Development and application of a new Attended Field of View (AFOV) test.

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

<u>Purpose</u>: An important challenge for eye care practitioners is meeting the needs of an ever-increasing elderly population. Standard vision tests are inadequate for determining performance in real life situations. One test that was developed to address this issue is the Attended Field of View (AFOV) test (Coeckelbergh et al, 2004). This test was designed to assess the functional field of view when people are allowed to make habitual head and eye movements. The original AFOV test is no longer available. This research seeks to develop a replacement AFOV test and to demonstrate its reliability as an assessment tool.

<u>Methods</u>: Two groups of participants were recruited. The first group consisted of seven participants between the ages of 15-41 years. The second group consisted of seven participants between the ages of 59–79 years. All subjects had visual acuities equal or better than 20/25 and no history of visual field loss. A computer-generated display was observed from a 60cm distance. The display consisted of 24 white circles on a gray background and one open circle (target). The circles were organized with one circle in the centre and eight located radially at three eccentricities (4, 8, and 12 degrees). Participants were required to locate the target circle and identify the gap direction. A response was considered correct when both the location and gap direction were accurate. Using a weighted staircase method based on presentation time each location was evaluated independently. Viewing efficiency [log (1/threshold presentation time)] was obtained for each location. The data was analyzed using repeated measures ANOVA.

Results: A comparison of viewing efficiency for the two age groups demonstrates that viewing efficiency is consistently lower for the older group at all three visits. The main effect of age was observed ($F_{1,12}$=25.842;p=0.000). In the older group, a significant difference was found between the second and third visits. This difference was not found in the younger group. A main effect of eccentricity was found in both groups ($F_{2,36}$=30.84;p<0.000), but no interaction was observed between eccentricity and group ($F_{2,36}$=0.42;p=0.662). Viewing efficiency values in the older group were lower in all directions (main effect of age) ($F_{1,96}$=150.36;p<0.000). Directional variations in viewing efficiency were observed showing higher values in the horizontal axes (directions Right and Left) than along the vertical axes (directions Up and Down) in both groups. A comparison of superior and inferior hemifield data shows consistent differences for both age groups. The superior hemifield (average of directions located superiorly to the horizontal axis) demonstrate higher viewing efficiency values (better performance) than the inferior hemifield.

Conclusions: The use of the new AFOV test requires a practice time before its use in order to avoid the confound of a learning effect, but subsequent data is reliable in young people. The learning effect was more significant in older people and for this reason the use of the test should be preceded by a longer practice session in this population. When interpreting the results of this test one must account for eccentricity, direction, and age.

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First of all, I want to thank God for giving me the strength and belief that I was capable of accomplishing this goal.

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Finally, I would like to thank my family for being beside me in my good and bad days, and for giving me love and support until the end.

Dedication

This thesis is dedicated to my husband Andres, who has been a wonderful companion and support, and with whom I have had the most beautiful moments of my life.

To my children Ale and Juan, who have been my inspiration to become a better person each day, and for whom I have done things that I thought were impossible to do.

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To God who lives in my heart, who is always showing me the pathway that I need to follow, and who has given me the strength to overcome my own weaknesses.

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1. Introduction

The relentless decline in visual capability with age is described in both the vision and aging literature (Brabyn et al, 2001; Scialfa, 2002; Haegerstrom- Portnoy, 2005). Visual acuity, stereopsis, colour discrimination (Faubert, 2002), contrast sensitivity (West et al, 2002), and visual fields (Johnson, et al 1989) show a characteristic decline as people age. Older people also exhibit heightened susceptibility to adverse viewing conditions such as the presence of competing light sources within the field of view (disability glare) (Abrahamsson & Sjostrand, 1986), divided attention (Ball et al, 1990), or when the overall illumination is too bright (discomfort glare), too variable, or too dim. These visual performance deficits are correlated with physical functional ability deficits in older people (West et al, 2002). Although some age-related changes are amenable to treatment (such as presbyopia and cataracts) (Back et al, 1989; Ross et al, 2003), changes to the visual field are usually caused by irreversible changes in peripheral and central retina, or irreversible changes to the brain and visual pathway.

2. Ocular changes that occur with age

A decline in visual function is characterized by a generalized loss of sensitivity throughout the visual field (Johnson et al, 1989). Color discrimination, stereopsis, and contrast sensitivity show a decline with age especially in people over 50 years (Johnson & Choy, 1987). Losses in perceptual and attentional capabilities also contribute to a reduction in the functional visual field of older adults (Rezec & Dobkins, 2004). Ocular changes that are often related in the literature with sensitivity losses in the visual field of older people are those that occur in pupil and crystalline lens.

2.1 Pupil

Older adults have relatively small pupils at all levels of illumination, probably because of atrophy of the dilator muscle fibers; this reduction in pupil size begins during the second decade of life (Matjucha & Barrett, 1994). The small diameter of the pupil reduces the overall retinal luminance, which results in greater difficulty seeing clearly at low light levels. This is one reason why older people require higher levels of lighting than younger people to perform the same activities (Crocker, 2007).

2.2 Crystalline lens

The transparency of the crystalline lens is indispensable to the process of vision, allowing light to pass through it to focus images onto the retina. The transmission of the lens depends on two processes: absorption and scatter. It is known that the transmission of the lens is greatly reduced in people older than 60 yrs (Johnson et al, 1989); because the lens absorbs the short wavelengths, therefore acquiring a yellowish color. This condition contributes to a decrease in the ability to discriminate colors, especially blue and green (Rosenbloom, 1992).

Scatter is produced when a beam of light hits particles that produce the emission of secondary light in different directions. This scatter may be caused by both small (soluble proteins in the lens) and large particles (structures that could be seen with magnification). The transparency of the lens is a consequence of a number of factors such as regular organization of lens fibers, distribution and conformation of proteins within cells, regulation of ion and water balance, and tight packing of lens cells. In the aging process, some of these factors are affected by the presence of protein aggregates, degeneration of cell membranes, vacuoles, and distortion of the structure of the lens. All of these changes are responsible for the increase of light scatter in the eyes of older adults (Alio, J., et al 2008).

Elasticity of the crystalline lens is another characteristic that is modified by age. The lens continues to grow throughout life and the new fibers are laid down within the lens capsule. Significant condensation and compaction of nuclear fibers in the lens, due to loss of water and proteins, starts in early adulthood and increases with age (between the fourth and eight decade) resulting in the hardening of the lens, a loss of accommodation and the onset of presbyopia (Alio, J., et al 2008). Even though, it has been shown that the functional ability of the ciliary muscles do not play a major role in the decline in the eye's accommodation capacity, a diminution in the ciliary muscle diameter that occurs with age and the subsequent reduction in tension by the ciliary ring in the lens could affect and influence the capacity of the crystalline lens to accommodate (Strenk, 1999).

The small size of the pupil and changes in the crystalline lens causes a reduction in retinal luminance, which is most problematic at mid or low mesopic levels. However, some studies have concluded that changes in the pupil and crystalline lens related to age are not responsible for the observed sensitivity losses in the visual field (Ball, et al 1990), (Johnson et al, 1989). The decrease in sensitivity of the visual field is considered to be mainly because of the neural losses that occur with age in the afferent pathway.

2.3 Retina and visual pathway

2.3.1 Retinal pigment epithelium

In the young, the retinal pigment epithelium (RPE) absorbs excess light and prevents light scatter within the eye. With age, the RPE has less pigment than in adulthood. Also its cells become irregular in size and shape and accumulate a degenerative aging pigment called lipofuscin (Wassell, 1999). The cells of the RPE are not mitotic at all, yet are responsible for the daily phagocytic function and degradation of the outer segment membranes of the photoreceptors throughout life. The end product of the lysosomal enzyme action of the RPE is the lipofuscin granules that are found mostly after the age of 40 in the macular region (Berman, 1994). As a consequence of these changes, the pigment epithelium is less able to absorb excess light and less able to help control light scatter in the eyes of elderly people.

2.3.2 Photoreceptors

Some studies have found that there are age related changes in the number of nuclei in the outer nuclear layer of the retina, and a loss of photoreceptors (Keunen et al, 1987; Faubert, 2002; Gartner & Henkind, 1981). The number of nuclei in the outer nuclear layer (ONL) is not constant throughout the life span. Some of the nuclei of rods and cones are displaced either into the outer plexiform layer (OPL), or into the rods and cones layer. A small displacement of the nuclei into the OPL is seen from birth, but the rate of displacement increases around the age of 30, and is even more noticeable after age 50. This phenomenon of the nuclei is noted mostly in the macular region but not in the foveal region and it can be accompanied by changes in the shape (elongation) of the nuclei. Gartner & Henkind (1981) found that sometimes there is a complete absence of nuclei in the cones and rods cells. These authors concluded that the displacement of the nuclei is probably due to some traction caused by shrinkage of the fibers that attach the nuclei at one end to the photoreceptors and on the other end to the axonal fibers that cross the OPL. Berman (1994) reported that there is a parallel loss of cones and rods and RPE cells due to aging, and the loss of photoreceptors is higher in the equatorial area than in the fovea. Keunen et al (1987) described a loss of cones in the foveal region with age that is responsible for the decrease in cone pigment density.

2.3.3 Ganglion cells

One of the first changes in the ganglion cells that occur with aging is a tortuous course of the dendrites. Some isolated dendrites also appear to be grossly enlarged. Another change related to age in some dendrites of the ganglion cells is that they end in retraction balls or in growth cones (Vrabec, 1964). On the other hand, there are losses of optic nerve fibers, estimated to be between 5,000 and 9,000 per year on average in every human being. Modern imaging techniques also have demonstrated a progressive thinning of the retinal nerve fiber layer. All of these morphological and physiological neural changes reflect the impact of aging, not only on visual fields (Brusini, 2007) , but also on how people process visual information that they receive within their visual fields in order to perform daily activities (Ball et al, 1990).

3. Visual field and functional visual field

It is important to clarify the difference between the two commonly confused concepts of "visual field" and "functional visual field". The visual field is a measure of an individual's peripheral vision; how far one can detect objects off to the side of the direct line of sight (Peli, 2002). The visual field is assessed monocularly or binocularly with no head or eye movements being allowed, under optimal illumination and target contrast conditions, and without any distracters being present. A study about changes in the sensitivity of the retina with age (Calixto et al, 2006) showed that aging is associated with a diminution of sensitivity values within the central 26 degrees visual field. An Octopus 1-2-3 auto perimeter was used to assess subjects between 10 and >60 years of age. Significant differences in average sensitivity were found between age groups (10 to 19 yr; 20 to 29yr; 30 to 39 yr; 40 to 49 yr; 50 to 59 yr and >60 years). A number of investigations have reported reductions in visual field sensitivity as a function of aging in normal subjects (Johnson et al, 1989; Brusini, 2007). These studies indicate a generalized depression of the visual field, although some investigators have reported larger age related sensitivity losses at more peripheral visual field locations as well as regional variations in sensitivity loss (Heijl, 1987; Katz & Sommer, 1986).

The integrity of an individual's visual field is important because it correlates directly with performance in many activities of daily living, including routine interactions with the individual's living environment. Standard visual field testing may fail to provide an accurate prediction of the limitations experienced by elderly people while performing activities of daily living because the results are obtained under unnatural viewing conditions.

To understand the meaning of functional visual field, it is important to understand the distinction between “visual function” and “functional vision”. Visual function is used to describe a person’s tested level of visual ability, while functional vision refers to how the person uses this level of visual ability to carry out daily tasks or activities (Wright, 2006). Accordingly, a funcional visual field describes how people utilize their fields of vision while performing activities of daily living. The assessment of functional visual fields in a laboratory setting should imitate a real world environment. It is assessed binocularly and can be measured with or without head and eye movements. To better simulate daily living conditions during the assessment, the test target should be surrounded by a number of distracters. The person’s attention may be focused or divided during the test. Focused attention occurs when there is only one target to be attended during the testing. Divided attention occurs when the person must attend to one primary target as well as another target that is located elsewhere in the displayed field. Several functional visual field tests were devised to better reflect visual activities in everyday living. Tests that were developed to assess the functional visual field include the Useful Field of View (UFOV®) test (Ball et al, 1988; Sekuller et al, 2000), the attentional visual field (Brabyn et al, 2001), and the Attended Field of View (AFOV) test (Coeckelbergh et al., 2004). The AFOV is the only one of these tests that allows a person to use head and eye movements during testing; and is based on a visual search paradigm. This is a useful tool for evaluating functional seeing capabilities under natural viewing conditions, where head and eye movements are inevitable.

There is limited information about the functional vision of older people, and the size of this population is increasing rapidly. It is relevant to study the conditions under which older people frequently report problems in everyday life. This necessitates functional vision testing under realistic conditions, such as low contrast objects being viewed under less than ideal lighting conditions, and under realistic visual field conditions (with an attentional component and allowing for potentially compensatory eye and head movements).

3.1 Useful Field of View (UFOV®) test

The Useful Field of View test (UFOV®; Visual Resources, Inc., Chicago, Illinois, USA) is defined as *"the total visual field area in which useful information can be acquired without eye and head movements"* (Ball et al, 1988 p. 2210). The UFOV test is usually performed binocularly. It measures an individual's ability to process rapidly presented information that is increasingly complex, within a restricted time period. Unlike conventional measures of the visual field that assess visual sensory sensitivity, this test relies on higher-order visual processing skills, such as selective and divided attention and rapid visual processing. It is assessed by means of computer-based software and comprises three (or four, in some versions) increasingly difficult visual subtests, evaluating central, divided and selective attention. See figure 3.1.

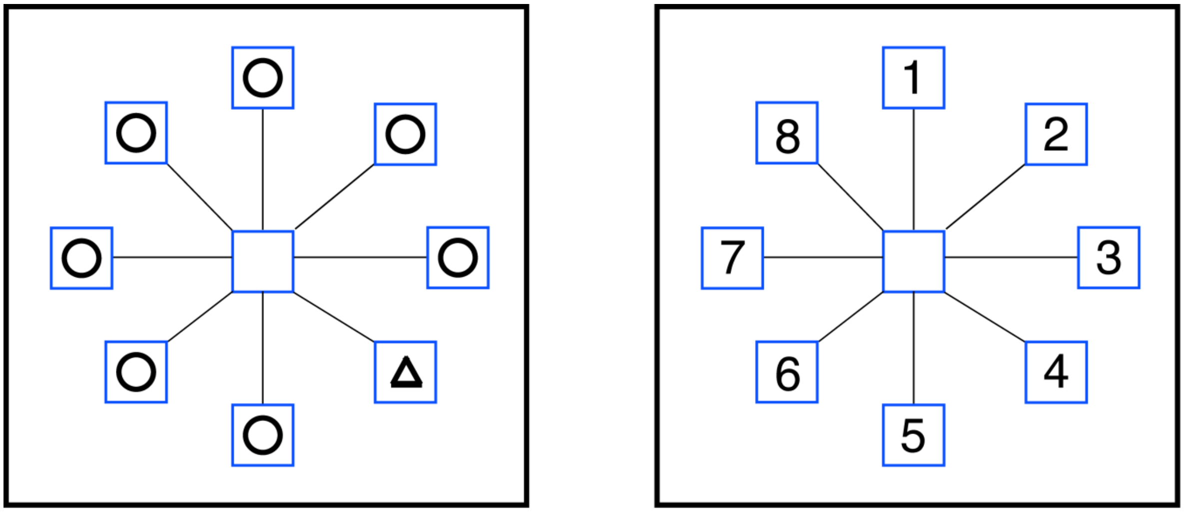


Figure 3.1: Representation of the UFOV test. In the first display, the participant task is to find the location of the triangle. In the second display the participant's task is to indicate the location of the target.

3.2 Attentional visual field

Attentional visual field is an assessment of the functional visual field that incorporates the cognitive component of divided attention. It is measured with a standard perimeter. Standard perimetry is performed initially, using standard isopters against a standard background. The observer steadily fixates a central red fixation light, and presses a button each time a target is seen in the periphery (See figure 3.2). The test is then repeated, but the red fixation light is now blinking. The observer must count the number of times that the central light blinks, while simultaneously reporting when peripheral targets appear at different eccentricities and locations (Brabyn et al, 2001). This procedure measures the impact of attention on the size of the standard visual field.

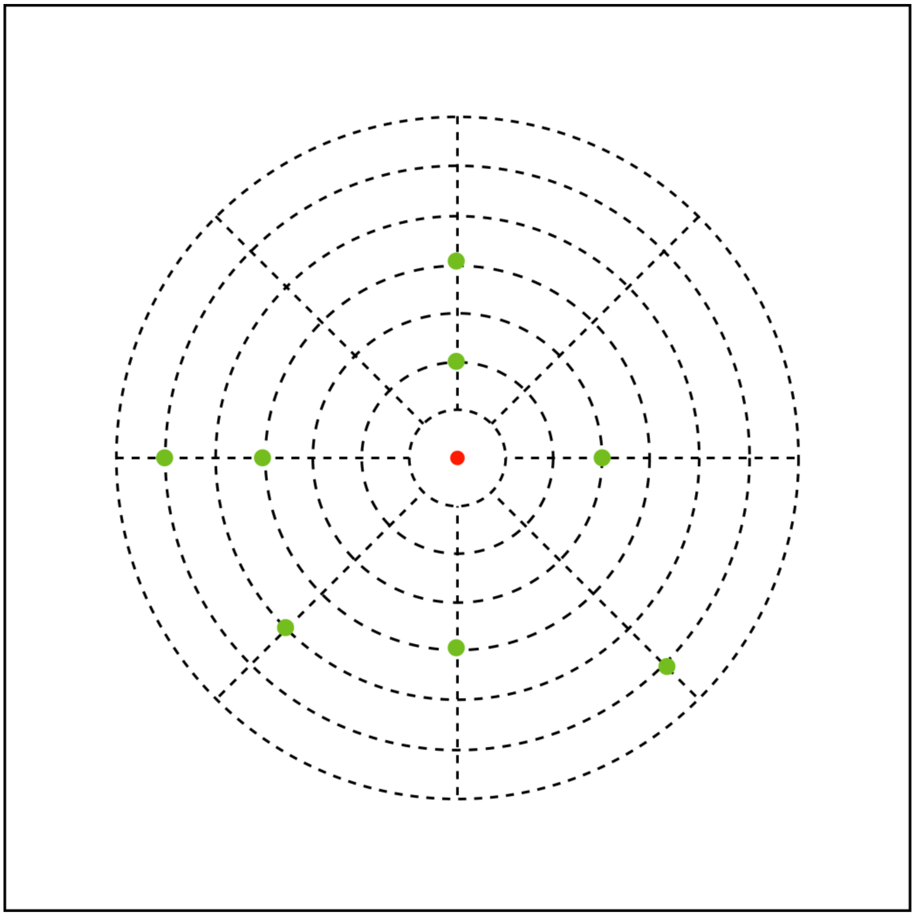


Figure 3.2 : Representation of the Attentional field of view test. The red dot is the fixation point and the green dots are representative locations of peripheral targets

Brabyn and colleagues (2002) found that a divided attention component reduced the diameter of the visual field by 50% in patients 85 years of age when compared with patients who are younger than 65 years. This reduction in the functional visual field in older adults interferes with many social and physical activities such as driving, watching television, or reading the newspaper (Rosenbloom, 1992). These consequences are attributed to a reduction in the efficiency with which information can be extracted from a crowded scene (Sekuller et al, 2000). This reduction is even greater when divided attention is involved (Ball et al, 1988).

3.3 Attended Field of View (AFOV) test

The Attended Field of View *(*AFOV) test was developed (Coeckelbergh et al, 2004) as an alternative procedure for assessing the functional visual field. This test more closely mimics the viewing conditions of daily life, because it allows people to make eye and head movements while searching for a target of interest among an array of distracters. Results from the AFOV test and the UFOV® test are correlated with specific problems encountered by older people in the performance of daily activities that involve visual search, mobility, and speed of processing (Coeckelberg et al, 2004; Coeckelbergh et al, 2002; Ball et al, 2007). In everyday seeing activities, people use both eye and head movements to observe objects located in the surrounding environment. These same free viewing conditions are allowed during the AFOV test, which is based on a visual search paradigm. In other words, the main difference between the UFOV® test and the AFOV test is that head and eye movements are allowed in the latter one.

The Attended Field of View (AFOV) test relies on an effective visual search and detection strategy with three distinct cognitive components. The first is an overall recognition of the pattern seen (i.e., the general impressions that the observer gets of the image on the retina).

During this process, a person uses cognition or previous knowledge regarding the image. The second component is focal attention, which is the use of the central retina to analyze the location where the peripheral retina may have detected the target. In other words, this is the confirmation of the presence or absence of the target in a specific location using central vision. The third component is decision-making, which is dependent on the result of the second component. If the target is not at that specific location, the observer moves to a new location, and continues to search for the target using saccades and head movements (Motter & Simoni, 2008; Zelinsky, 2008). Studies reveal that saccades, the rapid conjugate movements of the eyes that allow the fovea to be directed to a specific target, and fixations are involved in the process of visual search (Nodine & Kundel, 1987). Fixation holds the image of an object steadily on the fovea (Leigh & Zee, 2006). There are many areas of the brain involved in the production of saccades such as frontal and parietal cortices, basal ganglia, thalamus, superior colliculus, cerebellum, and brainstem reticular formation; therefore, any change with age in any of these areas may produce alterations in the latency, velocity, or accuracy of saccades (Irving et al, 2006).

During the AFOV test, participants are required to detect a target that is located at one of three different eccentricities (4, 8, 12 degrees) along one of eight possible radial meridians (0, 45, 90, 135, 180, 225, 270, 315 degrees). The target is a broken circle that is 0.5 degrees in diameter with a 0.1 degree gap. It is situated among 24 radially arrayed similarly sized closed circles (see fig.3.3). Participants must successfully identify the location of the target (direction and eccentricity) and the direction of the gap (up, down, left, right) (Coeckelbergh et al, 2004). All targets are white on a gray background (50% contrast).

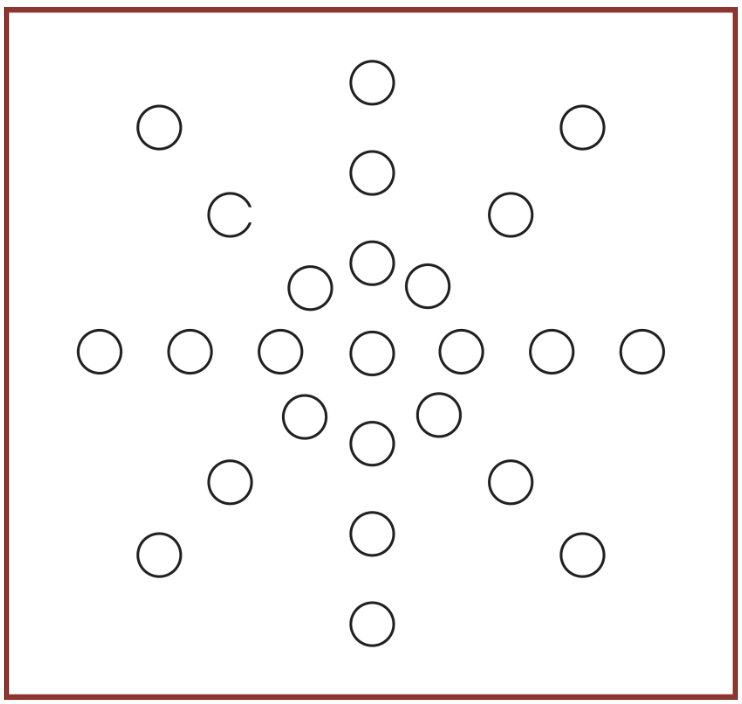


Figure 3.3 : Example of the AFOV test design.

4. Purpose

- Develop a new Attended Field of View (AFOV) test since the original test (Coeckelbergh et al, 2004) is no longer available.
- Demonstrate reliability of the new AFOV test.
- Compare the result of older individuals on the new AFOV test with those of young adults.
- Compare the results from the new AFOV test to those of Coeckelbergh et al (2004).
- Compare the viewing efficiency of various locations

5. Hypotheses

My hypotheses are as follows:

1. The results with the new AFOV test are reliable**.**

2**.** The results with the new AFOV test are similar to those obtained by Coeckelbergh (2004).

3. Young adults will perform better than older individuals, and performance will increased eccentricity for all individuals (main effects of eccentricity and age).

6. Methods

6.1 Description of New AFOV test and procedure

A computer-generated display was observed from a 60cm distance. It consisted of 24 white circles on a gray background and one open circle (target). The circles were organized with one circle in the centre (location 0) and eight circles located radially at three eccentricities (4, 8, and 12 degrees). Locations were distributed in eight different meridians (0, 45, 90, 135, 180, 225, 270, 315 degrees). One number was assigned to each location in each eccentricity to facilitate the analysis. Each number is located as follows:

Eccentricity (4˚):

1(right); 2(right down); 3(down); 4(left down); 5(left); 6(left up); 7(up); 8(right up).

Eccentricity (8˚):

9(right); 10(right down); 11(down); 12(left down); 13(left); 14(left up); 15(up); 16 (right up).

Eccentricity (12˚):

17(right); 18 (right down); 19 (down); 20(left down); 21(left); 22(left up); 23(up); 24(right up).

The size of the circles was 12mm (1.1˚) and the size of the gap of the open circle was 2mm (0.2˚). Participants were required to identify the location of the broken circle and to identify the gap direction. See Figure 6.1.

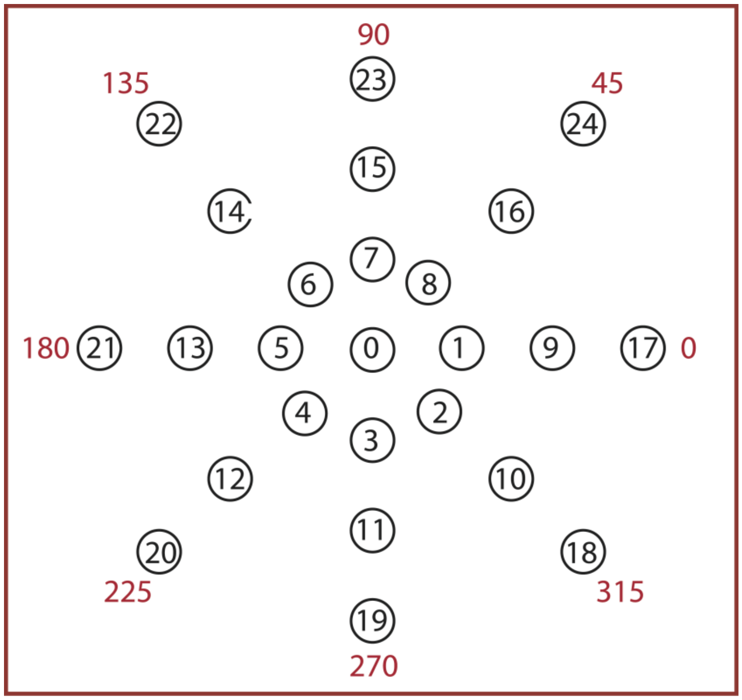


Figure 6.1: Distribution of locations in the new AFOV. Each location has a black number that was used in the analysis. Red numbers represent the meridians.

All testing was performed under binocular viewing conditions, with participants wearing their habitual spectacle corrections for near vision if it was needed. Participants wearing correction for near in the older group were using progressive lenses; none of them were using bifocals lenses.

The test instructions were provided verbally to each participant at the beginning of the first session, and then were presented on the screen for them to read. When they felt that they were ready to begin, they initiated the start of testing by a keyboard press.

During each test session, participants were instructed to look at the center of an unstructured screen where a small black cross appeared. The test screen with the circles was presented with the open circle's location randomized between trials. Participants were asked to locate the open circle and to observe the location of the opening. Eye and head movements were allowed. A backward masking screen was then presented in order to eliminate the presence of any afterimages that could persist from the previous display. A second display was then presented with 25 closed circles. Participants were instructed to use the computer mouse to indicate where they had seen the open circle, and to use the arrow keys on the keyboard to indicate the direction of the gap (up, down, right or left) See figure 6.2.

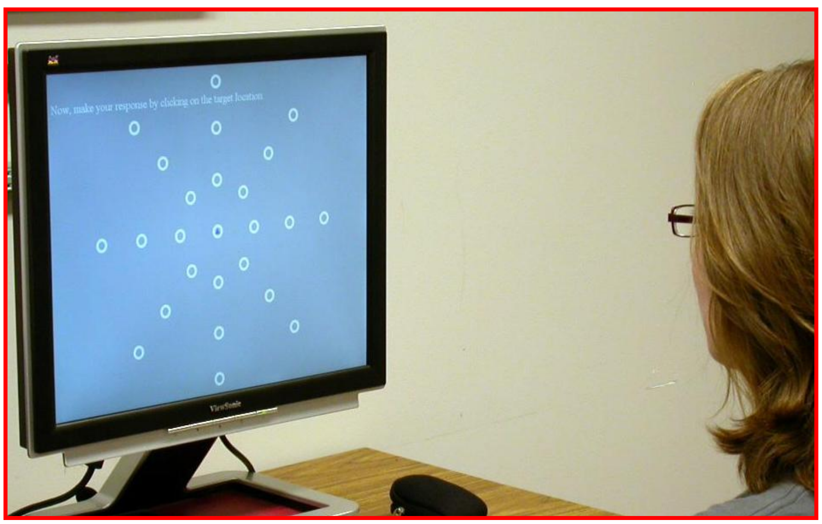


Figure 6.2: Picture of the second (response) display of the new AFOV test

Responses were considered correct if the target location and the gap direction were both identified correctly. Forty trials were randomly presented at each location. Whenever participants were unsure of the target location or gap orientation, they were instructed to guess.

Presentation time was based on a staircase method with the following rules (Cornsweet, 1962):

- Starting presentation time for each target location: 350 ms.
- The presentation time of the target in each location varied in logarithmic steps (0.1log unit=1.2589msec) with every correct or wrong response.
- The end point was 40 trials at each location.
- A simple up-down weighting procedure was applied. The weighting procedure was such that when the subject had a correct response, the presentation time decreased by 0.1 log units, and when the subject gave an incorrect response, the presentation time increased by 0.2 log units. It is important to emphasize that each location had presentation times which were independent of the other locations.
- The staircase converges on 67% correct (Kaernbach, 1991).

Short breaks were offered every 20 minutes to all participants. The duration of the test was 1 hour and 30 minutes on average in the younger group for the first visit, and 1 hour for the second and third visits. In the older group the duration of the test was 1 hour and 45 minutes on average for the first visit, and 1 hour and 20 minutes for the second and third visits.

6.2 Sample

Participants were recruited from the University of Waterloo, School of Optometry, and included undergraduate students, graduate students, family members, and friends. The study took place on campus at the School of Optometry. Potential subjects received an information letter and provided written consent in order to participate in the study. The study was approved by the Office of Research Ethics of the University of Waterloo.

Participants were divided into two age groups. The first group consisted of seven participants (including 5 females) between the ages of 15-41 years (mean age 29.3). The second group consisted of seven participants (including four females) between the ages of 59–79 years (mean age 67.4).

6.3 Inclusion criteria:

To be included in the study, participants were required to meet the following inclusion criteria:

- *V*isual Acuity equal or better than 20/25 (0.5 M) with best correction for near (measured binocularly with the lighthouse near visual acuity chart).
- Normal levels of contrast sensitivity function for each age group: 1.8 in young adults and 1.68 in older adults (measured binocularly with the Mars letter contrast sensitivity test).
- No history of visual field loss.
- Healthy or medically stable, without any neurological disease or cognitive impairment that could affect their understanding and/or completion of the test.
- Fluent in English or Spanish.

6.4 Analysis

For each participant, the threshold at each location was obtained by analyzing data for all correct and incorrect reversals. The correct and incorrect reversals were sorted and averaged independently for each location. In order to exclude outliers, the mean and standard deviation of the mean were calculated. Reversal values (correct and incorrect) that were more than two standard deviations away from the mean were removed. The threshold was then taken as the average of the correct and incorrect reversals.

This procedure was the same for both age groups. The data was analyzed with repeated measures ANOVA and Bonferroni correction when significant statistical differences were found in order to avoid type I errors. The results were expressed in viewing efficiency that was considered the log of the inverse of presentation time in seconds required to correctly locate and identify the target. High viewing efficiency is equivalent to better performance during the test. The data were log transformed in order to compare the current results with those obtained by Coeckelbergh et al (2004).

7. Results

The visits of each group were analyzed in order to identify any differences between them with respect to the time taken for a correct response at each location. This analysis is described by group and after that the result of the comparisons between the groups are presented.

7.1 Younger group (14 – 41 years old)

7.1.1 Visits

The ANOVA showed a significant difference in viewing efficiency values between visits ($F_{2,12}$=12,35;p=0.0012). A Bonferroni post hoc test revealed a significant difference between the viewing efficiency values in visit 1 versus visits 2 and 3, but no difference between the last two visits. Lower viewing efficiency values were found in Visit 1, which means that the participants needed more time to correctly detect the target and the orientation of the gap in all locations during the first visit. On the other hand, there were no significant differences between visits 2 and 3, see table 7.1.

Table 7-1 : Younger group: p values from the Bonferroni test showing the difference between visit 1 when compared with visits 2 and visit 3.

VISIT	1	2	3
1		0.004596	0.002188
2	0.004596		1.000000
3	0.002188	1.000000	

7.1.2 Visits and locations

One of the main objectives of this study was to demonstrate the reliability of the new AFOV test, and therefore, it was necessary to compare viewing efficiency values across locations between visits. An analysis of viewing efficiency between visits and locations was performed. In this analysis for each visit, the mean viewing efficiency at each location for all participants was calculated.

This analysis showed that there was a difference in viewing efficiency between visits and there were differences in viewing efficiency between locations, but there was no interaction between visits and locations ($F_{46,276}$=0.8697;p=0.7101). This is clearly seen in figure 7.1 where mean viewing efficiency values for the three visits are almost parallel to each other.

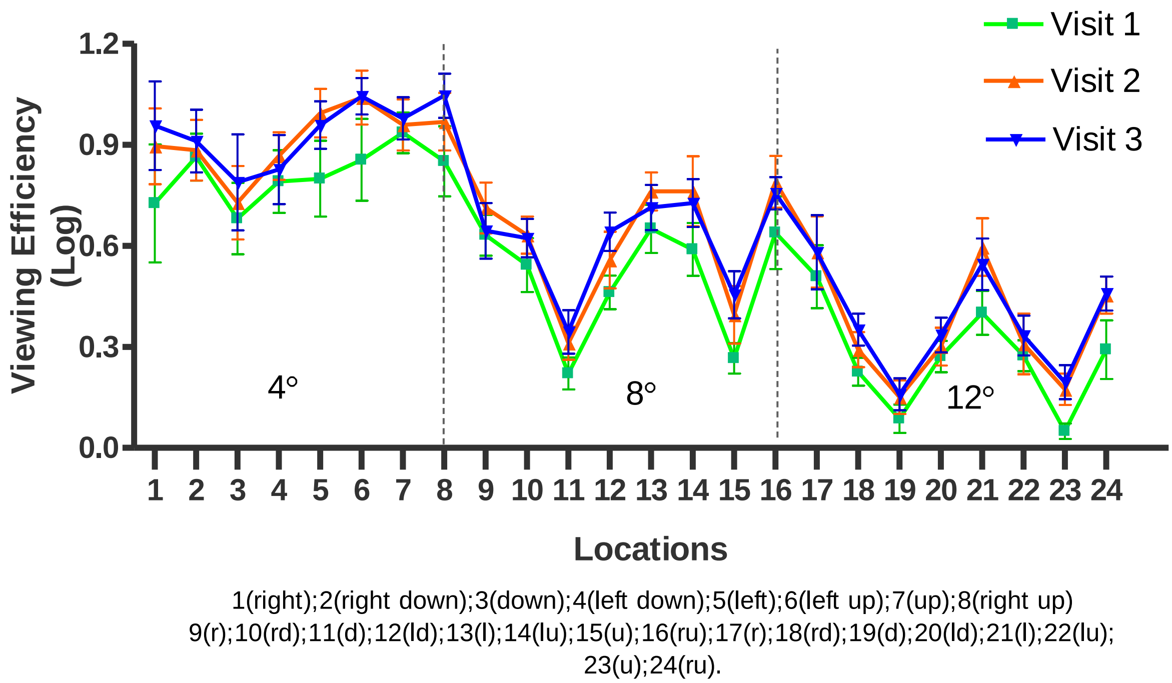


Figure 7.1: Younger group: viewing efficiency showing that there is no interaction between visits and locations. The error bars represent the standard error of the mean.

A significant difference was found between the first visit and the other two visits, so the following comparisons were made using the mean of the last two visits.

7.1.3 Eccentricity effect

The results comparing all eccentricities showed a difference in viewing efficiency which decreased with eccentricity. The statistical analysis confirmed a significant difference between each of the eccentricities ($F_{2,12}$=128;p=0.000), see table 7.2. The lowest value of viewing efficiency in this group was 1.22 (60 ms). The average of viewing efficiency values for eccentricity 4˚ was 0.853 (140 ms); for eccentricity 8˚ was 0.560 (275ms), and for eccentricity 12˚ was 0.320 (478 ms).

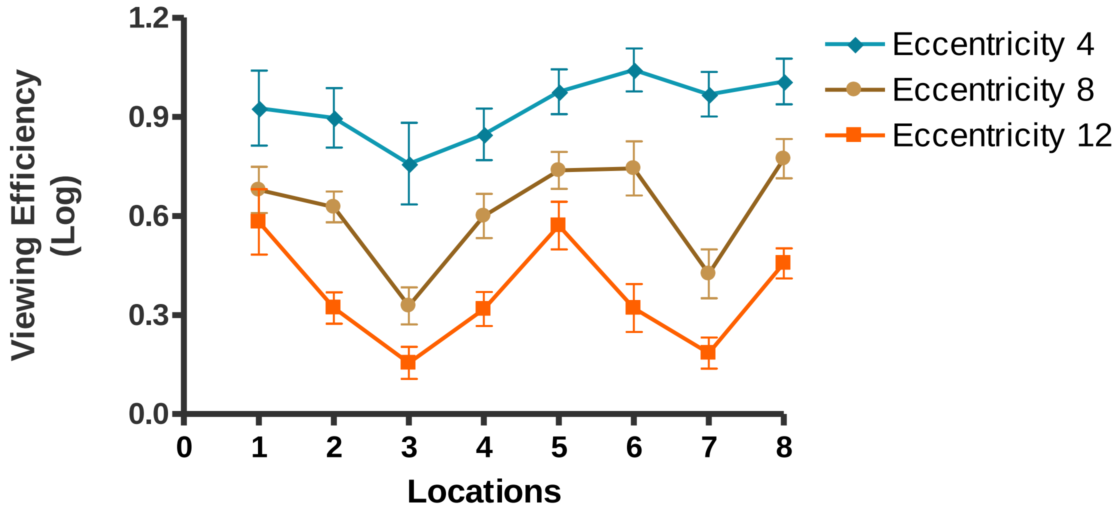
Table 7-2: Younger group: p values from the Bonferroni test showing significant difference between all eccentricities.

ECCENTRICITY	4	8	12
4		0.000004	0.000000
8	0.000004		0.000042
12	0.000000	0.000042	

7.1.4 Locations by eccentricity

Locations in the new AFOV test are assigned numbers from 0 to 24, see figure 2.1. The location corresponding to zero was not included in the analysis because it is located at the initial fixation point. The others are located along eight meridians at the three different eccentricities. This analysis strategy is identical to that used for the original AFOV (Coeckelbergh & al, 2004), which looked at eight locations at each eccentricity (4, 8, and 12 degrees).

An analysis of locations by eccentricity revealed a significant eccentricity effect with viewing efficiency being inversely proportional to eccentricity ($F_{14,84}$=4.4435;p=0.000). Viewing efficiency at the eight locations with a 4, 8 and 12degree eccentricity showed a significant variation that can be seen in figure 7.2.



Location 1(right); 2(right down);3(down);4(left down);5(left);6(left up);7(up), and 8(right up).

Figure 7.2: The difference in viewing efficiency between eccentricities, and the differences in viewing efficiency between locations at each eccentricity. The lower viewing efficiency values were found at location 3 at all eccentricities and location 7 at 8˚ and 12˚ eccentricities.

In figure 7.2, the blue line (uppermost dataset) represents the 4 degree eccentricity where there was a significant difference in viewing efficiency between locations 3 (down) and 6 (left up); and 3 and 7 (up) (p=0.026), see table 7.3. The viewing efficiency values are higher at this eccentricity than at the other two eccentricities. The 8 and 12 degrees eccentricities represented by the brown and orange colors respectively (middle and lower datasets), show lower viewing efficiency, and significant differences between locations. Eccentricity 8 presented significant differences in viewing efficiency between location 3(down), and 7(up) with respect the other locations as can be seen on the figure 7.3 and table 7.4; and eccentricity 12 showed significant differences between locations 3(down) and 7(up) with locations 1(right), 5(left), and 8(up right), see table 7.5. Both eccentricities have a similar pattern of viewing efficiency where the lowest values are at locations number 3(down) and

7(up). The figure shows clearly that the viewing efficiency values decreased with eccentricity.

Table 7-3: Younger group: Bonferroni test showing significant differences between locations in the 4 degrees eccentricity

4˚Ecc	Right	Right Down	Down	Left Down	Left	Left Up	Up	Right Up
Location	1	2	3	4	5	6	7	8
1		1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000		1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000		1.000	0.461	0.010	0.043	0.051
4	1.000	1.000	1.000		1.000	1.000	1.000	1.000
5	1.000	1.000	0.461	1.000		1.000	1.000	1.000
6	1.000	1.000	0.010	1.000	1.000		1.000	1.000
7	1.000	1.000	0.043	1.000	1.000	1.000		1.000
8	1.000	1.000	0.051	1.000	1.000	1.000	1.000	

Table 7-4: Younger group: Bonferroni test showing significant differences between locations in the 8 degrees eccentricity

8˚Ecc	Right	Right Down	Down	Left Down	Left	Left Up	Up	Right Up
Location	1	2	3	4	5	6	7	8
1		1.000	0.001	1.000	1.000	1.000	0.120	1.000
2	1.000		0.010	1.000	1.000	1.000	1.000	1.000
3	0.001	0.010		0.047	0.000	0.000	1.000	0.000
4	1.000	1.000	0.047		1.000	1.000	1.000	1.000
5	1.000	1.000	0.000	1.000		1.000	0.005	1.000
6	1.000	1.000	0.000	1.000	1.000		0.003	1.000
7	0.120	1.000	1.000	1.000	0.005	0.003		0.001
8	1.000	1.000	0.000	1.000	1.000	1.000	0.001	

Table 7-5 :Younger group: Bonferroni test showing significant differences between locations in the 12 degrees eccentricity.

12˚Ecc	Right	Right Down	Down	Left Down	Left	Left Up	Up	Right Up
Location	1	2	3	4	5	6	7	8
1		0.088	0.000	0.074	1.000	0.086	0.000	1.000
2	0.088		1.000	1.000	0.150	1.000	1.000	1.000
3	0.000	1.000		1.000	0.000	1.000	1.000	0.010
4	0.074	1.000	1.000		0.127	1.000	1.000	1.000
5	1.000	0.150	0.000	0.127		0.147	0.000	1.000
6	0.086	1.000	1.000	1.000	0.147		1.000	1.000
7	0.000	1.000	1.000	1.000	0.000	1.000		0.047
8	1.000	1.000	0.010	1.000	1.000	1.000	0.047	

7.1.5 Directions

An analysis of location by direction was performed using data from the analysis of eccentricities and locations. One direction is considered to be the average of data for all three eccentricities along the same directional meridian. In this way, there were eight directions to analyze. The purpose of this analysis was to find out if the differences in the values of viewing efficiency found at each eccentricity were the same in each direction.

As seen in figure 7.3, the direction “Right” includes locations 1, 9 and 17; “Down Right” includes locations 2, 10, and 18; “Down” includes locations 3, 11, and 19; “Down Left” includes locations 4, 12, and 20; “Left” includes locations 5, 13, and 21; “Up Left” includes locations 6, 14, and 22; “Up” includes locations 7, 15, and 23; and “Up Right” includes locations 8, 16, and 24.

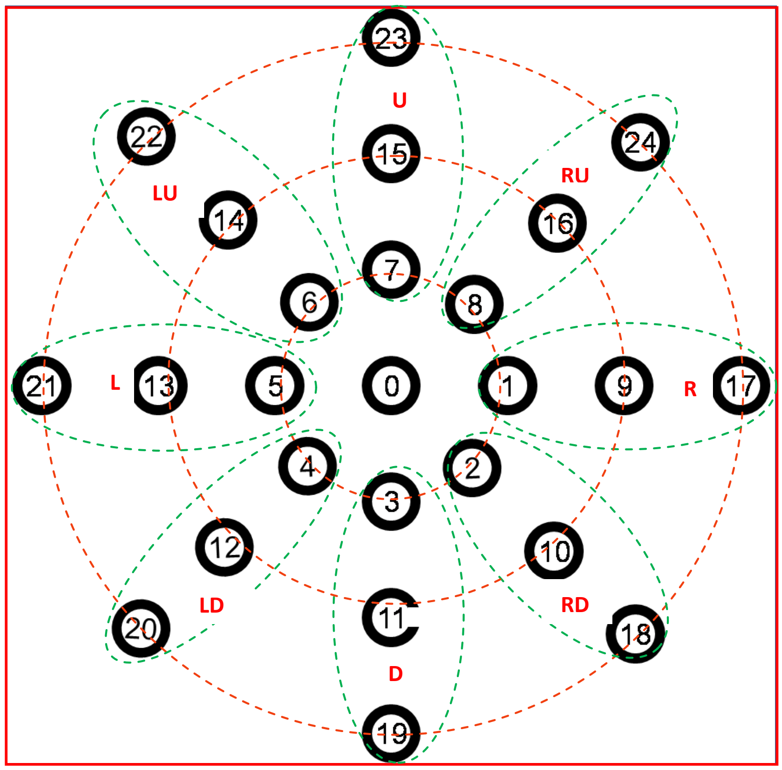


Figure 7.3 For the analysis of directions: the locations groupings with the eight directions U (Up), RU (Right Up), R (Right), RD (Right Down), D (Down), LU (Left Up), L (Left), LD (Left Down).

An ANOVA reveals significant differences between directions ($F_{7,42}$=13.069;p=0.000), with greater differences between horizontal (Left and Right**)** and vertical (Up and Down**)** directions, see figure 7.4 and table 7.6.

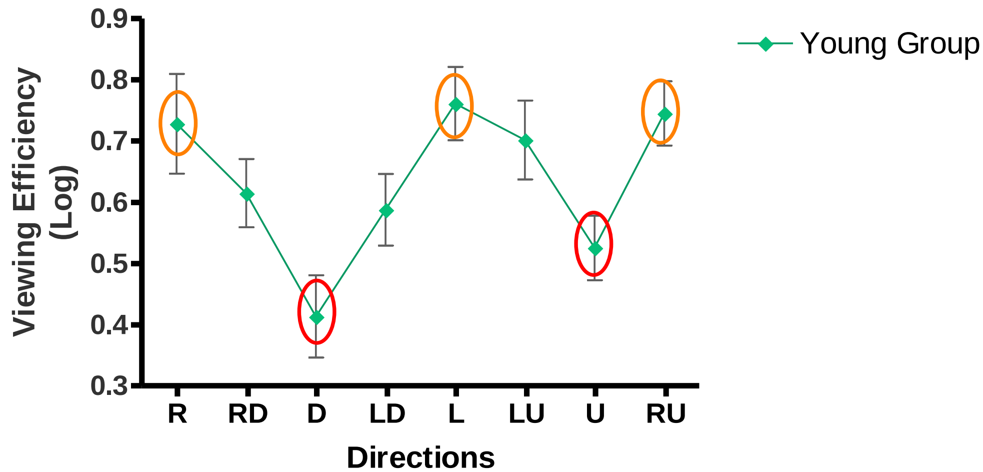


Figure 7.4: Viewing efficiency values at directions where directions Down and Up (red ovals) were the lowest and directions Right, Left and Right Up were the highest (yellow ovals).

Table 7-6: Younger group p values from the Bonferroni test show differences in viewing efficiency between directions. Direction R (Right), RD (Right Down), D (Down), LD (Left Down), L(Left), LU (Left Up), U (Up), RU (Right Up).

Directions	R	RD	D	LD	L	LU	U	RU
R		0.633	0.000	0.151	1.000	1.000	0.003	1.000
RD	0.633		0.004	1.000	0.110	1.000	1.000	0.267
D	0.000	0.004		0.021	0.000	0.000	0.672	0.000
LD	0.151	1.000	0.021		0.022	0.612	1.000	0.058
L	1.000	0.110	0.000	0.022		1.000	0.000	1.000
LU	1.000	1.000	0.000	0.612	1.000		0.018	1.000
U	0.003	1.000	0.672	1.000	0.000	0.018		0.001
RU	1.000	0.267	0.000	0.058	1.000	1.000	0.001	

In general, viewing efficiency values are lower for targets presented along the vertical axis than those that were presented along the horizontal axis. Hemifields analysis reveals higher viewing efficiency for the superior hemifield than for the inferior hemifield in younger participants ($F_{1,36}$=6.13p=0.018). On the other hand, the right hemifield (including Right obliques Up and Down, and direction Right) did not show significant difference relative to the left hemifield (including Left obliques Up and Down, and direction Left)(p=0.8), see figures 7.5 and 7.6.

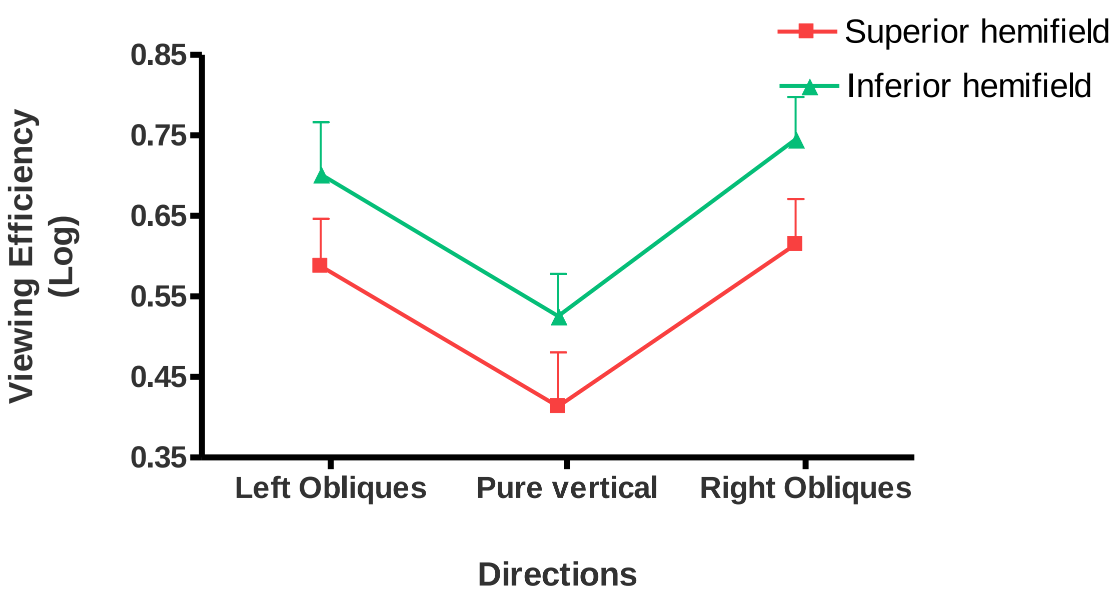


Figure 7.5: Younger group: viewing efficiency at hemifields where the superior hemifield show better performance than the Inferior hemifield.

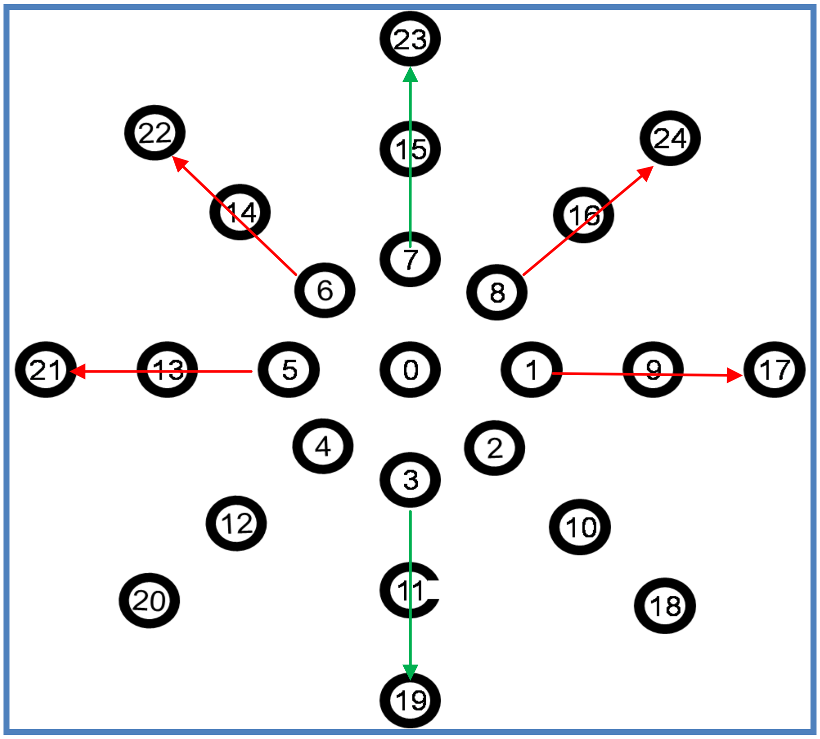


Figure 7.6 Directions at the AFOV test where green arrows indicate the directions with lower viewing efficiency values (lower performance), and red arrows indicate the directions with higher viewing efficiency values (higher performance).

7.1.6 New AFOV test vs. original AFOV test

The results obtained from the younger participant group were compared with those obtained by Coeckelbergh et al (2004) for a similar age group using the original AFOV test. For this comparison, log viewing efficiency was plotted against eccentricity in order to compare the slopes with the different AFOV tests, see figure 7.7. The slopes were compared applying the formula:

$$m = \frac{\Delta y}{\Delta x} \qquad m = Y_2 - Y_1 / X_2 - X_1$$

Where Y_1= mean value of viewing efficiency at 12˚ eccentricity and Y2= mean value of viewing efficiency at 4˚ eccentricity; X_1= Ecc 4 and X_2= Ecc12.

Slope with the new AFOV test:
(7 subjects, range 14-41, five females)
m= 0.363-0.927/12-4= ***-0.564***

Slope with the original AFOV test
(7 subjects, range 22-28, four females)
m= 0.400 -1.63/12-4= ***-1.23***

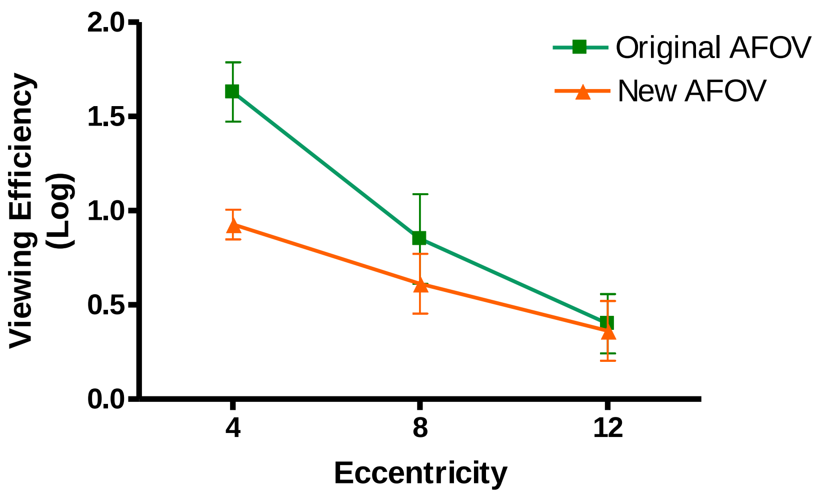


Figure 7.7 The figure shows the different slopes between the new AFOV and the original AFOV (Coeckelbergh et al 2004). The error bars denote the standard deviation.

As seen in figure 7.7, the slopes for the respective AFOV tests are different. At the first eccentricity (4 degrees) the viewing efficiency is lower with the new AFOV test, while the results are similar for the farthest eccentricity (12 degrees) location.

A Two-Way analysis of variance was used to determine differences between AFOVs at all eccentricities. The analysis was done using the reported values for the original AFOV test, which included the mean and standard error for each eccentricity (Cohen, 2002). Table 7.7 provides a summary of this analysis.

Table 7-7: Younger group factorial ANOVA with means and standard errors of Viewing efficiency.

	d.f	SS	MSE	F	P
Eccentricity (4˚,8˚,12˚)	2	1.907	0.954	22.311	<0.001
AFOV test (New vs Old)	1	0.555	0.555	12.989	<0.001
Interaction (Test * Eccentricity)	2	1.415	0.707	16.550	<0.001
Error	36	1.539	0.043		

ANOVA results indicated the presence of an interaction between tests, and therefore the significance of the test and eccentricity main effects were not considered.

Significant differences between thresholds were found, higher log 1/threshold values being reported for the original AFOV than are found using the new one. ANOVA shows that there is a significant difference between the log 1/threshold of the old and new test between eccentricities ($F_{2,36}$=16.55; p<0.001).

Multiple independent t-tests were performed to determine the difference between the two AFOV tests at all eccentricities. The t-tests were Bonferroni -corrected to avoid a Type I error in multiple comparisons. Since a total of nine comparisons were made, critical t values were obtained for values of p=0.0056, 0.0011, 0.0001 that corresponded to 0.05/9, 0.01/9, and 0.001/9, respectively.

Bonferroni analysis indicates that the 4˚ log 1/threshold is significantly higher for the original test than for all eccentricities of the new test (t-test; $t_{12}>5.628$; $p<0.0001$ for all comparisons); the log 1/threshold at 8˚ was higher for the original test than the log 1/threshold at 12° of the new test (t-test; $t_{12}=3.995$; $p<0.0056$) and the log 1/threshold at 12° was lower for the original test than the log 1/threshold at 4° of the new test (t-test; $t_{12}=4.964$; $p<0.0011$). At equivalent eccentricities, a significant difference was only found for the log 1/threshold at 4° (t-test 8° and 12°; $t_{12}<3.371$; $p>0.0056$).

7.2 Older group (59 – 79 years of age)

The study followed the same procedures for the group of older participants as for the younger group. Older participants were given the option of breaking up the study into two separate sessions because of the long duration of the test, but none of them chose this option. All older participants completed the experiment in a single session, taking breaks as often as necessary in each individual case. Participants who were unfamiliar with using the computer mouse were allowed to verbally describe the direction of the gap (right, left, up, down) and they were assisted using the arrows keys to indicate it.

7.2.1 Visits

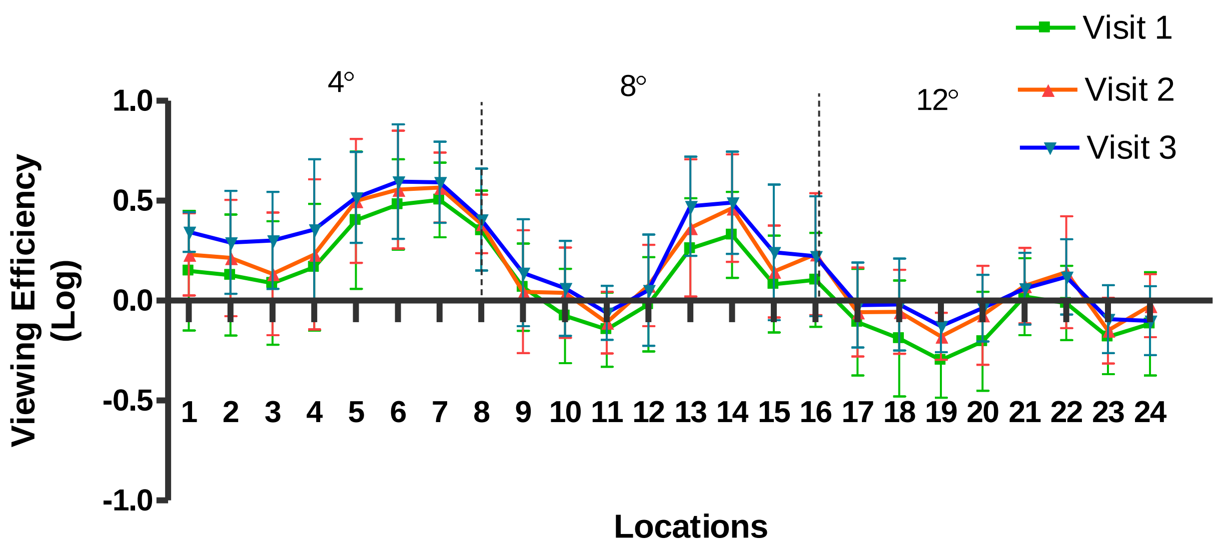
For the older group of participants a significant difference was found between all visits ($F_{2,12}$=62.299;p=.000). However, the difference between the second and third visit was almost half the difference between the first and the second visit, see table 7.8. We assumed this to represent a significant practice effect for this group. Therefore, in the next analyses only the viewing efficiency obtained in the third visit was used.

Table 7-8: Older group p values from the Bonferroni test showing significant differences between all visits.

VISITS	1	2	3
1		0.000035	0.000000
2	0.000035		0.006933
3	0.000000	0.006933	

7.2.2 Visits and locations

Although significant differences were found between visits, ANOVA revealed no interactions between visits and location ($F_{46,276}$=.9411;p=0.5844).), Ssee Figure 7.8.



1(right);2(right down);3(down);4(left down);5(left);6(left up);7(up);8(right up)
9(r);10(rd);11(d);12(ld);13(l);14(lu);15(u);16(ru);17(r);18(rd);19(d);20(ld);21(l);
22(lu);23(u);24(ru).

Figure 7.8: Older group: mean viewing efficiency values at the three visits. There was no interaction between visits and locations. The error bars indicate the standard error of the mean.

7.2.3 Eccentricity effect

As with the younger group, in the older group, there was a main effect of eccentricity; viewing efficiency decreased with eccentricity. Table 7.9 shows that there was a significant difference between all eccentricities ($F_{2,12}$=111.14;p=0.000).

Table 7-9: Older group p values from bonferroni test showing significant differences between all eccentricities

ECCENTRICITY	4	8	12
4		0.000	0.000
8	0.000		0.000
12	0.000	0.000	

The lowest value of viewing efficiency in this group was 0.896 (threshold = 130 ms). The average of viewing efficiency values for eccentricity 4˚ was 0.343 (threshold = 453 ms); for eccentricity 8˚ was 0.101 (threshold = 792ms), and for eccentricity 12˚ was -0.066 (threshold = 1165 ms).

7.2.4 Locations

The analysis of locations by eccentricities showed significant differences in viewing efficiency between locations at all eccentricities ($F_{23,138}$=21.951;p=0.000), see figure 7.9. This graph shows that the viewing efficiency is higher at locations 6 (left up) and 7(up) at 4˚eccentricity. Eccentricity 8˚ and 12˚show higher values of viewing efficiency at locations 5 (left), and 6 (left up). The viewing efficiency values are lower at locations: 1 (right), 2 (right down), and 3 (down) at eccentricity 4˚; 3 (down) at eccentricity 12˚ and at 3 (down), 7 (up), and 8 (right up) at eccentricity 12˚.

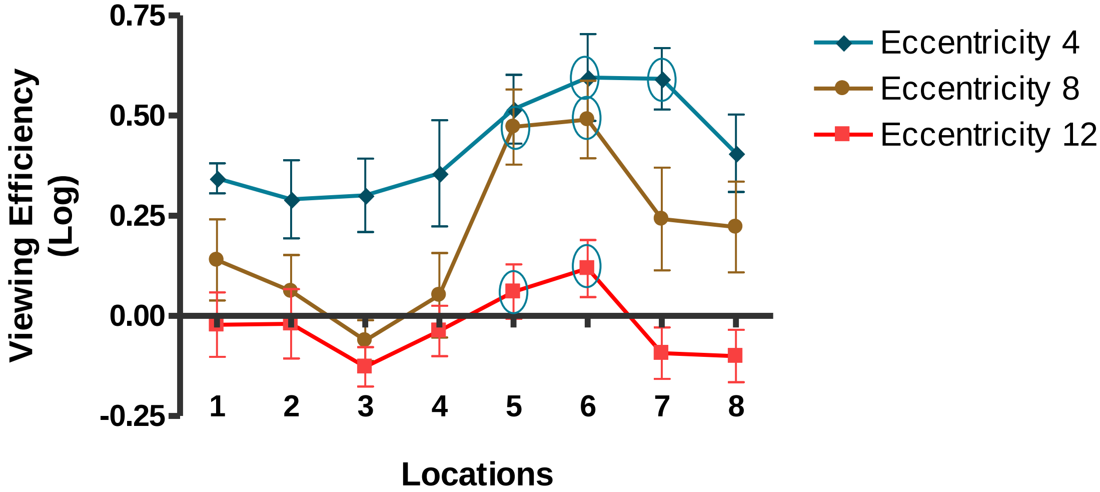


Figure 7.9: Mean viewing efficiency at three eccentricities (4º, 8°, and 12°) at the eight locations. The 4º eccentricity shows higher mean viewing efficiency at locations , 6 (left up), and 7 (up)blue circles. The 8° and 12° eccentricities show higher mean viewing efficiency at locations 5 (left) and 6 (left up)blue circles. The error bars denote the standard error of the mean.

7.2.5 Directions

It was interesting to analyze locations by directions for the older group to see if there were any significant differences between the eight directions tested. These analyses revealed that directions Left and Left Up presented the highest viewing efficiency on this group, and the lowest viewing efficiency was found at direction Down. As can be seen in figure 7.10 and table 7.10 there are significant differences between directions.

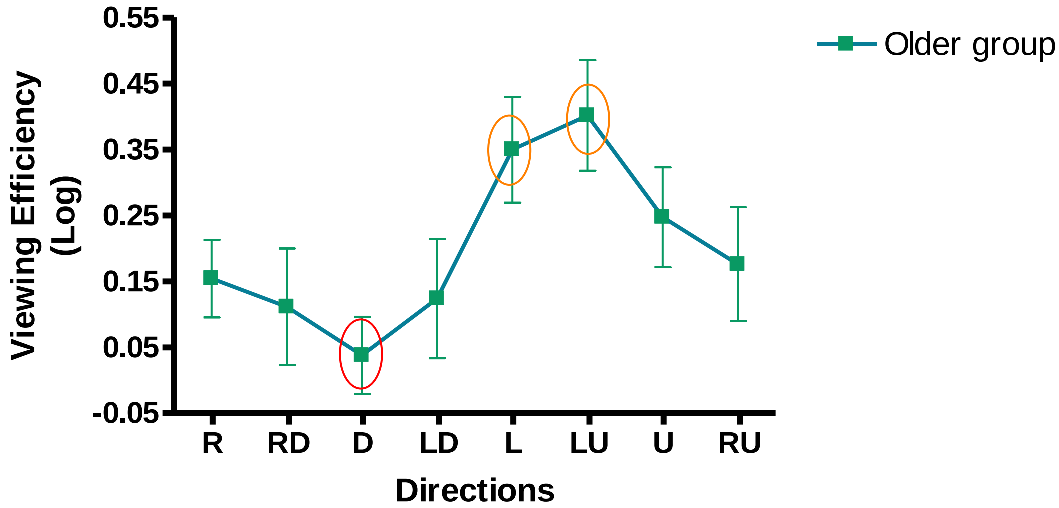


Figure 7.10 Older group: viewing efficiency values at directions, where direction L (Left) and LU (Left Up) were the highest values (yellow ovals) and direction D (Down) the lowest value (red oval). The error bars denote the standard error of the mean.

Direction L(Left) includes locations 5, 13, and 21 (located left at 4˚,8˚,12˚ eccentricity respectively); direction LU (Left Up) includes locations 6, 14, 22 (located up left at 4˚,8˚,12˚ eccentricity respectively); and direction D (Down) includes locations 3, 11, 19 (located down at 4˚,8˚,12˚ eccentricity respectively).

Table 7-10: Older group: p values from Bonferroni test showing significant differences between directions.

Direction	R	RD	D	LD	L	LU	U	RU
R		1	1	1	0.041	0.001	1	1
RD	1		1	1	0.002	0.000	1	1
D	1	1		1	0.000	0.000	0.016	1
LD	1	1	1		0.005	0.000	1	1
L	0.041	0.002	0.000	0.005		1	1	0.164
LU	0.001	0.000	0.000	0.000	1		0.504	0.005
U	1	1	0.016	1	1	0.504		1
RU	1	1	1	1	0.164	0.005	1	

The comparison by hemifields reveals lower viewing efficiency (lower performance) for the inferior hemifield than for the superior hemifield ($F_{1,36}$=7.69;p=0.0087). In addition, directions on the left side (especially in the superior hemifield) demonstrate higher viewing efficiency (better performance) than for directions located on the right side, see figure 7.11.

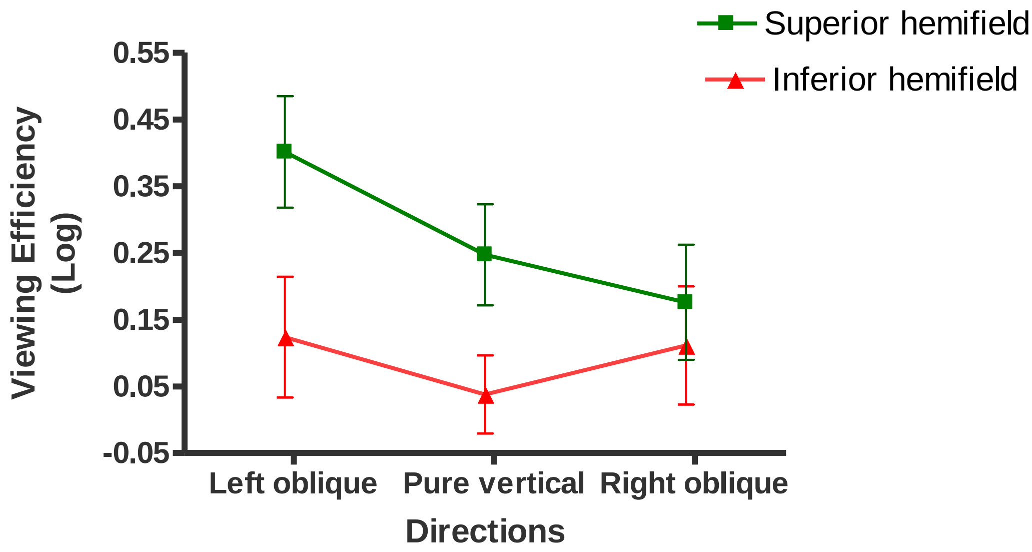


Figure 7.11 Older group: Viewing efficiency values between hemifields showing that inferior hemifield presents lower values than the superior hemifield. The error bars denote the standard error of the mean.

7.2.6 New AFOV test vs. Original AFOV test

The reported results for the original AFOV were compared with those for a similar older population using the new AFOV test by analyzing the slopes using the mean of each eccentricity for each version of the test (figure 7.12).

The slopes were compared applying the formula:

$m = \frac{\Delta y}{\Delta x}$ $\quad$ $m = Y_2 – Y_1 / X_2 – X_1$

Where Y_1= mean value of viewing efficiency at 12˚ eccentricity and Y2= mean value of viewing efficiency at 4˚ eccentricity; X_1= Ecc 4˚ and X_2= Ecc12˚.

Slope with the new AFOV test:

(7 subjects, range 59-79, four females)

m= -0.0274-0.1285/12-4= **-0.02**

Slope with the original AFOV test

(7 subjects, range 58-78, three females)

m= 0.05-0.79/12-4= **-0.093**

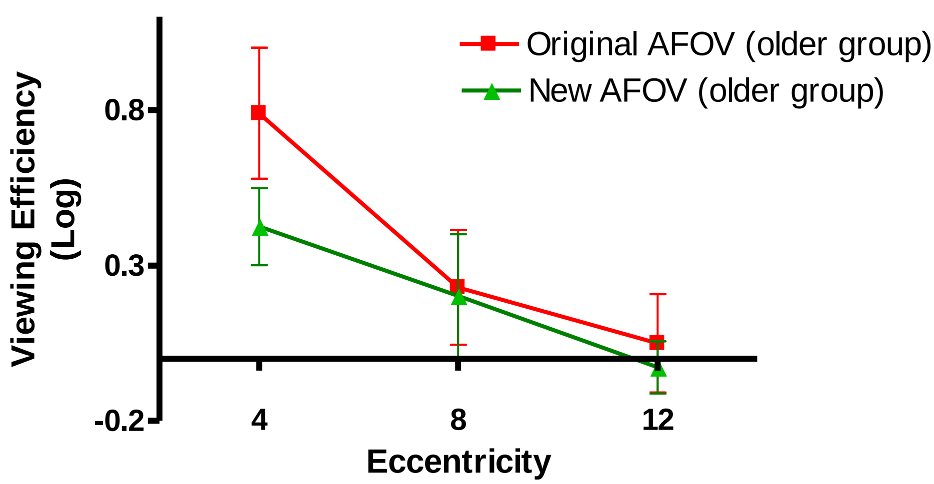


Figure 7.12: Older group: Viewing efficiency showing the different slopes between the New AFOV test vs the Original AFOV test. The error bars represent standard deviation.

The slopes between AFOVs are different as seen on figure 7.12. The original AFOV at 4 degrees eccentricity had higher viewing efficiency values than the new AFOV test.

Also, Two-Way analysis of variance was used to find differences between AFOVs at all eccentricities. The analysis was done using the values reported for the original AFOV test, which included the mean and standard error at each eccentricity location (Cohen, 2002).

A summary of the ANOVA is in table 7.11.

Table 7-11: Results of Two-way analysis of Variance between AFOVs in the older group.

	d.f	SS	MS	F	p
Eccentricities (4˚,8˚,12˚)	2	1.6723	0.8361	16.3752	<0.001
AFOVs (New vs Old)	1	3.032	3.032	59.372	<0.001
Interaction (Test*Eccentricity)	2	0.732	0.366	7.163	<0.001
Error	36	1.838	0.051		

ANOVA results indicated the presence of an interaction between tests, and therefore the significance of the test and eccentricity main effects were not considered.

Significant differences between thresholds were found, with higher log 1/thresholds values being reported for the original AFOV than those found for the new one. The ANOVA shows a significant difference between the log 1/threshold of the original test and the new one between eccentricities ($F_{2,36}$=7.163; p<0.001).

As in the younger group, multiple independent t-tests were used to determine the difference between the two AFOV tests at all eccentricities. The t-tests were Bonferroni-corrected to avoid a Type I error in multiple comparisons. Since a total of nine comparisons were made, critical t values were obtained for values of p=0.0056, 0.0011, 0.0001 that corresponded to 0.05/9, 0.01/9, and 0.001/9, respectively.

Bonferroni pos hoc tests indicated that the 4˚ log 1/threshold was significantly higher for the old test than for 8 eccentricity of the new test (t-test; $t_{12}>3.371$; p<0.00); and also for 12˚ of the new test (t-test; $t_{12}>5.627$; p<0.0001). At equivalent eccentricities, no significant difference was found between tests (t-test 4˚, 8˚and 12˚; $t_{12}<3.371$; p>0.005).

7.3 Younger group vs. older group

A comparison of the results for the two different age groups reveals that viewing efficiency in the older group is generally lower (poorer performance) than for the younger group.

7.3.1 Visits

A comparison of viewing efficiency performance for the two age groups demonstrates that viewing efficiency is consistently lower for the older group at all three visits, but no interaction between groups was present ($F_{2,}24=.7338$;p=0.490). The main effect of age was demonstrated ($F_{1,12}=25.842$;p=0.000). In the older group, a significant difference was found between the second and third visits. This difference was not found in the younger group.

7.3.2 Locations

There were significant differences in viewing efficiency values in locations between age groups ($F_{23,276}$=3.7134;p=0.000). The trend of both lines was very similar in both groups showing that there was no interaction between them (p=0.092). The lowest viewing efficiency values (worst performance) were the same for both age groups and they are locations 3, 11, 19 (located down at all eccentricities), and 23 (up at 12˚ eccentricity) and seen in figure 7.13. It is important to highlight that for these analysis the data of the first group was the mean of the second and third visit, and on the other hand for the second group the data corresponds to the third visit only.

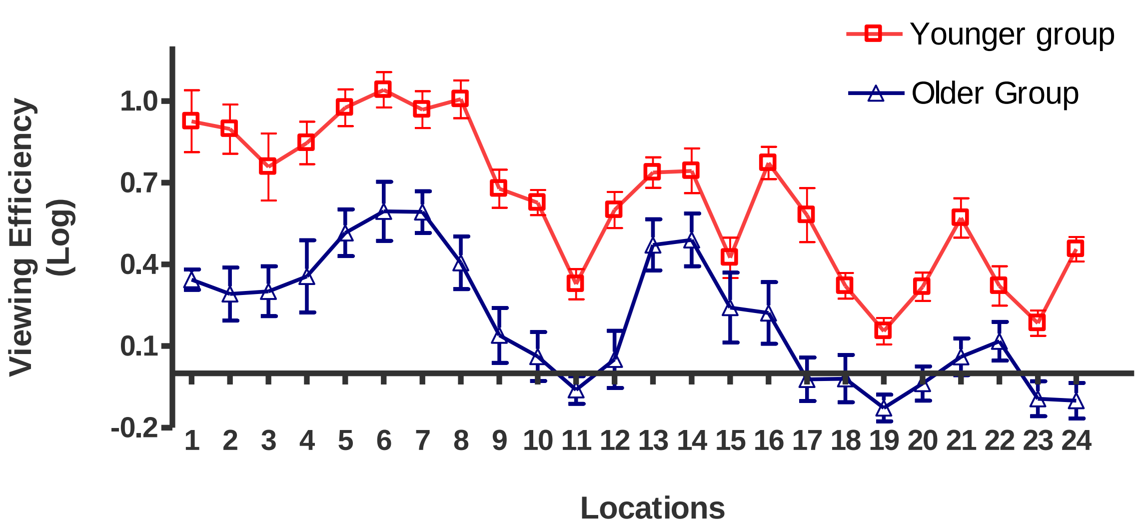


Figure 7.13 Mean (SE) viewing efficiency of the two groups (younger and older) at all locations. Lower viewing efficiency were found at locations number 3, 11, 19 (located down at all eccentricities), and 23 (located up at eccentricity 12) for both groups (green ovals).

7.3.3 Target Location (Eccentricity)

A main effect of eccentricity was found in both groups ($F_{2,36}$=30.84;p<0.000), but no interaction between eccentricity and group ($F_{2,36}$=0.42;p=0.662). Figure 7.14 shows how the viewing efficiency goes down (lower values) with an increase in eccentricity.

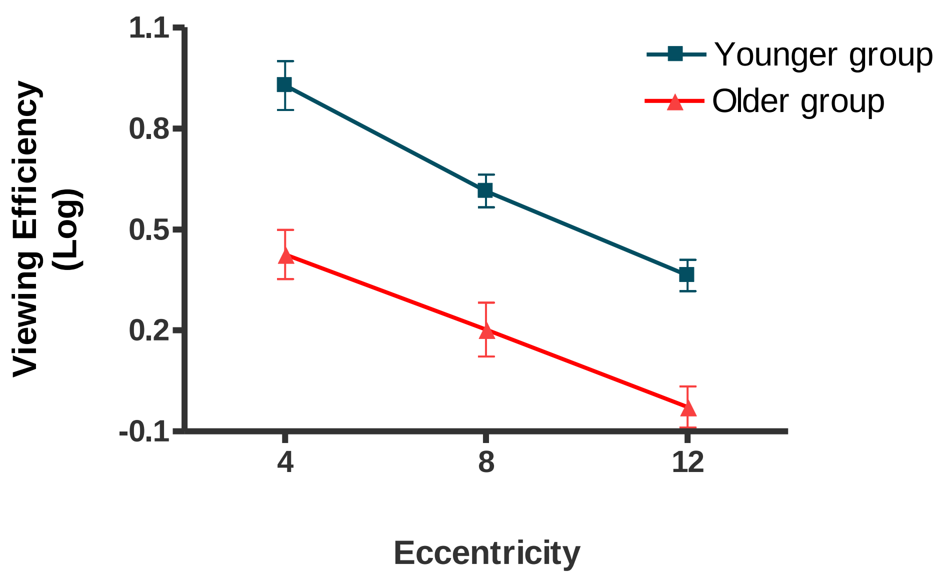


Figure 7.14: Viewing efficiency for the younger and older group at the three eccentricities (4, 8, and 12 degrees). Main effect of eccentricity present in both groups of ages. The error bars represent the standard error of the mean.

7.3.4 Target Location (Direction)

Comparing target directions between these two groups of participants, it was found that the viewing efficiency values in the older group were lower in all directions (main effect of age) ($F_{1,96}$=150.36;p<0.000). Also, significant differences were found in directions between age groups ($F_{7,96}$=4.77;p=0.000), but there was no interaction between directions and age groups in this analysis ($F_{7,96}$= 1.27;p=0.271).

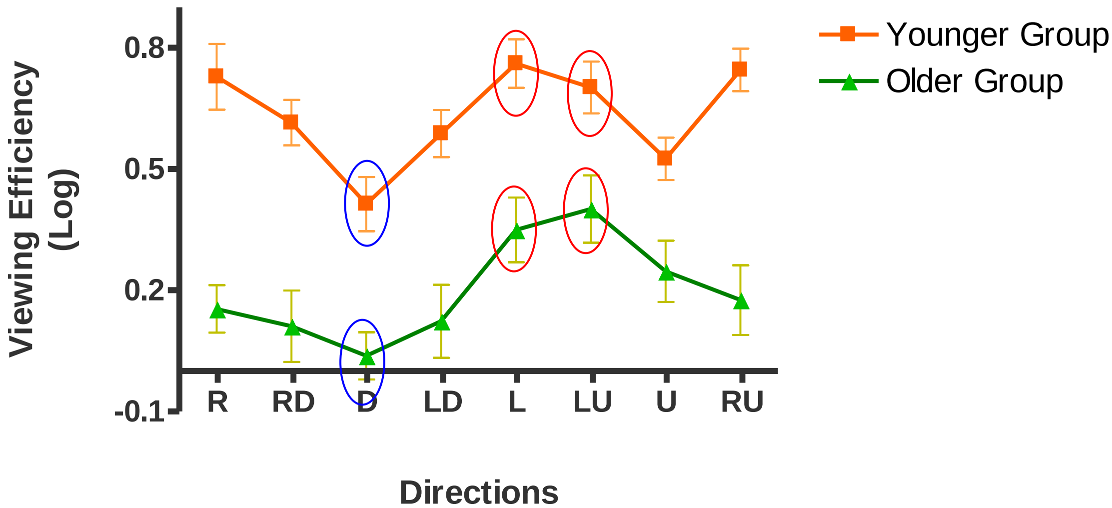


Figure 7.15: Viewing efficiency for both the younger and older groups in the eight different directions. Direction D (Down) has the lowest viewing efficiency in both groups (blue circles), while direction L (Left) and LU (Left Up) have the highest (red circles). Error bars indicate standard deviation.

Analyzing each direction, direction L (Left) and LU (Left Up) had the highest viewing efficiency values (better performance), while direction D (Down) had the lowest viewing efficiency (worst performance) for both the younger and older group. Also it is important to note that viewing efficiency values decreased at directions R (Right) and RU (Right Up) in the older group, see figure 7.15 and figure 7.16.

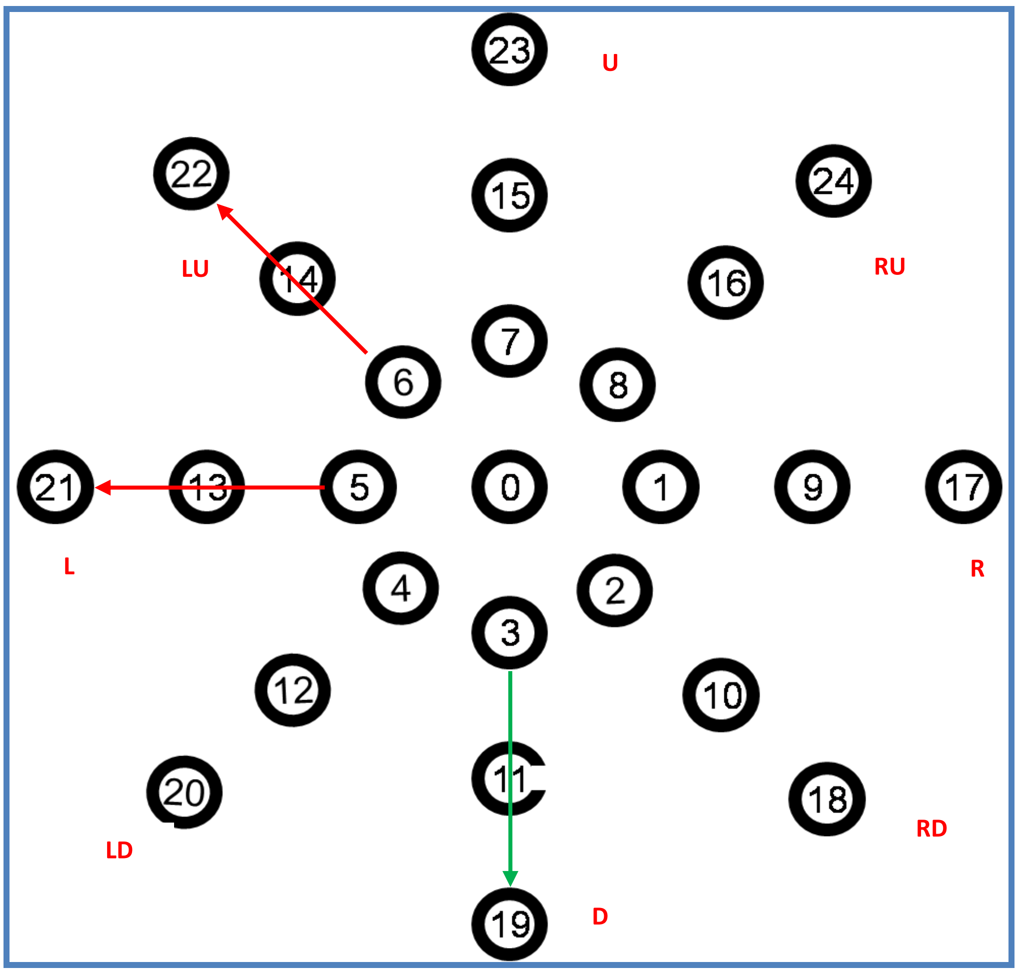


Figure 7.16 Schematic drawing showing the directions (locations) with the highest viewing efficiency at direction L(Left)and LU (Left Up) red arrows, and that with the lowest viewing efficiency direction D (Down), green arrow for both the younger and older groups.

8. Discussion

8.1 Reliability

My original hypothesis was that the new AFOV test would demonstrate test-retest reliability. The ANOVA revealed a significant difference between the first visit and the next two visits for the younger group of participants, but there were no significant differences between the second and third visit results. The viewing efficiency values increased significantly between the first and the second visit, and the viewing efficiency values on the third visit were not significantly different from those on the second visit. These differences are likely attributable to a learning effect. The fact that there is no difference between the last two visits suggests that the data obtained with the new AFOV test are reliable if the testing is preceded by a practice "learning" session.

For the older group of participants, the viewing efficiency values became significantly higher with each subsequent visit. For example, the second visit data showed a mean improvement of 18.7% over the first visit, and the mean improvement from the second to the third visit was 9.1%. If subsequent improvement continues to follow the same trend (half of the previous improvement), one might expect that the results would plateau at the next visit, with little or no significant change in viewing efficiency. This suggests that the learning effect in older people takes longer than the learning effect in younger people and for this reason the use of the test should be preceded by more practice in this population than in the young one.

8.2 Effect of age and eccentricity

The main effect of age and eccentricity that was found in this study is in agreement with the results obtained with the original AFOV (Coeckelbergh et al, 2004). The viewing efficiency values for older participants were lower (poorer performance) than for younger participants (p=0.002), and both groups presented higher viewing efficiency (better performance) at less eccentricity (4 degrees) than at greater eccentricity (8 and 12 degrees respectively). No interaction was found between age and eccentricity. This result is inconsistent with those reported by Coeckelbergh et al (2004) who describe an inverse age by eccentricity effect with log transformed data (the difference in performance between groups was higher in the first eccentricity than in the last eccentricity). Their results with linear data coincide with the results in this study. Seiple et al (1996) also found that both group of ages had the worst performance in the periphery, results that coincide with the findings in the present study.

It was found in this study that older people take approximately three times longer to correctly locate the target and the direction of the gap at each eccentricity than the younger group; results that agree with the results obtained with the original AFOV.

Significant differences were found between locations along each eccentricity for both age groups. These differences could not be compared with other studies because other studies reported the average of the performance in each eccentricity or the average within different hemifields.

8.3 Directions and hemifields

With respect to directional variations in viewing efficiency, the horizontal axes (directions Right and Left) yielded higher values than along the vertical axes (directions Up and Down) in both young and older participants in this study. These results are consistent with functional visual field data from other studies (Hassan et al, 2008; Carrasco et al, 2004; and Mackeben, 1999).

This study found no significant difference between the Up and Down directions along the vertical axis in the younger group (p=0.672), but the difference between the Up and Down directions was significant for the older group (p=0.016), where the viewing efficiency was higher (better performance) in the Up direction than the Down direction. These results for the older group are consistent with the results from studies of the attentional visual fields of older drivers (Hassan et al, 2008) and from other related research (Mackeben, 1999; Carrasco et al, 2004).

A comparison of superior and inferior hemifield data shows consistent differences for both age groups. The superior hemifield (average of directions located superiorly to the horizontal axis) demonstrate higher viewing efficiency values (better performance) than the inferior hemifield (average of directions located inferiorly to the horizontal axis). Other research with older people found that for the average of the intermediate meridians (oblique directions) in the inferior hemifield in peripheral localizations (largest eccentricity), the viewing efficiency values were significantly lower than in the superior hemifield (Wood et al, 2006), results that are in accordance with our study.

Inconsistencies in the asymmetries between values of retinal sensitivity and process of information along the visual field have been reported when comparing the superior and inferior hemifields (Rezec & Dobkins, 2004). Some authors have suggested that improved visual search and attentional processing in the superior hemifield give it an advantage over the inferior hemifield (Christman, 1993; Hagenbeek & Van Srien, 2002). Christman also suggest that visual search for far distances is performed mainly using the superior hemifield because objects or information at far distances tend to be located above the horizontal meridian; on the other hand visual search for near distances is directed principally on the inferior hemifield as information at short distances is located mostly below the horizontal meridian. The question is why during the AFOV test the advantage is for the superior hemifield and results with the UFOV® test, and other different test show an advantage for the inferior hemifield if those test are assessing the functional visual field and they are also performed at near distances?. The answer is not easy and more studies are needed in order to fully understand these findings. The main difference between the AFOV test and the others tests is that the AFOV allows eye and head movements while the others preclude them. Also for the same reason of using eye and head movements during the AFOV test, both parallel and serial searches are present while in the other studies the researchers used very short presentation time of the stimuli in order to avoid serial searches (Rezec & Dobkins, 2004).

If we take into account the above mentioned conclusions about the advantage of the superior hemifield related with far visual search and attentional processing, we can speculate that ocular and head movements serial searches are very useful and effective for far visual searches. Since the AFOV test is based on a visual search paradigm and attentional components are involved during the test, this may explain why the viewing efficiency values are higher for the superior hemifield than those obtained for the inferior hemifield.

The probable reason for other studies to show an advantage for inferior hemifield targets is that near visual searches use attentional weighting as described by Rezec and Dobkins (2003) when ocular movements are not allowed. Mindful of these factors, it could be argued that if eye and head movements are allowed during the UFOV®test, then it might be expected that the results would be similar to those found in this study; or the opposite, if during the AFOV test the eye and head movements are precluded, it would be expected that the results are similar to those found using the UFOV® test.

For younger participants there were no significant differences in viewing efficiencies between right and left hemifields. A different result was found for the older group, where viewing efficiency values were higher for the left hemifield than for the right hemifield. For some reason yet to be determined there is an attentional bias that gives advantage at the upper left quadrant in the older population in this study. One possible reason might be the return saccade during the reading process.

More studies have found there to be greater differences in performance between superior and inferior hemifields than between the right and left hemifields, but the differences between left and right hemifields are in agreement with the current study (Christman, 1993).

8.4 Original AFOV vs New AFOV

In general all values of viewing efficiency were higher for the original AFOV test in comparison with the new one. These results are may be attributable to the use of a backward masking presentation, which has been demonstrated to increase the localization target error in all ages and all eccentricities (Seiple et al, 1996). Other differences in study design and statistical analyses also may contribute to some discrepancies in the results. One difference is the psychophysical method used to find the thresholds at each location. In the original AFOV the Quest procedure was used, instead of the staircase method used in the present study. This probably made the test shorter and resulted in a higher number of reversals obtained at each location. The shorter duration of the test might give higher values of sensitivity with the original AFOV. The number of reversals is not likely the cause of the differences since they only used 6 reversals for their analysis. In the current study the minimum number of reversals used was 5 at each location. A comparison of equivalent eccentricities using analysis of variance showed significant differences between AFOV tests for the younger group, differences that were not found in the older group. The reason for finding differences only in the younger group at the 4˚ eccentricity might be attributable to the inverse age x eccentricity effect that was found in Coeckelbergh and colleague's study in 2004. They found an interaction between age groups and eccentricity where differences in performance were higher at eccentricity 4 between groups and the younger group obtained a considerable less rate of errors at this eccentricity.

Although differences were found between tests in the younger group, the main effects that were reported for the original AFOV (age and eccentricity effect) were also found with the new AFOV test.

The development and application of the new Attended Field of View (AFOV) test is the base line for further studies where modifications on the methodology and analysis can be applied in order to make the test more practical. One modification could be to assess just the obliques directions on the upper and lower hemifields avoiding the vertical (Up and Down) directions and the horizontal (Right and Left) directions. The test duration would be decreased by at least half of the original duration and the bias about the higher and lower values of viewing efficiency found in this study would be eliminated. Another modification would be to use fewer trials on each location in a bigger group of participants.

The AFOV test was designed to assess the functional visual field. It was used to assess the driving performance of people with visual field defects, who have failed a driving test, and who have developed compensatory viewing strategies after some driving training program (Coeckelbergh et al, 2001). Also, this test had been used to assess the viewing behavior of people with central and peripheral visual field defects (Coeckelbergh & al, 2001). These studies indicated that the AFOV test measures the functional visual field. Since the results with the new AFOV test are similar to the original AFOV, it is highly probable that the new AFOV test measures the functional visual field of people.

It is necessary to clarify that this is not a diagnostic test or a test that by itself measures the performance of people during their daily activities, this test measures viewing efficiency in people that experience difficulties in the performance of daily life activities.

9. Conclusions

The use of the new AFOV test requires a practice time before its used in order to avoid the confounds of learning.

The data with the new AFOV test are reliable in the younger group after one practice session. For the older group, a longer learning effect is evident. Accordingly, older people require more practice than younger people before being tested using the AFOV test.

Using the new AFOV, significant differences were found in viewing efficiency between the horizontal and vertical meridian and superior and inferior hemifields in both age groups.

When interpreting the results of this test one must account for eccentricity, direction and age.

Further investigations with the AFOV test should be done dividing participants in age groups in order to examine the change with age in viewing efficiency measurement.

Additional studies with the AFOV test analyzing ocular movements during visual search techniques for young and older people will provide useful information about different search strategies that may account for the observed differences in viewing efficiency by directions and hemifields.

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