Object width	Driving speed	Driving speed	Time interval in table
z0 [m]	l0 [m]	v0 [km/h]	v0 [m/s]	Δt [s]
6	0,01745	129,6	36,0	0,500

t [s]	Distance to car in front	Object width on screen	SVA for resolved object	Magnification speed on screen	Relative magnification speed on screen
	z [m]	l [mm]	VA [1/']	Δl [mm/s]	[%/s]
0	186	0,562	3,100		
0,500	168	0,623	2,800	0,121	19,4%
1,000	150	0,698	2,500	0,150	21,4%
1,500	132	0,793	2,200	0,190	24,0%
2,000	114	0,918	1,900	0,250	27,3%
2,500	96	1,090	1,600	0,344	31,6%
3,000	78	1,342	1,300	0,503	37,5%
3,500	60	1,745	1,000	0,805	46,2%
4,000	42	2,492	0,700	1,496	60,0%
4,500	24	4,362	0,400	3,739	85,7%
5,000	6	17,450	0,100	26,175	150,0%
5,500	-12	-8,725	0,000	Crash	Crash

Table 4-3 Landolt ring size calculation for test simulating driving speed at 130 km/h and magnification speed calculation

The Landolt ring dynamically increased simulating approaching velocity of 130 km/h. Every measurement started with the size of Landolt ring corresponding the visual acuity VA=3.1, and its size increased in the same orientation to visual acuity VA=0.1. At the moment when the subject recognized the direction of the Landolt ring opening, he/she would press the keyboard spacebar, which caused the animation to stop. The measure of visual acuity was then displayed at the bottom of the LCD screen. The subject then had to state the correct orientation of the Landolt ring opening. The test was repeated five times (only correct answers were taken into account) for binocular vision. Results were compared to the static visual acuities measured by the same Landolt test displayed on the LCD screen.

Same principle of measurement was used with red sign on black background. This test was created for measurement in dim condition. Every subject spent 20 minutes in dim

environment before measurement; the illumination values were between 6 and 9 lux that simulates night driving. The aim was to determinate if there were some difference between dynamic visual acuity in lit and dim condition.

For all dynamic tests visual acuity data was subtracted from static visual acuity results to see if there are differences. In addition from all dynamic visual acuities reaction time or motoric component was subtracted to see interaction on dynamic visual acuity and to compare if there are some changes with higher speed. The reaction time subtraction method is described in Chapter 3.9.

The speed of 72 km/h and 130 km/h was used because aim was simulate allowed speed between in the city and suburbia. Another use of this test was to compare the results when the speed of driving is 80% higher. Also the aim was to determinate if there are interactions between age groups. The graph shows change flow of dynamic visual acuity magnification speed compared to distance (Figure 3-10).

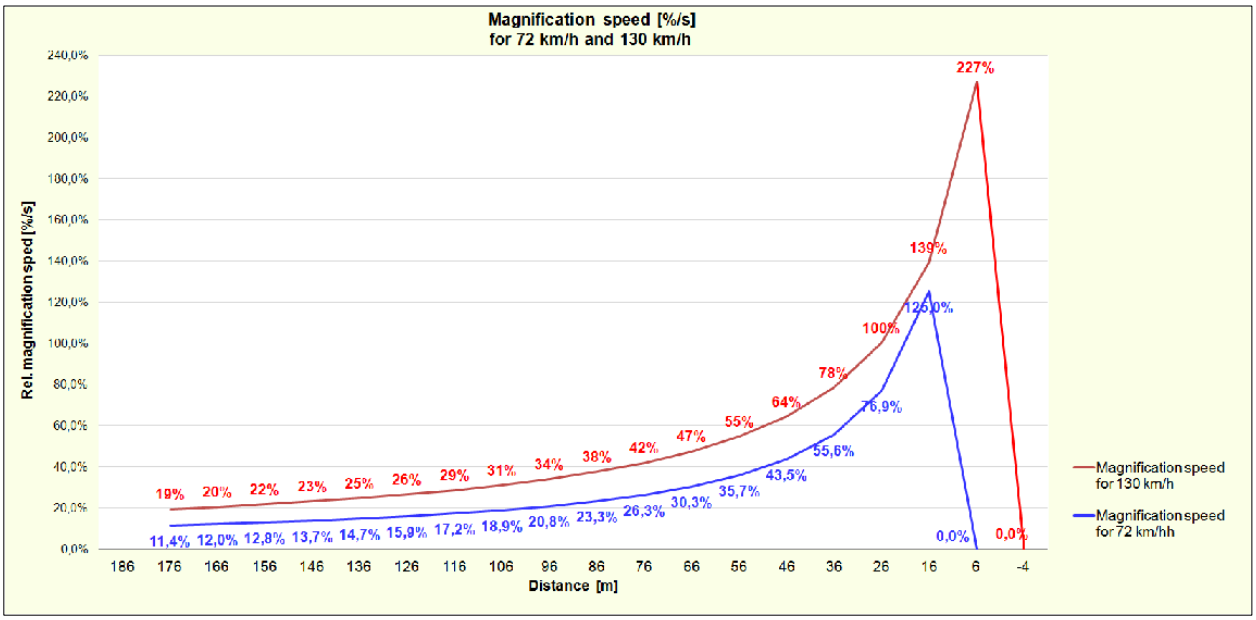

Figure 4-12 Comparison of dynamic visual acuity magnification speed for tests at 72 km/h and 130 km/h relative to distance

The Figure 4-12 and the Table 4-4 shows magnification speed rate and difference between those two tests. The presented magnification speed results suggest that test is highly non-linear.

t [s]	Visual acuity values for Dynamic visual acuity test at 72 km/h	Visual acuity values for Dynamic visual acuity test at 130 km/h	Relative magnification speed on screen for test at 72 km/h	Relative magnification speed on screen for test at 130 km/h
	VA [1/']	VA [1/']	[%/s]	[%/s]
0	3,100	3,10		
0,500	2,905	2,80	10,8%	19,4%
1,000	2,740	2,50	11,4%	21,4%
1,500	2,575	2,20	12,0%	24,0%
2,000	2,410	1,90	12,8%	27,3%
2,500	2,245	1,60	13,7%	31,6%
3,000	2,080	1,30	14,7%	37,5%
3,500	1,915	1,00	15,9%	46,2%
4,000	1,750	0,70	17,2%	60,0%
4,500	1,585	0,40	18,9%	85,7%
5,000	1,420	0,10	20,8%	150,0%
5,500	1,255	0,00	23,3%	Crash
6,000	1,090		26,3%	
6,500	0,925		30,3%	
7,000	0,760		35,7%	
7,500	0,595		43,5%	
8,000	0,430		55,6%	
8,500	0,265		76,9%	
9,000	0,100		125,0%	
9,500	-0,065		Crash	

Table 4-4 Comparison of visual acuity magnification speed for dynamic visual acuity tests simulating driving conditions at 72 km/h and 130 km/h

All data was processed with IBM SPSS Statistics and StatSoft Statistica 7 software packages.

Analysing the results of subject groups and individual tests, the descriptive statistic were calculated for each variable. Analysis was conducted using variance, paired simple t-test, and analysis of variance (ANOVA) with F-test which compares the variances for two sets of data to see if they are equal or not, depending on number of analysed variables.

Variance of a single variable represents the average amount that the data vary from the mean and if two variables are associated they covary. Standard deviation is typically

used as a unit of measurement into which any scale of measurement can be converted and is used for calculating covariance.

Paired samples t-test is used when we want to compare means of two experimental conditions and the same participants took part in both conditions of the experiment. If the samples came from the same population then we expect their means to be roughly equal. The t-statistic is used to test whether the differences between two means collected from the same sample or related observations are significantly different from zero. Student's t-test produces test statistics, which can be interpreted using p-values. The p-value is the probability of obtaining the observed sample results or any stronger deviation if the null hypothesis is actually true [24]. If this p-value is very small, usually less than or equal to a threshold value previously chosen called the significance level, traditionally 5% or 1%, it suggests that the observed data is inconsistent with the assumption that the null hypothesis is true, and thus that hypothesis must be rejected and a suitable chosen alternative hypothesis accepted as true [25]. If p is lower than 0.01 then probability that the null hypothesis is true is 1% (or 5% when $p<0.05$).

In statistics, an effect size is a quantitative measure of the strength of a phenomenon. Effect sizes complement statistical hypothesis testing, and play an important role in statistical power analyses.[26]

5 Results

In 45 days 115 subjects showed up for testing eventually 75 were comprised in this study.

They were categorized in three age groups:

1) younger group (10-20 years old, 15 female, 10 male),

2) middle-aged group (30-40 years old, 13 female, 12 male) and

3) older group (50-60 years old 11 female, 14 male).

The dropout was due to exclusion criteria see chapter 4, Methods, before starting of measurements (35 subjects).

A t-test-test was conducted for three subject groups, with younger, middle-aged and older group to determine whether there are differences in response time when viewing a black Landolt ring on a white background and red Landolt ring on a black background.

Standard deviation was calculated to see how the results are spread out around mean value. Because there were several runs of measurements standard error of mean was also calculated to obtain better characterization of random uncertainty to get the most accurate set of data.[27,28] It is also known that standard deviation is outliers resistant.

It was found that there was no statistically significant difference between the reaction time and the change in colour of the displayed Landolt ring and the background in the younger and middle-aged group(t-test (24) = 1.67; $p > 0.05$).

In older group of subjects a statistically significant difference between the reaction time and the changes in colour of the signs and the backgrounds (t-test = 3.99, $p < 0.01$) was determined. Elderly subjects responded more quickly to the red sign on a black background than to the black sign on a white background it is about 4% of difference.

Index of effect size with the change in colour of signs and backgrounds in older group explains 39% reaction time variance.

The mean reaction time in the younger subjects group was faster than middle-aged group for 8 ms, which makes around 2% of difference. The older group was 5% slower compared to two other groups. The results are shown in Table 5-1.

	REACTION TIME TEST BLACK SIGN ON WHITE BACKGROUND			REACTION TIME TEST RED SIGN ON BLACK BACKGROUND		
	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION [ms]	STANDARD ERROR MEAN [ms]	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION [ms]	STANDARD ERROR MEAN [ms]
YOUNG GROUP (10 – 20 YEARS OLD)	25	423 ± 59	12	25	420 ± 60	12
MIDDLE-AGED GROUP (30 – 40 YEARS OLD)	25	430 ± 111	22	25	433 ± 114	23
OLDER GROUP (50 – 60 YEARS OLD)	25	448 ± 62	12	25	431 ± 52	10

Table 5-1 Obtained Mean, Standard Deviation and Standard Error of the Mean values for reaction by test groups and test types

Index of effect size with the change in colour of signs and backgrounds explains 10% of the variance of the reaction time of the subjects in the younger group and 2% of the variance of the reaction time of the subjects in middle-aged group.

The obtained results of mean value and standard error of the mean for reaction time measurements are shown in Figure 5-1.

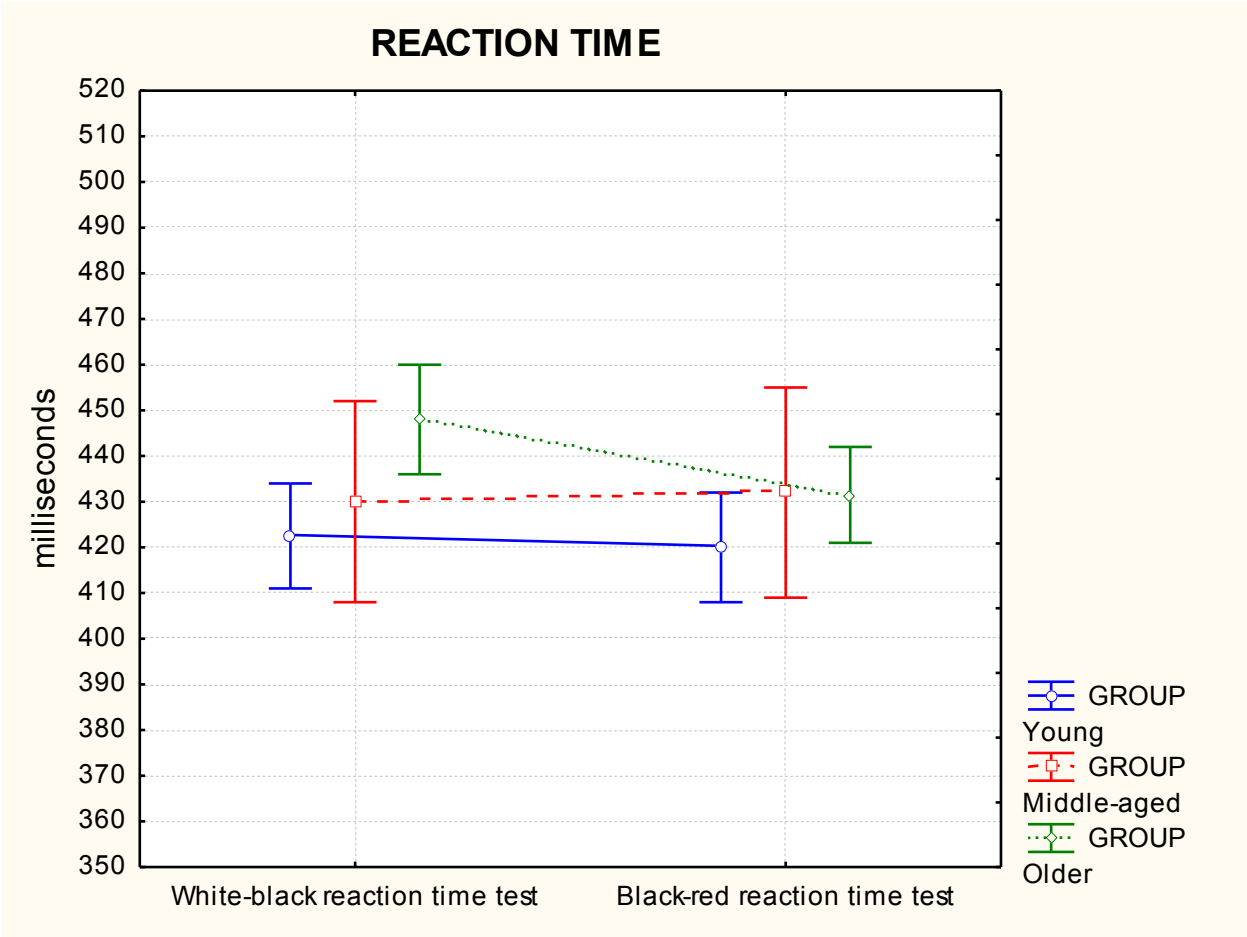

Figure 5-1 Reaction time test black sign on white background and reaction time test red sign on black background for all three subject groups with mean values and standard error of the mean

If standard deviation is analyzed regardless of p-value result, a question arises, why the standard deviation values are so high while p-value indicates statistically significant difference. The reason for the abovementioned is standard deviation resistance to outliers that is why the extreme values were plotted to show the cause of high values in standard deviation (Figure 5-2).

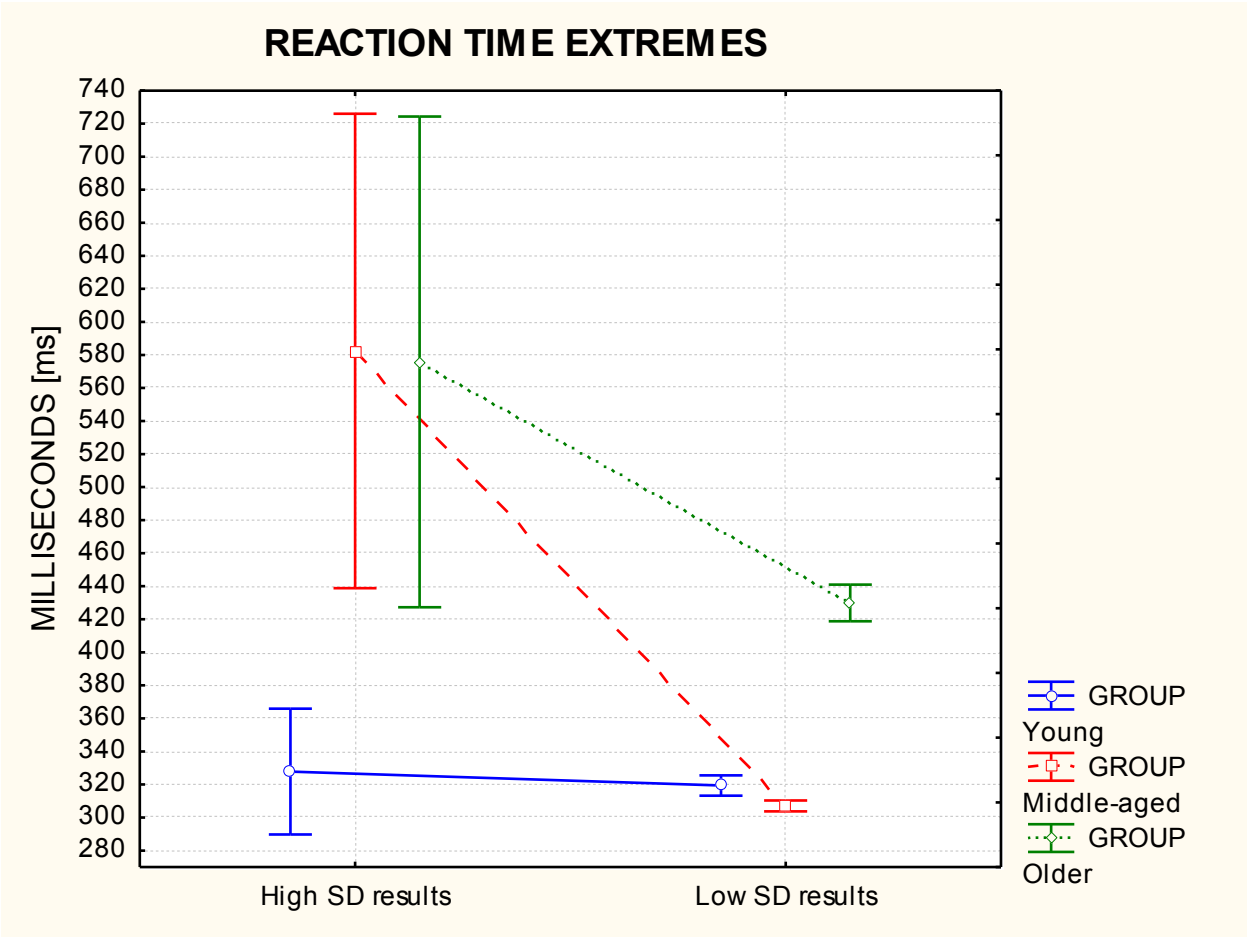

Figure 5-2 Reaction time extremes with standard deviation

Analysis of tests results in which Landolt ring radial increase in size with magnification speed at 20%, 40%, 60%, 80% and 100% per second showed as follows: a one-way analysis of variance for dependent groups results was conducted in order to determine whether there is a difference in the visual acuity (VA) when subjects looks at a static Landolt ring and when that sign radial increase with magnification speed at 20%, 40%, 60%, 80% and 100% per second. The dependent variable consists of VA and the factors, which differentiate dependent sets of results, are the increments of the sign at 20%, 40%, 60%, 80% and 100% per second

ANOVA results indicate a statistically significant effect of radial increase of Landolt ring size on VA in all three groups of subjects:

younger group F-test (5.12) = 192.62, $p < 0.01$,

middle-aged group F-test (5.12) = 886.90; $p < 0.01$,

older group F-test (5.12) = 369.52, p <0.01.

Comparing the results obtained by an radial increase in size speed of Landolt ring (with Least Significant Difference method of controlling alpha error), it was found that the results for all the groups are statistically significantly different. Analysis resulted in following mean values and standard deviations as shown in Table 5-2.

	YOUNG GROUP (10 – 20 YEARS OLD)		MIDDLE- AGED GROUP (30 – 40 YEARS OLD)		OLDER GROUP (50 – 60 YEARS OLD)	
	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA
SVA BINO	25	1.37 ± 0.22	25	1.37 ± 0.37	25	1.37 ± 0.22
VA MAGNIFICATION 20%	25	1.22 ± 0.21	25	1.18 ± 0.36	25	1.15 ± 0.21
VA MAGNIFICATION 40%	25	1.06 ± 0,28	25	1.10 ± 0.37	25	1.06 ± 0.22
VA MAGNIFICATION 60%	25	0.93 ± 0.28	25	0.94 ± 0.38	25	0.92 ± 0.22
VA MAGNIFICATION 80%	25	0.86 ± 0.21	25	0.82 ± 0.34	25	0.86 ± 0.29
VA MAGNIFICATION 100%	25	0.71 ± 0.20	25	0.68 ± 0.34	25	0.63 ± 0.20

Table 5-2 Analysis of tests results for all three groups in which Landolt ring with radial increase in size with magnification speed at 20%, 40%, 60%, 80% and 100% per second

Graphic presentation of mean value and standard error of the mean are shown in Figure 5-3.

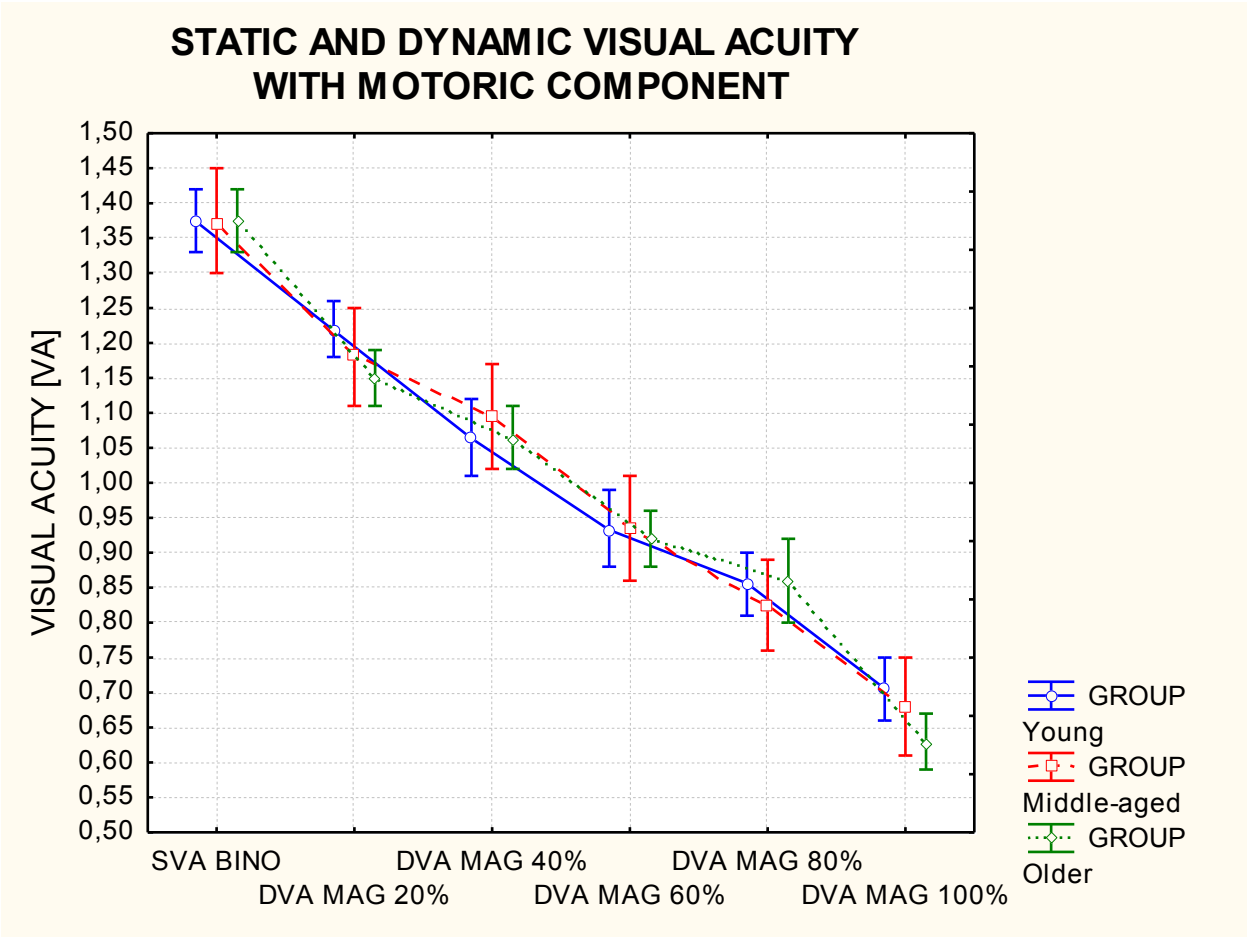

Figure 5-3 Tests results for static and dynamic visual acuity for all three groups with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60%, 80% and 100% per second with mean values and standard error of the mean

Radial magnification speed of the Landolt ring animation caused the decrease in visual acuity with the subjects from all three age groups. As shown in Table 5-2 and Figure 5-3 dynamic visual acuity decreases with increase of velocity of sign magnification.

An ANOVA analysis of the differences between static and dynamic VA for all three groups was performed and showed a statistically significant effect of radial increase Landolt ring the difference on static and dynamic VA in all three groups of subjects:

- younger subjects F-test (4.96) = 1396.71; $p < 0.01$,
- middle-aged subjects F-test (4.96) = 634.03, $p < 0.01$,
- older subjects F-test (4.96) = 239.28, $p < 0.01$.

The results show that decreases of visual acuity with increase of magnification speed are:

- magnification speed 20% - decrease 14.5% (0.20 VA),
- magnification speed 40% - decrease 22% (0.30 VA),
- magnification speed 60% - decrease 30% (0.40 VA),
- magnification speed 80% - decrease 37% (0.50 VA) and
- magnification speed 100% - decrease of 51% (0.70 VA) in all three groups.

Analyzed results of difference mean values and standard error of the mean are shown in Table 5-3.

	YOUNG GROUP (10 – 20 YEARS OLD)		MIDDLE- AGED GROUP (30 – 40 YEARS OLD)		OLDER GROUP (50 – 60 YEARS OLD)	
	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 20%	25	0.16 ± 0.02	25	0.18 ± 0.03	25	0.20 ± 0.03
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 40%	25	0.28 ± 0.03	25	0.26 ± 0.06	25	0.30 ± 0.03
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 60%	25	0.41 ± 0.04	25	0.42 ± 0.02	25	0.44 ± 0.02
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 80%	25	0.52 ± 0.06	25	0.54 ± 0.04	25	0.5 ± 0.13
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 100%	25	0.67 ± 0.06	25	0.68 ± 0.06	25	0.73 ± 0.04

Table 5-3 Analysis of difference between static and dynamic visual acuity with motoric component for all three groups with radial increase in size of Landolt ring with magnification speeds at 20%, 40%, 60%, 80% and 100% per second

Graphic presentation of difference mean value and standard error of the mean are shown in Figure 5-4.

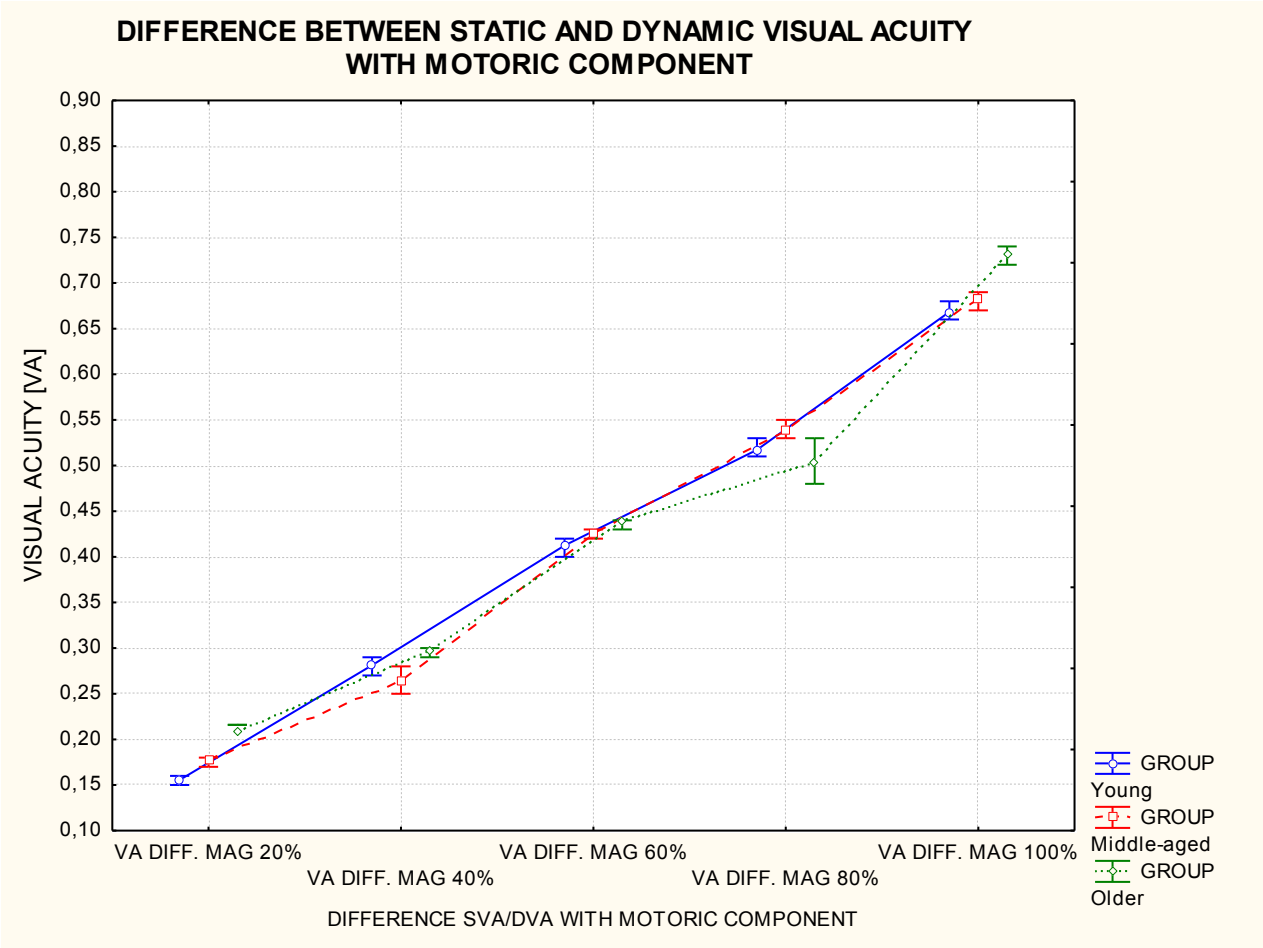

Figure 5-4 Difference between static and dynamic visual acuity with motoric component for the tests with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60%, 80% and 100% per second with mean values and standard error of the mean

The following are results comparison with subtracted motor component (reaction time) in the test where Landolt ring radial increase in size with magnification speed at 20%, 40%, 60%, 80% and 100% per second.

Once obtained the results of the test where Landolt ring radial increase in size with magnification speed at 20%, 40%, 60%, 80% and 100% per second reaction time was subtracted and a one-way analysis of variance for dependent groups was conducted. It showed a statistically significant effect of radial increase Landolt ring size on subjects VA:

- younger group (F-test (4.96) = 369.76, p <0.01,
- middle-aged group (F-test (4.96) = 287.25, p <0.01),

- the older group (F-test (4.96) = 565.58, p <0.01)).

Index of effect size with the radial increase in size of the Landolt ring with magnification speed changes explains 94 % VA variance in younger group and 92% in middle-aged and older groups.

Comparison of the results obtained by tests with radial increase of sign with magnification speeds (with Least Significant Difference method of controlling alpha error) showed as follows:

- magnification speed 20% - decrease 5% (0.08 VA),
- magnification speed 40% - decrease 9% (0.12 VA),
- magnification speed 60% - decrease 16% (0.22 VA),
- magnification speed 80% - decrease 22% (0.30 VA) and
- magnification speed 100% - decrease of 27% (0.37 VA) in all three groups.

Listed results are shown in Table 5-4.

	YOUNG GROUP (10 – 20 YEARS OLD)		MIDDLE- AGED GROUP (30 – 40 YEARS OLD)		OLDER GROUP (50 – 60 YEARS OLD)	
	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA
SVA BINO	25	1.37 ± 0.22	25	1.37 ± 0.37	25	1.37 ± 0.22
VA MAGNIFICATION 20%	25	1.31 ± 0.23	25	1.27 ± 0.36	25	1.23 ± 0.22
VA MAGNIFICATION 40%	25	1.25 ± 0.23	25	1.23 ± 0.38	25	1.13 ± 0.25
VA MAGNIFICATION 60%	25	1.15 ± 0.24	25	1.13 ± 0.40	25	0.99 ± 0.25
VA MAGNIFICATION 80%	25	1.09 ± 0.26	25	1.04 ± 0.37	25	0.89 ± 0.26
VA MAGNIFICATION 100%	25	0.95 ± 0.25	25	0.93 ± 0.70	25	0.89 ± 0.26

Table 5-4 Analysis of tests results for all three groups with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60%, 80% and 100% per second without motoric component

The results for dynamic visual acuity (DVA) with subtracted motoric component are given in a Figure 5-5.

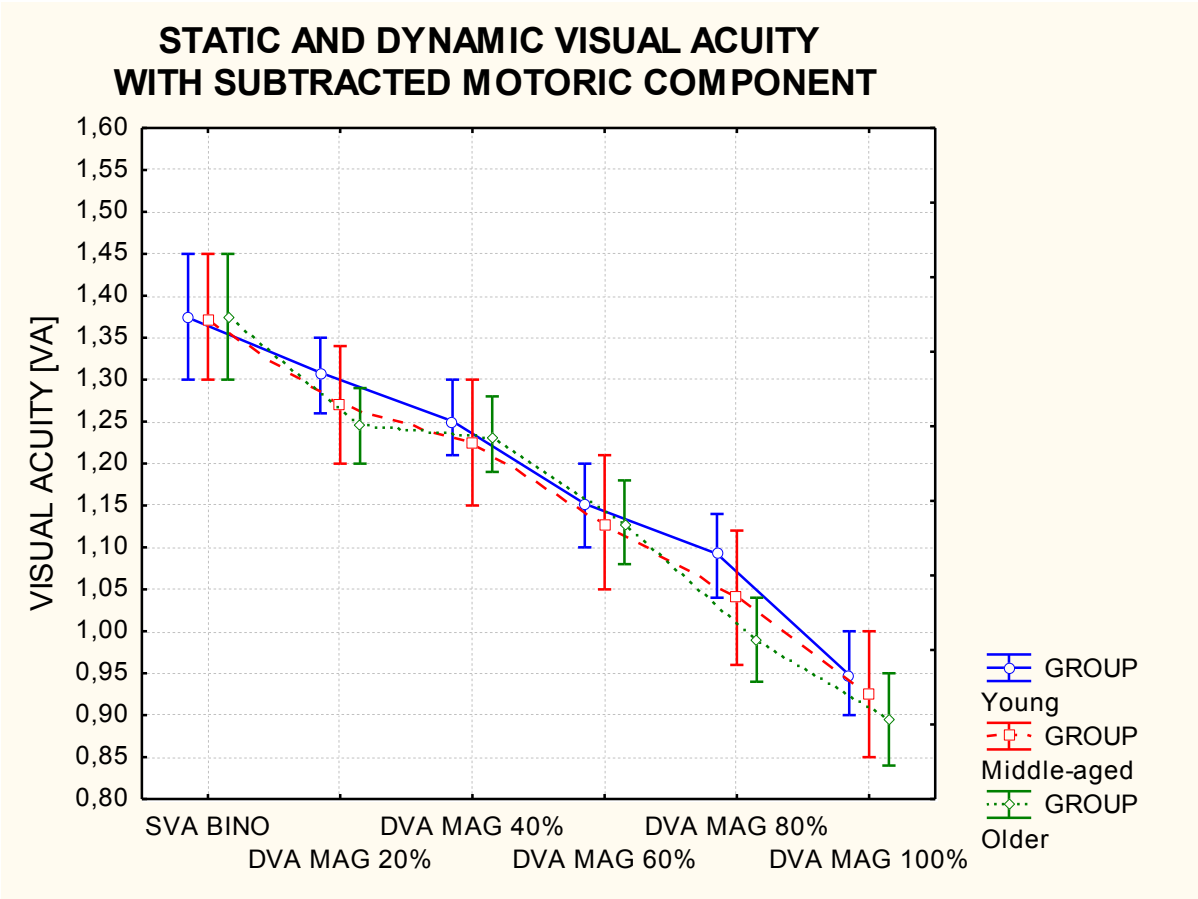

Figure 5-5 Tests results for all three groups with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60%, 80% and 100% per second with subtracted motoric component with mean value and standard error of the mean

Also for measurement in which the response time was subtracted from the obtained results an ANOVA analysis of the differences between static and dynamic VA was made and showed a statistically significant effect of radial Landolt ring size on the difference in static and dynamic VA values in all three groups of subjects:

- younger subjects F-test (4.96) = 387.85, $p < 0.01$,
- middle-aged subjects F-test (4.96) = 285.41, $p < 0.01$,
- older subjects F-test (4.96) = 563.65 $p < 0.01$.

Listed results are shown in Table 5-5.

	YOUNG GROUP (10 – 20 YEARS OLD)		MIDDLE- AGED GROUP (30 – 40 YEARS OLD)		OLDER GROUP (50 – 60 YEARS OLD)	
	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA	NUMBER OF SUBJECTS	MEAN VALUE ± STANDARD DEVIATION VA
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 20%	25	0.06 ± 0.02	25	0.09 ± 0.03	25	0.11 ± 0.03
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 40%	25	0.12 ± 0.02	25	0.14 ± 0.03	25	0.13 ± 0,02
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 60%	25	0.22 ± 0.04	25	0.23 ± 0.04	25	0.23 ± 0.04
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 80%	25	0.28 ± 0.07	25	0.32 ± 0.06	25	0.37 ± 0.05
DIFFERENCE BETWEEN SVA AND DVA AT MAGNIFICATION 100%	25	0.42 ± 0.06	25	0.43 ± 0.05	25	0.46 ± 0.05

Table 5-5 Analysis of difference between static (SVA) and dynamic (DVA) visual acuity with subtracted motoric component for all three groups with radial increase in size of Landolt ring with magnification speed at 20%, 40%, 60%, 80% and 100% per second

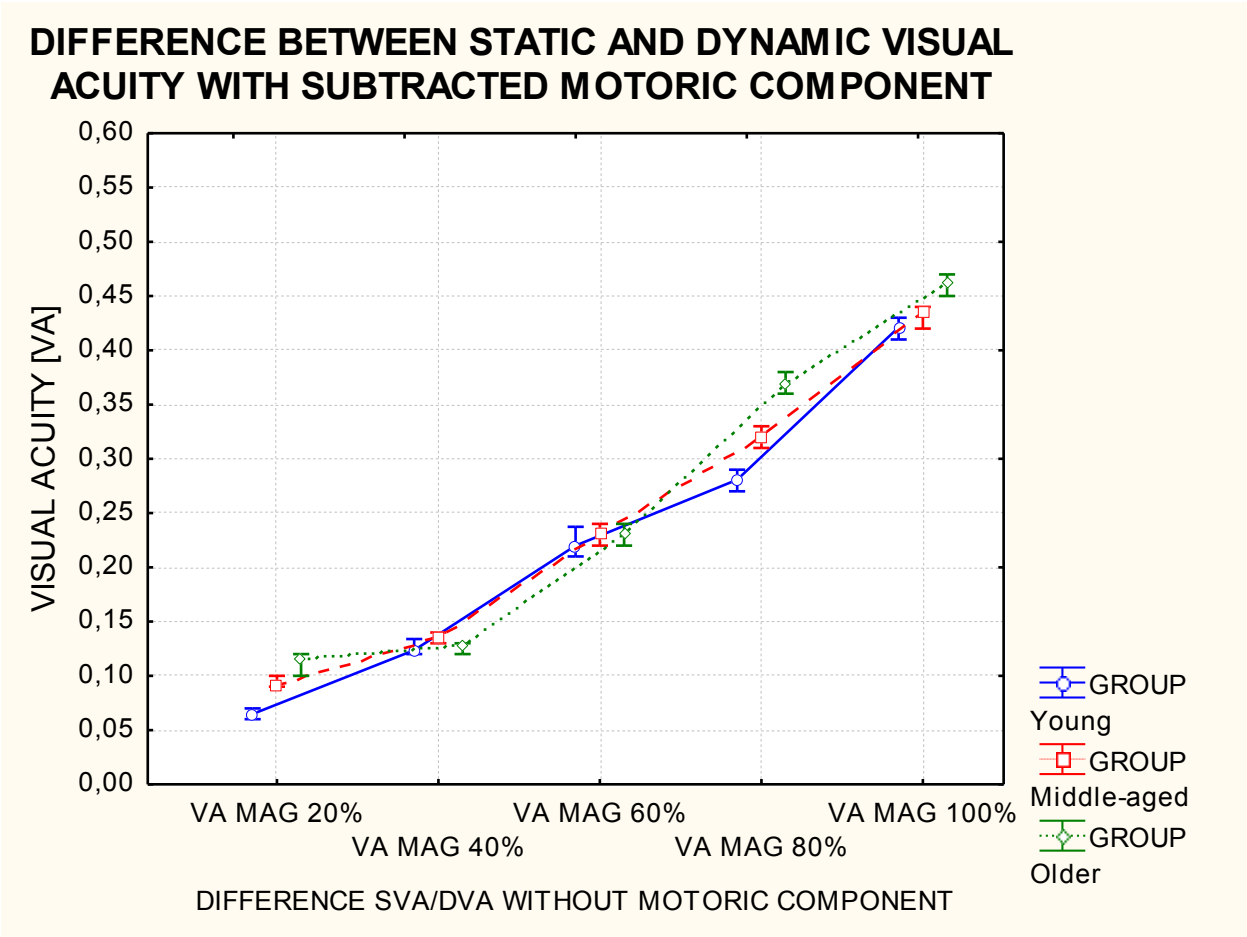

Figure 5-6 Difference between static visual acuity and dynamic visual acuity with subtracted motoric component for the test with radial increase in size of Landolt ring with speed magnification 20%, 40%, 60%, 80% and 100% per second with mean value and standard error of the mean

The analysis proved that the difference in visual acuity with motoric component and with subtracted motoric component is the result of reaction time.

This step clearly shows the interaction between motoric component and the values of visual acuity. It shows that the visual acuity values are higher when motoric component was subtracted.

Following results were obtained by analysing further tests that simulate driving conditions. Comparison of the test with the motoric component and black Landolt ring on a white background at the speed of 72 km/h and 130 km/h had given the following results.

ANOVA analysis results indicate a statistically significant effect of increase Landolt ring size on VA in all three groups of subjects:

- younger group F-test (2.48) = 165.49, p <0.01,
- middle-aged group F-test (2.48) = 195.29, p <0.01,
- older group (F-test (2.48) = 125.09, p <0.01).

It was found that there is a statistically significant difference between static and dynamic VA as the results of the test with motoric component included in all three groups of subjects in the animation of the sign at 72 km/h.

A t-test-test was conducted for dependent groups of subjects in order to determine whether there are statistically significant differences between static and dynamic VA results of a test with the motoric component included in animated black-and-white Landolt ring at a speed of 72 km/h and at a speed of 130 km/h:

- younger group t-test = 4.49, p <0.01),
- middle-aged group t-test = 2.45, p <0.05,
- older group t-test (24) = 7.60, p <0.01.

Analyzing the differences between static and dynamic VA values in younger group it has been found that when animating the sign at 72 km/h the difference is smaller than when animating it at 130 km/h. Index of effect size suggests that changes in the speed of Landolt ring animation can explain 46% variance of the difference of static and dynamic VA when mechanical component was not subtracted.

The following results have been obtained for middle-aged group for the animation of the sign at 72 km/h there was less difference than at 130 km/h.

Index effect size suggests that changes in the Landolt ring animation speed can explain 20% of the variance of the difference of static and dynamic VA when the mechanical component is not subtracted.

Furthermore, in the older group of subjects with the animation of the sign at 72 km/h there is less difference than at 130 km/h.

Index of effect size suggests that changes in Landolt ring animation speed can explain 71% of the variance of the difference of static and dynamic VA whe the mechanical component was not subtracted.

In addition results for the test with the subtracted reaction time using black Landolt ring on white background and animation speed of 72 km/h and 130 km/h were compared.

A t-test-test conducted for dependent groups of subjects in order to determine whether there are statistically significant differences in dynamic VA when we exclude the motoric component, i.e. reaction time subtracted from the result, while subjects look at black Landolt ring on a white background animated at a speed of 72 km/h and at speed of 130 km/h.

A statistically significant difference between the sign animated at a 72 km/h and 130 km/h speed has been found (t-test = 2.10, $p < 0.05$). Younger subjects showed less dynamic VA when animating sign at the speed of 72 km/h than with the animation of the sign at 130 km speed / h.

Index of effect size suggests that changes the speed of Landolt ring animation can explain 15% of the variance of dynamic VA when the mechanical component was subtracted.

After the analysis of a middle-aged group can be confirmed that there is a statistically significant difference between the signs moving at a speed of 72 km/h and 130 km/h (t-test = 2.13, $p < 0.05$). Dynamic VA is lower at the animation speed of of 72 km/h than with the animation of the sign at 130 km/h. As the animation of the sign is faster, reaction time has a greater impact.

Index of effect size suggests that changes in Landolt ring animation speed can explain 16% of the variance of dynamic VA when the mechanical component was subtracted.

Analyzing the results of the older group of subjects it was found that there was no statistically significant difference between the sign animated at a speed 72 km/h and 130 km/h (t-test = 1.07; $p > 0.05$). Older subjects had equal dynamic VA and at both 72 km/h and 130 km/h animation speed.

Index of effect size suggests that changes in the speed of Landolt ring animation can explain 4% of the variance of dynamic VA when the mechanical component was subtracted.

Analyzing the differences between static and dynamic VA values in younger group it has been found that when animating the sign at 72 km/h the difference is smaller than when animating it at 130 km/h

Index of effect size suggests that changes in the speed of Landolt ring animation can explain 46% variance of the difference of static and dynamic VA when the mechanical component was subtracted.

The following results has been obtained for middle-aged group for the animation of the sign at 72 km/h there is less difference than at 130 km/h.

Index effect size suggests that changes in the Landolt ring animation speed can explain 20% of the variance of the difference of static and dynamic VA when the mechanical component was subtracted.

Furthermore, in the older group of subjects with the animation of the sign at 72 km/h there is less difference than at 130 km/h.

Index of effect size suggests that changes in Landolt ring animation speed can explain 71% of the variance of the difference of static and dynamic VA when the mechanical component was subtracted.

The results obtained in the analysis are shown in the following tables and figures.

Comparison of static visual acuity and dynamic visual acuity at the animation speed of 72 km/h and 130 km/h, with and subtracted motoric reaction for all three groups is shown in Figure 5-7.

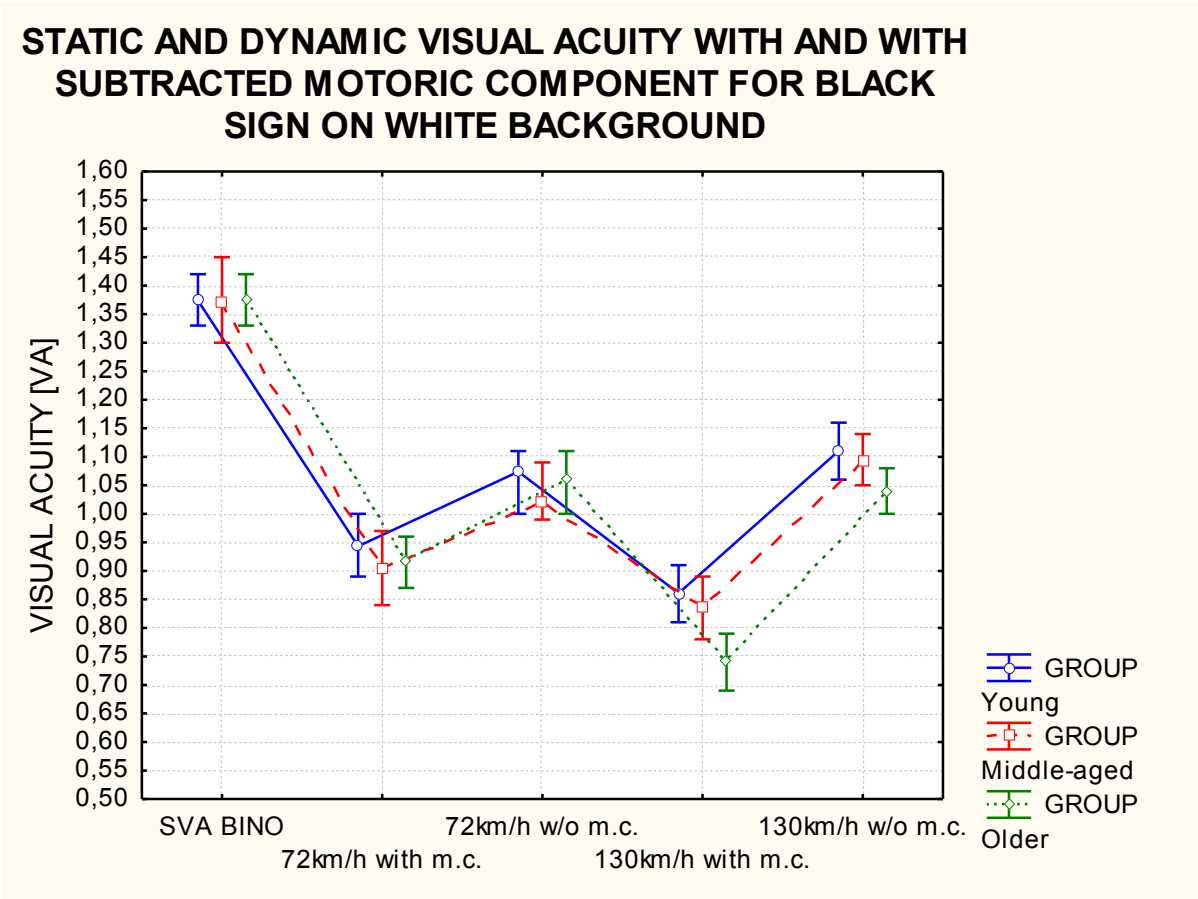

Figure 5-7 Comparison of static visual acuity and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and with subtracted motoric component for all three groups for black Landolt ring on white background with mean values and standard error of the mean

Difference between static visual acuity and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and with subtracted motoric component for all three groups for black Landolt ring on white background is showed in Figure 5-8.

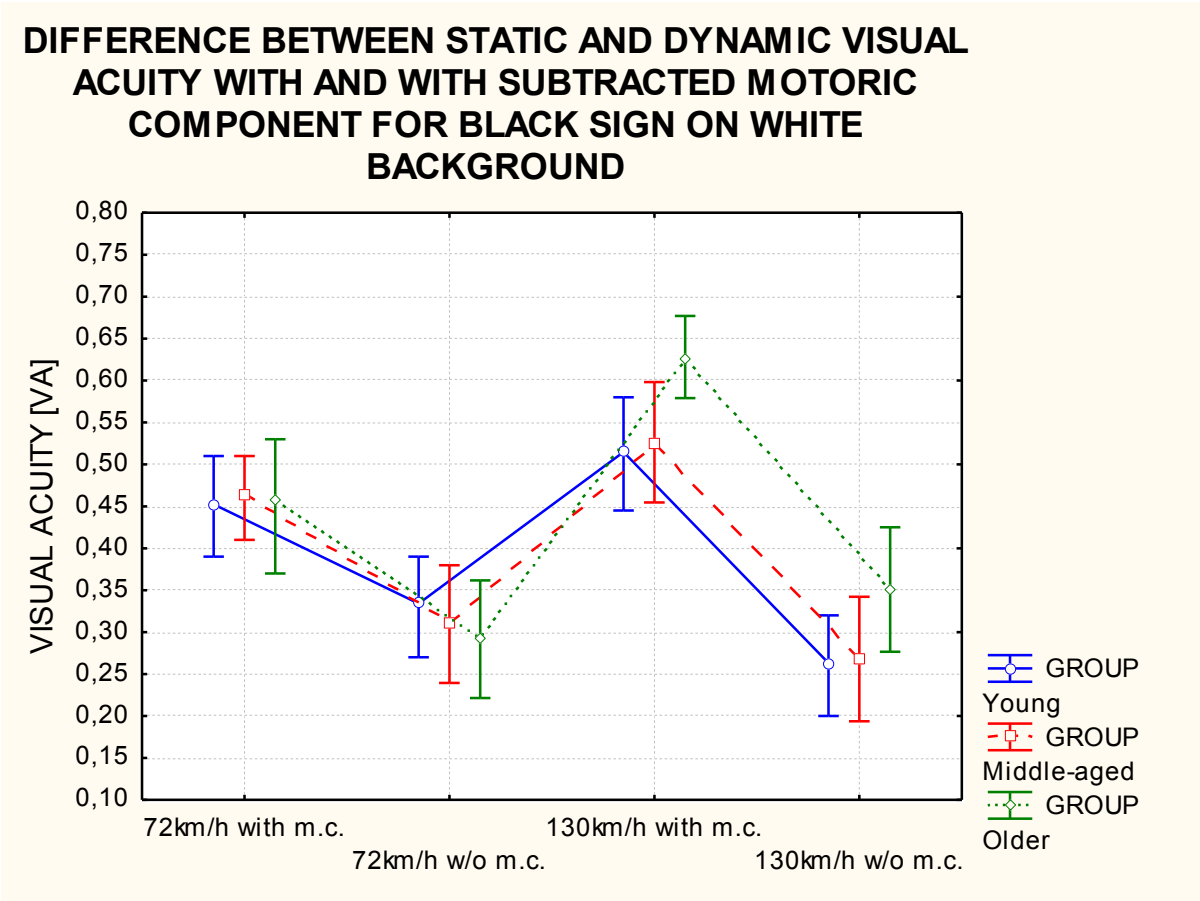

Figure 5-8 Difference between static and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and with subtracted motoric component for all three groups for black Landolt ring on white background with mean value and standard error of the mean

Complete results summary in given in the Table 5-6.

	STATIC VISUAL ACUITY	DYNAMIC VISUAL ACUITY WITH MOTORIC COMPONENT		DIFFERENCE BETWEEN STATIC AND DYNAMIC VISUAL ACUITY WITH MOTORIC COMPONENT		DYNAMIC VISUAL ACUITY WITH MOTORIC COMPONENT SUBTRACTED		DIFFERENCE BETWEEN STATIC AND DYNAMIC VISUAL ACUITY WITH MOTORIC COMPONENT SUBTRACTED	
		72 km/h	130 km/h	72 km/h	130 km/h	72 km/h	130 km/h	72 km/h	130 km/h
YOUNG GROUP (10 – 20 YEARS OLD)	1.37 ± 0.22	0.94 ± 0.27	0.86 ± 0.25	0.43 ± 0.18	0.51 ± 0.15	1.07 ± 0.26	1.11 ± 0.28	0.30 ± 0.19	0.26 ± 0.15
MIDDLE- AGED GROUP (30 – 40 YEARS OLD)	1.37 ± 0.22	0.90 ± 0.31	0.84 ± 0.29	0.47 ± 0.18	0.53 ± 0.17	1.02 ± 0.31	1.09 ± 0.22	0.35 ± 0.18	0.28 ± 0.17
OLDER GROUP (50 – 60 YEARS OLD)	1.37 ± 0.22	0.92 ± 0.22	0.74 ± 0.25	0.49 ± 0.27	0.63 ± 0.25	1.06 ± 0.22	1.04 ± 0.20	0.31 ± 0.20	0.33 ± 0.22

Table 5-6 Complete test results for comparison of static and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and with subtracted motoric component and difference between the two for all three groups for black Landolt ring on white background

Obtained results shows that at 72 km/h speed simulation was a difference in the visual acuity drop between all three groups that is in average 33%. In the simulation of 130 km/h speed, the difference in visual acuity drop is greater:

- younger and middle-aged group - average 37%,
- older groups is in average 44%.

When motoric component is subtracted the difference for 72 km/h speed is in average 23% for all three groups. In the simulation of 130 km/h:

- younger and middle-aged groups - average 20%
- older group 24%.

The tests proves the dependency of movement speed and reaction time influence on visual acuity values, especially in older group of subjects because their results in reaction time test were already slower.

Another test with red sign on black background at the speed of 72 km/h and 130 km/h was performed on the same groups of subjects, following results were obtained.

ANOVA analysis results indicate a statistically significant effect of increase Landolt ring size on VA in all three groups of subjects:

- younger group F-test (2.76) = 163.18, $p < 0.01$,
- middle-aged group F-test (3.13) = 156.30, $p < 0.01$,
- older group F-test (3.64) = 187.21, $p < 0.01$.

It was found that there is a statistically significant difference between static and dynamic VA as the results of the test with motoric component included in all three groups of subjects in the animation of the sign at 72 km/h and in the animation at 130 km/h.

Index of effect size for young group suggests that changes in the speed of Landolt ring animation can explain 46% variance of the difference of static and dynamic VA when the mechanical component was not subtracted.

Index effect size for middle-aged suggests that changes in the Landolt ring animation speed can explain 20% of the variance of the difference of static and dynamic VA when the mechanical component was not subtracted.

Index of effect size for older group suggests that changes in Landolt ring animation speed can explain 71% of the variance of the difference of static and dynamic VA when the mechanical component was not subtracted.

In addition results for the test with the subtracted reaction time using red Landolt ring on black background and animation speed of 72 km/h and 130 km/h were compared.

A statistically significant difference between in DVA results for the tests with the sign animated at a 72 km/h and 130 km/h speed has been found (t-test = 2.10, $p < 0.05$).

Younger and middle-aged groups had significant difference between the sign animated at a 72 km/h and 130 km/h speed.

Older group of subjects had equal DVA and at both 72 km/h (Mean VA = 1.04; Standard Deviation =0.25) and 130 km/h (Mean VA = 1.04; Standard Deviation = 0.20) animation speed.

Comparison of static and dynamic visual acuity in the animation of red Landolt ring on black background at the speed of 72 km/h and 130 km/h, with and subtracted motoric reaction for all three groups is shown in Figure 5-9.

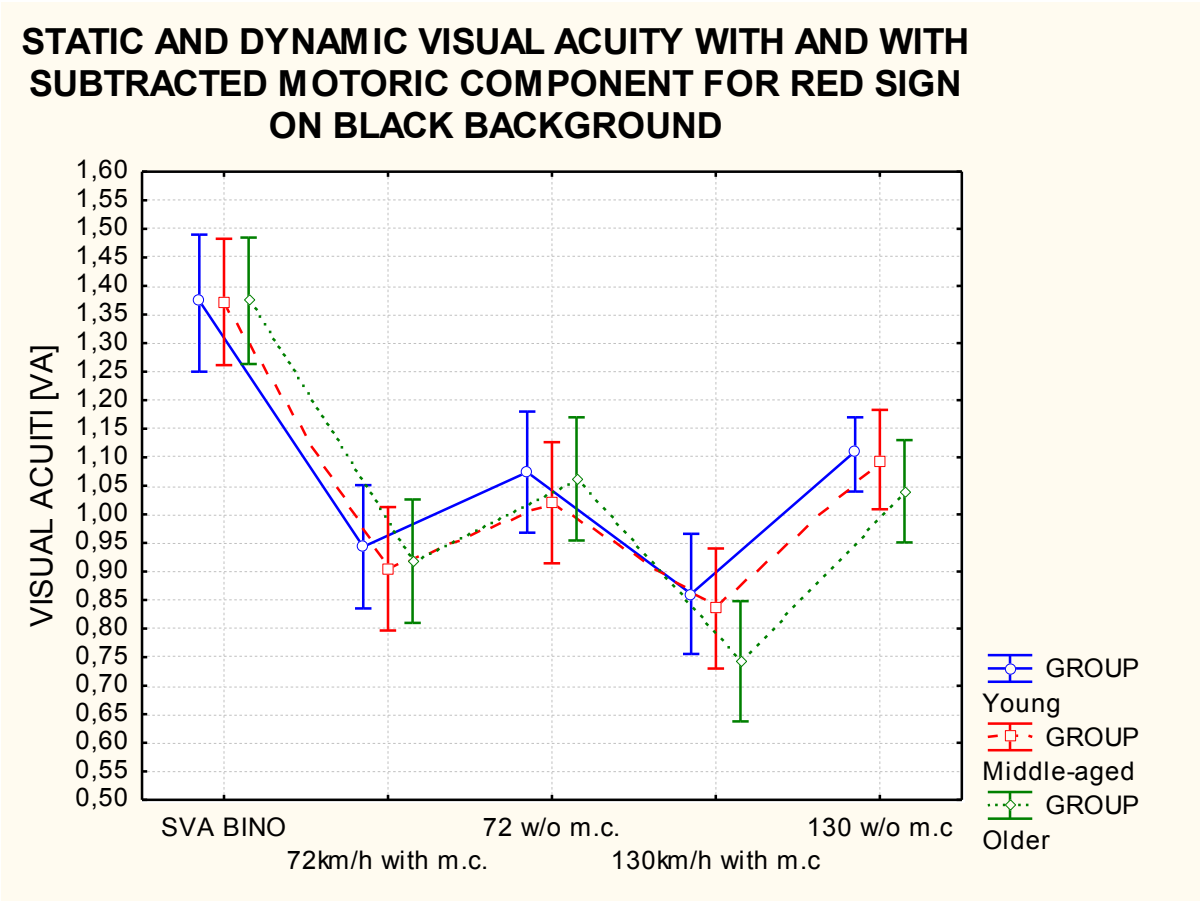

Figure 5-9 Comparison of static and dynamic visual acuity in the animation of red Landolt ring on black background at the speed of 72 km/h and 130 km/h, with and subtracted motoric component with mean value and standard error of the mean

Analyzing the differences between static and dynamic VA values in it has been found:

- younger group:
- sign at 72 km/h the - difference Mean VA = 0.34.; Standard Deviation = 0.16
- sign at 130 km/h - difference Mean VA = 0.26; Standard Deviation = 0.14.
- middle-aged group:
- sign at 72 km/h the - difference Mean VA = 0.31.; Standard Deviation = 0.15
- sign at 130 km/h - difference Mean VA = 0.27; Standard Deviation = 0.16.
- older group:
- sign at 72 km/h the - difference Mean VA = 0.29.; Standard Deviation = 0.15
- sign at 130 km/h - difference Mean VA = 0.35; Standard Deviation = 0.16.

Difference between static visual acuity and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and subtracted motoric component for all three groups for red Landolt ring on black background is showed in Figure 5-10.

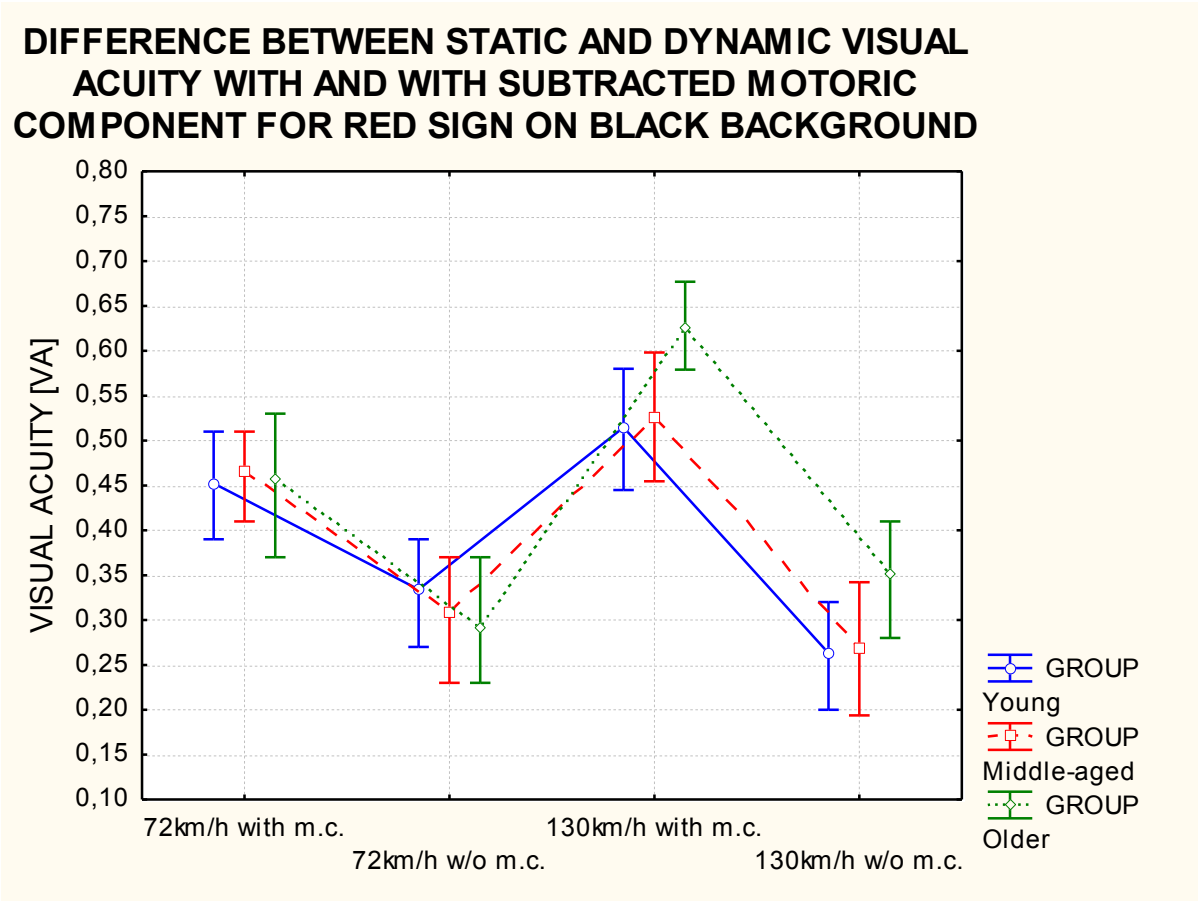

Figure 5-10 Difference between static and dynamic visual acuity, at 72 km/h and 130 km/h speed, with and subtracted motoric component for all three groups for red Landolt ring on black background with men value and standard error of the mean

There was no statistically difference between the test with black sign on white background and red sign on black background, with and without motoric component.

Test results with the tests at respectively 72 km/h and 130 km/h showed lower DVA values in comparison with the test with radial magnification speed at 20%, 40%, 60%, 80% and 100%. Considering that for both test speed of magnification per second was calculated, evidently difference in obtained results is caused by the linearity of the firs and non-linearity of the second test. The high non-linearity of the second tests resulted in values that were lower than expected considering the speed of magnification per second. If mean value of speed magnification per second was calculated for the test

simulating driving at 72 km/h, the result was 14% per second and for the test simulating driving at 130 km/h the result was 30% per second, compared to results of the first test results should not be as low. Drop in results of DVA for the tests simulating driving at 72 km/h and 130 km/h approximates the values obtained with the tests with radial magnification speed at 60% and 80% per second.

6 Discussion

The results of this study suggest that reaction time or motoric component in signal processing and perception has influence on of dynamic visual acuity values. It was found in many previous studies that the movement of objects affects visual acuity.[13]
Also dependence between visual perception and reaction time was found as in some previous studies.[29] This dependence was examined further and more closely in this study. Compared to static visual acuity in both tests, the results obtained with measurements of dynamic visual acuity resulted in lower values (mean = 0.42 VA) depending on Landolt ring size and magnification speed of animation, but after subtracting the motoric component (reaction time), the values of visual acuity rise (mean=0.20 VA). Reaction time is highly genetically determined and can only be marginally improved with practice, as shown in previous studies.[5]
A number of studies analysed dynamic visual acuity and it dependence on velocity, like the study „A novel computer software for the evaluation of dynamic visual acuity“.[30] The mentioned study compared the outcome of a series of trials consisting in different speeds and contrasts, measured at 2 meters distance. Measurements were done with DinVA 3.0 software; the sign for dynamic visual acuity measurements was rotating. Results proved that there was dependence of dynamic visual acuity values and velocity, the differences between static and dynamic visual acuities found were of 0.3-0.5 VA units. The conclusion was that evaluation of dynamic visual acuity was especially relevant in drivers. The present study confirmed both the dependence and the results range of before mentioned study. This was the starting point for second test used in this study, which simulates driving condition.

As already mentioned, according to this study's findings, the value of visual acuity was lower because of object's movements. When the data were plotted according to the test

age groups and animated speed of the sign, difference between static and dynamic visual acuities with and with subtracted motoric component, significant difference was found in all three groups of subjects. Older subjects did not differ significantly in their dynamic visual acuities from younger and middle-age groups in the tests where sign changed radial by magnification, but in the tests were driving conditions were simulated the dynamic visual acuity of older group differed more than in two other groups. After subtracting motoric component, the dynamic visual acuity results were less different compared to other groups.

When data was plotted according the magnification speed used in the tests a data analysis of dynamic visual acuity values for the first test set calculated according the magnification speed with radial increase in Landolt ring size at 20%, 40%, 60%, 80% and 100% per second where the linear velocity was present in each of the tests, showed linear decrease in visual acuity values with all three age groups. Also, an influence of reaction time on the final result of visual acuity values was found, for all subjects, after subtracting motor component values from visual acuity, it's values were higher when reaction time was shorter.

The difference between static and dynamic visual acuity found here in all the tests and regardless of speed of animation is also in accordance with findings of Yoshimitsu Kohmura et al., where it was used for dynamic visual acuity speed of 30 km/h and was compared with static visual acuity for young group of students. In this study, the relationships among DVA, simple reaction time, choice reaction time and Visual Evoked Potential (VEP) latency, which records the reaction of the cerebral visual area to visual stimulation, were examined. On the other hand, a low coefficient of correlation between dynamic visual acuity and reaction times was revealed.

In this study the demand for visual acuity was simulated in specific way to serve a little different purpose, there were different signs of animation speeds to represent different demand for every single subject because the detection of sign on different animation speed has shown individual reaction time and dynamic visual acuity. There are studies that found drop in visual acuity caused by changing in velocity like in study "A study of static, kinetic, and dynamic visual acuity in 102 Japanese professional baseball players", from Hoshina et al..[16]

The relation between measured visual acuity under static and dynamic conditions is mostly in accordance with results of other authors who tested subjects of the same age.[31] Although using different instruments and methods. Research related to the influence of visual motor response explains the significant decline in visual acuity when it is measured dynamically.[32,33] Al Saif AA et al. measured vestibular ocular reflex (VOR) using the computerized dynamic visual acuity (cDVA) and they also found the difference between SVA and DVA, the difference was of 0.5 VA values. The difference from tests that they used and tests in the present study is that their tests were moving radial.[34]

The abovementioned studies dealt with the topic of dynamic visual acuity and its interaction with reaction time and age. The major difference in dynamic tests was in velocity, direction of movement and testing distance.

The apparatus used in this study showed some true advantages due to researcher familiarity with testing environment and polarized screens for vision testing. On the other hand as the disadvantage it should be emphasized that dynamic visual acuity examination is difficult to perform in classic exam rooms since it requires special devices for presenting moving targets like computer program for dynamic visual acuity animation and reaction time measurement.

But it is possible to set up this type of test in collaboration with software companies that produces computer optotypes for optometry needs. The visual display of the unit used in this study is increasingly becoming the instrument for presenting optotypes and it requires only a software simulation of approaching objects and a mechanical trigger. Unsuccessful measurements in this study were due to subjects trying to be as fast as possible and as a result recognition of signs was wrong and imprecise. After that, instructions were given to every subject not to hurry but at the same time to be as precise as possible.

The sample in this study was small and the conclusion based only upon this number of subjects cannot be absolute. The method of measuring presented in this study should be further researched and expanded, i.e. various conditions appearing in ”real”, everyday life that influence the perception of the moving target (such as changing

optotype contrast, various difficulties with visual-motor functions and adjustment processes during measurements should also be taken into account.

7 Conclusion

The idea behind measurements of dynamic visual acuity and reaction time and comparing results with static visual acuity was to examine if there are any differences and interactions.

Findings of this study revealed significant differences between static and dynamic visual acuity in all three age groups. The difference was more substantial with greater animation speed of Landolt's ring sign. Reaction time definitely influences dynamic visual acuity values. It is important to remember that motoric component influences processing of “dynamic visual stimulus”.

Results have revealed longer reaction time for the group of older subjects, approximately 15% slower, however when compared to the error bars with a large uncertainty (10%). Reaction time tests with different contrasts didn't produce any significant difference with younger and middle-aged groups. A small, difference of 3% with older group of subjects was detected. The older group was faster when tested with red sign on black background. Since the error bars is 12%, no practical relevance can be stated. Possible causes for that can be long wavelengths that are present in the test with red Landolt ring on black background. In order to assess the causes more precisely in the future, additional tests should be done. Because of the equipment (computer, keyboard and monitor) delay, the measured reaction times were relative and not highly precise but this wasn't of particular importance in this study.

The repeated measurements of reaction time and dynamic visual acuity tend to eliminate the errors and are quite relevant. Measurements conditions were controlled for well-lit condition and for dim-lit condition. The light value was measured in night drive and a mean value wear reproduced in testing room. To obtain more accurate results in dim-lit conditions the tests should be done in real environment for example by constructing a real polygon.

The test with radial increase in size of Landolt ring sign with different magnification speeds showed more consistent results between various test trials than the test simulating driving at 72 km/h or 130 km/h in which the results between trials varied to a greater extent for individual subject. The figure 3-10 and table 3-4 in chapter 3.11 show sudden increase in magnification speed of sign for measurement of dynamic visual acuity. Analyzing and comparing results became clear that reason for drop in visual acuity was in non-linearity of the tests.

The reason behind these results is the pace of Landolt ring size changes in order to achieve the simulation of the speed. The test with radial increase in size of Landolt ring has equal percentage of increment per second, while with the test simulating driving condition Landolt ring size changes observed in percentage is highly non-linear.

Subjects participating in this study had the visual acuity of 1.0 or higher, without difference between visual acuity of two eyes, without any ocular or systemic diseases. Obtained results for reaction time and visual acuity are satisfactory for everyday activities like walking, driving, etc. However, another study could be carried out in the future, including more subjects without exclusions based on visual acuity or diseases in order to determine how much moving objects influences dynamic visual acuity.

This future study should include contrast sensitivity measurements, stereopsis measurement, oculomotor function tests, accommodative and vergence functions tests, related to the real life conditions i.e. driving, visual field measurement, and related to reaction time, eye-hand or eye-foot coordination test. This type of study should include aberromety for measurements done in dim-lit conditions to assess how much the blurred retinal image reduces sensitivity.

The magnification speed test used in this study is first of its kind. Since it is easy to implement in everyday optometry practice, ophthalmologist and occupational health care practice, it could be used for testing and training of dynamic visual skill with drivers, sportsmen and people with visual-motor dysfunction with the equipment that is already in use. This area has attracted relatively little research and it is hoped that this thesis will positively contribute to this area.

8 References

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9 Table of figures

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