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Sustained attention under a gaze-controlled paradigm and its significance to patients with a central scotoma

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Für Amélie, Felicia und Marlon

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1. Introduction

1.1. Visual attention

1.1.1 Historical background

When visually experiencing the world, a massive amount of data in the form of retinal activation is sent to the brain by way of the optic nerve. Because some visual information is more important than other information, humans need to constantly sort important targets from unimportant ones. The management of this sorting is possible via the brain mechanism of “attention” (Carrasco, 2011). Attention is a “process of ordering, or prioritizing”, and “creating a constantly changing list of potentially important targets” (MacKeben, 2009).

While attention is something that has been studied experimentally since the 19th century, for example by Johannes Müller, William James and Hermann Helmholtz (Strasburger et al., 2011), this happened mostly outside vision research. The first article in the journal *Vision Research* that used “attention” as a keyword appeared in 1976 (Carrasco, 2011). Since then, interest in visual attention has increased steadily, with a total of approximately 250 articles on visual attention published in 2010 alone (Carrasco, 2011). The research on visual attention seemed to increase exponentially from 2000 – 2010 (Carrasco, 2011, Fig. 1). Empirical research on visual attention is thus a relatively recent and exciting focus of research at the intersection of vision research and experimental psychology. Visual attention is a highly important faculty, influencing all of human perception and behavior.

1.1.2 Sustained vs. transient visual attention

Several types of visual attention have been identified dating as far back as the late 1800s. Two types are necessary to describe (Helmholtz, 1896; MacKeben, 1999). They are distinguished by their time constant, where “sustained attention”, which works under voluntary control, is slow and active, and “transient attention”, which is reflex-like, fast and passive (Nakayama & MacKeben, 1989).

Transient attention rises and decays quickly. Its peak is at about 100-120 ms after stimulus onset. Sustained attention rises after about 300 ms, but once a location is fixated, attention can be held as long as needed (Cheal, Lyon, & Hubbard, 1991; Hein, Rolke, & Ulrich, 2006; Ling & Carrasco, 2006a; Liu, Stevens, & Carrasco, 2007; Muller & Rabbitt, 1989a; Nakayama & MacKeben, 1989; Remington, Johnston, & Yantis, 1992).

Spatial attention can be focused in a peripheral locus to improve visual perception there. Signals at spatially attended locations are processed faster (Eriksen & Hoffman, 1972; Tsal, 1983), seen in more detail (Bashinski & Bacharach, 1980; Downing, 1988), and with less error (Cave & Pashler, 1995) than signals at unattended locations.

In the present study, the participants had to shift their attention to an eccentric region, i.e. away from the fixation point. The task was to report the orientation of a Snellen E while maintaining fixation. This task is only possible with active and voluntary sustained attention, therefore the performance during sustained attention was measured.

1.1.3 Selective vs. focal attention

In this study the focus was on sustained attention. Sustained attention can further be split into two groups. Focal attention is spatially oriented attention, e.g., includes all objects in a precise area of the central visual field. Selective attention is feature-oriented, e.g., describes the ability to select features of a pattern, like attending only to the apples on an apple tree (MacKeben, 2009). Both mechanisms, the spatially oriented and the feature-oriented, were important for this study. Since 120 years, after the first experiments made by Helmholtz, we know that “Sustained focal attention” can enhance perception in eccentric positions of the central visual field (Helmholtz, 1896; Nakayama & MacKeben, 1989). More experiments since then showed that sustained focal attention can enhance signals as well as reduce noise (Dosher & Lu, 2000; Lu & Dosher, 2004; Carrasco, 2006). Similarly, sustained selective attention can improve specific target detection in the central visual field.

1.1.4 Modulators of sustained attention

Two modulators of sustained attention are the type of signal being attended to and external noise reduction. These modulators have been shown to enhance task performance or result in shorter reaction times.

Signal type

Sustained attention-dependent target detection can be optimized depending on the type of signal used. Previous studies have implemented an array of signals, including letters (Tsal, 1983; Eriksen & James, 1986; Kröse & Julez, 1989; MacKeben, 1999), shapes in different orientations (Downing, 1988; Nakayama & MacKeben, 1989), and colors (Nakayama & MacKeben, 1989; Morrone, Denti, & Spinelli, 2002), spots of light (Posner, 1980; Sagi & Julesz, 1986; Downing, 1988, MacKeben & Nakayama, 1993; Shiu & Pashler, 1995; Yeshurun & Carrasco, 1999) Landolt-squares (Yeshurun & Carrasco, 1999), broken lines (Yeshurun & Carrasco, 1999) or Snellen E patterns (Altpeter et al., 2000; MacKeben 2009). In addition, the number of stimuli shown – and in particular, the presence or absence of distractor stimuli – has also been varied in previous studies. For example, test stimuli have either been presented alone (Bashinsiki & Bacharach, 1980; Posner, 1980; Yeshurun & Carrasco, 1999) or together with distractors (Nakayama & MacKeben, 1989; Palmer et al., 1993; Cave & Pashler, 1995; MacKeben, 1999; Altpeter et al., 2000; Ling & Carrasco, 2006a; MacKeben, 2009), as discussed below. Sustained attention-dependent performance has been shown to be optimal when a target is presented together with distractors and high contrasts are used, such as the colors black and white.

External noise

It is also possible to optimize detection performance by attention by suppressing external noise. Sustained attention performane has been shown to be affected in high-noise, but not low-noise, conditions. High-noise conditions have been generated in previous experiments, for example by decreasing the number of pixels in the signal compared to the number of noise pixels (Dosher & Lu, 2000a, 2000b; Lu & Dosher, 1998, 2000).

A second type of external noise which can affect sustained-attention task performance is the relationship between the stimulus and the distractor. Studies have shown that not only the number of distractors but also the similarity between stimulus and distractor matters. Sustained attention performance is enhanced when the stimulus is similar to the distractors. If the stimulus differs considerably from the distractors, no increase in sustained attention is seen (Cave & Pashler, 1995; Shiu & Pashler, 1995).

1.1.5 Visual search and peripheral sustained visual attention

One of the most important uses of sustained visual attention in daily life is for visual search. Visual search refers to the scanning of the central visual field for a target object. As with enhancement of sustained visual attention itself, there are also aspects of the central visual field or of the target object which can improve participants´ visual search results. For example, participants make fewer errors when successive targets appear at the same location (Cave & Pashler, 1995). Sustained visual attention operates similar to a spotlight, such that it is allocated to the vicinity of a relevant stimulus, even when attention is cued by color or by shape rather than by location (Tsal & Lavie, 1988). In this way, selective attention to a particular size or color does not mean that something will be automatically seen, or excluded from being seen, but rather that attention is guided to specific spatial locations that contain the feature being searched for (Shih & Sperling, 1996).

Not only location, color or shape affect performance of visual attention in the visual field. Many experiments have shown that presenting target stimuli sequentially rather than simultaneously results in better task performance for

targets presented in close proximity at distinct peripheral areas. In addition, high contrast peripheral stimuli result in better search and performance of sustained attention, and for signaling peripheral attention shifts (Steinman et al., 1995)
With regard to the neural correlates of sustained attention, differences in neural responses to sequentially, compared to simultaneously, presented targets increase in magnitude from striate to extrastriate areas (Beck & Kastner, 2005, 2007; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Kastner et al., 2001; Luck, Chelazzi, et al., 1997; Miller et al., 1993; Moran & Desimone, 1985; Pinsk, Doniger, & Kastner, 2004; Recanzone et al., 1997; Reynolds et al., 1999; Snowden et al., 1991). Further, it can be said that, after directing attention to a specific location in the central visual field, baseline-activity is lower throughout the remaining field (Smith, Singh, & Greenlee, 2000).

1.2. Neural correlates and central versus peripheral sustained attention

1.2.1 Major brain areas for sustained attention

Visual attention plays an important role in collecting relevant information. It is a highly complicated mechanism of the human brain in which several brain areas are involved (Parhizi et al., 2018). Parhizi et al. (2018) describe a link between visual attention and frontal, prefrontal, parietal and occipito-temporal brain areas as well as the visual cortex.
Task-specific areas can be activated (when needed) or deactivated by task-irrelevant areas. Sustained attention has most clearly been related to processing at the level of areas V4, a visuotopically organized area in the human ventral visual cortex and additionally IT, an inferior temporal area in the monkey brain (Richmond et al., 1983; Moran et al., 1985; Spitzer et al., 1988), as well as in the parietal cortex (Bushnell et al., 1981). Posner & Petersen (1990) and Petersen & Posner (2012) indicate the role of the posterior-parietal cortex. Hopf & Mangun (2000) also implicate the posterior-parietal cortex along with lateral-prefrontal cortical structures.

Since 1999, areas that had been considered as purely sensory have also been found to be relevant for spatial attention, including the primary visual cortex (V1), as well as dorsomedial and ventral-occipital cortical areas (Brefczynski & DeYoe, 1999; Gandhi, Heeger, & Boynton, 1999; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999). Wardak (2011) describes an activation of two cortical areas, namely the lateral intraparietal area (LIP) and the frontal eye fields (FEF), and the possible interactions between those two areas, as relevant for spatial attention.

1.2.2 Differences between the central and peripheral visual field

Attention allows the collection of relevant information, thereby guiding behavior. However, not all signals present in the central visual field can be processed in detail at any one time, as this would overload the visual processing system. Rather, signals from the center of the visual field and in particular the fovea, have a higher spatial resolution, more color information and, due to less crowding (Strasburger, 2018), better shape recognition. However, when one is outside on the street as a pedestrian, it might be helpful to see an approaching car outside of the center of the visual field, and thus have a chance for closer examination before an accident happens. In the periphery we have a good motion detection. Therefore, an object of interest, such as the car moving in the periphery, can quickly be brought to the fovea for closer examination by a reflexive eye movement.

1.2.3 The role of attention for the performance of eye movements

Under normal viewing conditions, we continuously scan our environment with saccadic eye movements. Saccades bring important details to the foveal part of the retina. Similarly, while we are reading a text, we need saccades to explore new words. Patients suffering from an advanced maculopathy have a highly reduced reading speed and the number of forward and backward saccades is increased (Trauzettel-Klosinski et al., 1994; Rubin & Feely, 2009). For controlling saccadic eye movements, attention plays an important role. Saccade planning and attentional selection are intimately coupled from a behavioral point of view but correspond to distinct functional operations (Posner, 1980; MacKeben & Nakayama, 1993; Kowler et al., 1995; Deubel & Schneider, 1995; Wardak et al., 2011; Hoffman & Subramaniam, 1995). “Focal attention is guided by a short-term memory system which supports the fast re-fixation of gaze to recently foveated targets” (McPeek et al., 1999).

1.3. Sustained attention and the importance for everyday life

1.3.1 Maculopathies

The macula, or macula lutea, is the more pigmented area in the center of the retina and includes the fovea. The fovea covers an area of 5° diameter whereby the foveola covers 1° diameter (Trauzettel-Klosinski et al.,1994). The fovea enables resolving fine detail, with the highest spatial resolution, i.e. smallest minimal angle of resolution (MAR), of below half a minute of arc attained in the very center (the foveola). Damages to the macula are called maculopathies. Maculopathies can be classified in hereditary and acquired ones.

The most common hereditary maculopathy is Stargardt disease. It is a severe disease with a progressive, bilateral central vision loss, often beginning in childhood or adolescence.

Best vitelliform macular dystrophy (BVMD), also known as Best disease, is another common type of this group of hereditary diseases. It is also a progressive, juvenile-onset maculopathy. Typically, BVMD has a relatively good prognosis compared to Stargardt disease. An adult-onset type also exists, called adult vitelliform macular dystrophy (AVMD), which is accompanied by relatively mild vision loss.

The most common acquired maculopathy is age-related macular degeneration (AMD). This maculopathy is the main cause for severe visual impairment in industrialized countries. The disease affects older individuals, above the age of 50. In the US, 10% of the individuals older than 65 years and 30% of individuals older than 75 years are affected (Kanski, 2004).

AMD is caused by a dysfunction of the retinal pigment epithelium (RPE). With increasing age, metabolic products accumulate in the retinal pigment epithelium. This leads to a modification in the permeability of Bruch's membrane through an agglomeration of extruded material, so called drusen, between the membrane layers. Drusen formations cause pigment epithelium cell death and increased permeability of Bruch's membrane. The consequence is a visual impairment associated with a central vision loss. The pathophysiology behind AMD remains to be determined.

Risk factors:

AMD seems to be caused by a 'multifactorial interaction between metabolic, functional, genetic and environmental factors' (Waseem & Sanaa, 2017). Increasing age seems to be the strongest factor associated with AMD. Further factors include the family's history and genetics. Ethnicity also seems to play a role: Caucasians have the highest rate for AMD, while it is rarely reported within the African American population. Previous cataract surgery, blue iris color or high sunlight exposure may also increase the probability of developing AMD (Kanski, 2016).

Environmental factors are other risk factors. Here, the most important factor is a history of smoking, but also a high dietary intake of trans saturated fats, both vegetable and animal fats (Jager et al., 2008, Seddon et al., 2003) and many more not yet completely explored factors such as low dietary intake of antioxidants (e.g. vitamin C, E, beta carotene, zinc oxide or cupric oxide (Jager et al., 2008).

Types of AMD:

There are two main types of AMD: a non-exudative and an exudative form. The non-exudative form, also known as dry form, occurs in 90% of all diagnosed cases (Kanski, 2016). The exudative form, also known as wet form, occurs in 10% of all cases, but is liable for 80% of acute and severe visual impairment caused by AMD (Dahlmann & Patzelt, 2017).

"Dry AMD is characterized by a deposition of drusen and/or alterations of the retinal pigment epithelium" (Bandello et al., 2017). "In the beginning, patients often have minimal morphologic and functional changes, which can progress to a geographic atrophy with severe visual impairment caused by an atrophy of the retinal pigment epithelium and the photoreceptor cells". It always affects both eyes but often in an asymmetrical way. In 10-20% of cases dry AMD changes to the wet type. To date there is no approved treatment for dry AMD, but several innovative treatments are being investigated, e.g. drugs that might prevent the enlargement of the geographic atrophy (Bandello et al., 2017).

Wet AMD is caused by a choroidal neovascularization in the choriocapillaris, through Bruch`s membrane, which destroys the retinal pigment epithelium. The neovascularization and the newly-built fragile blood vessels (angiogenesis), lead to a hemorrhage and protein leakage with an accompanying edema on the retina. The results are newly built fibrovascular membranes and scars on the macula, and a rapid progressive loss of vision, sometimes within weeks or even days. The angiogenesis in the retina is stimulated by a vascular endothelial growth factor (VEGF). This factor can be inhibited. The goal is to slow down the neovascularization process, the recovering of retinal morphology, and the preservation of neurosensory function. The introduction of anti-VEGF agents has revolutionized the treatment of this disease and thereby caused a significant reduction of visual impairment from wet AMD (Mantel et al., 2018).

In summary one could say that there is no treatment for hereditary maculopathies and for the non-exudative form of the acquired maculopathy AMD. Lifestyle factors, such as not-smoking, a normal body mass index (Johnson, 2005), and nutritional components like increasing consumption of zinc and antioxidants, however, can help in some cases to slow down their progression to advanced AMD (Clemons et al., 2005). The treatment of the exudative form of AMD is based on targeting choroidal neovascular membranes. The revolutionary use of anti-VEGF agents has greatly improved outcomes for this disease.

1.3.2 Eccentric fixation in macular degeneration

After damage to the macula and the development of a central scotoma, directing the fovea to targets of interest becomes inefficient for visual processing due to the diminished or entirely lost foveal function. Many patients thus spontaneously shift their attention to an area where they can still see. They then also shift the fixation to that area. Sometimes they use suboptimal areas for this fixation. Patients with macular degeneration can therefore be helped greatly by making them aware of the possibility of shifting their attention and using retinal areas with the best remaining visual acuity for fixation. This mechanism can help them tremendously (Gaffney et al., 2014). However, for reading, a sufficient size of the reading visual field or perceptual span is necessary. This can be described as 'eccentric fixation', a technique which has been described and specified for over 50 years (v. Noorden & Mackensen, 1962; Aulhorn, 1975; Trauzettel-Klosinski & Tornow, 1994; Trauzettel-Klosinski, 2010; Trauzettel-Klosinski, 2018).

The target of fixation is projected to intact peripheral parts of the retina. Two different types can exist:

'Eccentric viewing' is mostly seen in patients with early stages of macular degeneration. The normal gaze direction is possible. The patient looks beside the stimulus on purpose.

'Eccentric fixation': the patient has developed an eccentric preferred retinal locus. With this locus outside the fovea the patient looks straight forward. The viewing direction is newly trained.

In the present study, the term 'eccentric fixation' is used for any fixation to a point that is located outside the fovea (Otto, 1969; Goodrich & Quillman, 1977; Nilsson & Nilsson, 1986; Nilsson, 1990; Aulhorn, 1975; Trauzettel-Klosinski et al., 1994; Trauzettel-Klosinski, 1997; Nilsson, Frennesson, Nilsson, 2003, Schumacher et.al., 2008). That location is the so called 'preferred retinal locus' (PRL), (v. Noorden & Mackensen, 1962) or 'pseudofovea' (PF) (Guez, Le Gargasson & Rigaudiere, 1993). To survey stimuli the previous described location is used more often compared to other areas (Timberlake et al., 1987). "After the PRL is stable, the PRL becomes the new center of the sensorimotor coordinate system" (White & Bedell, 1990).

A schematic of how patients with central vision loss see their environment, and the effect of eccentric fixation, is shown in Fig 1. If a patient with age-related macular degeneration looks directly at an object, the central scotoma covers the object (as seen in Figure 1b); if the patient looks away from the center of the object, the central scotoma falls onto another area (as shown in Figure 1c). The fovea has special capabilities, e.g. the highest spatial resolution and the lowest crowding effect (Strasburger et al., 2011; Strasburger, 2018). Figures 1a-d are shown as blurry, to imitate the indistinct appearance due to crowding occurring with increasing distance from the fovea center (Pelli & Tillman, 2008; Strasburger et al., 2011; Strasburger, 2018).

Losing the ability to read severely restricts the quality of life of patients with macular degeneration and makes them highly dependent on others. Thus, restituting the ability to read is one of the most important goals for these patients (Elliott et al., 1997; Trauzettel-Klosinski, 2009). To be able to find their way back to 'normal' life (i.e., more independence via restored reading ability), two prerequisites have to be met: First, patients must learn to shift their attention and fixation to an intact peripheral location in the central visual field. Second, they need help in low vision rehabilitation and require adjusted magnifying vision aids.

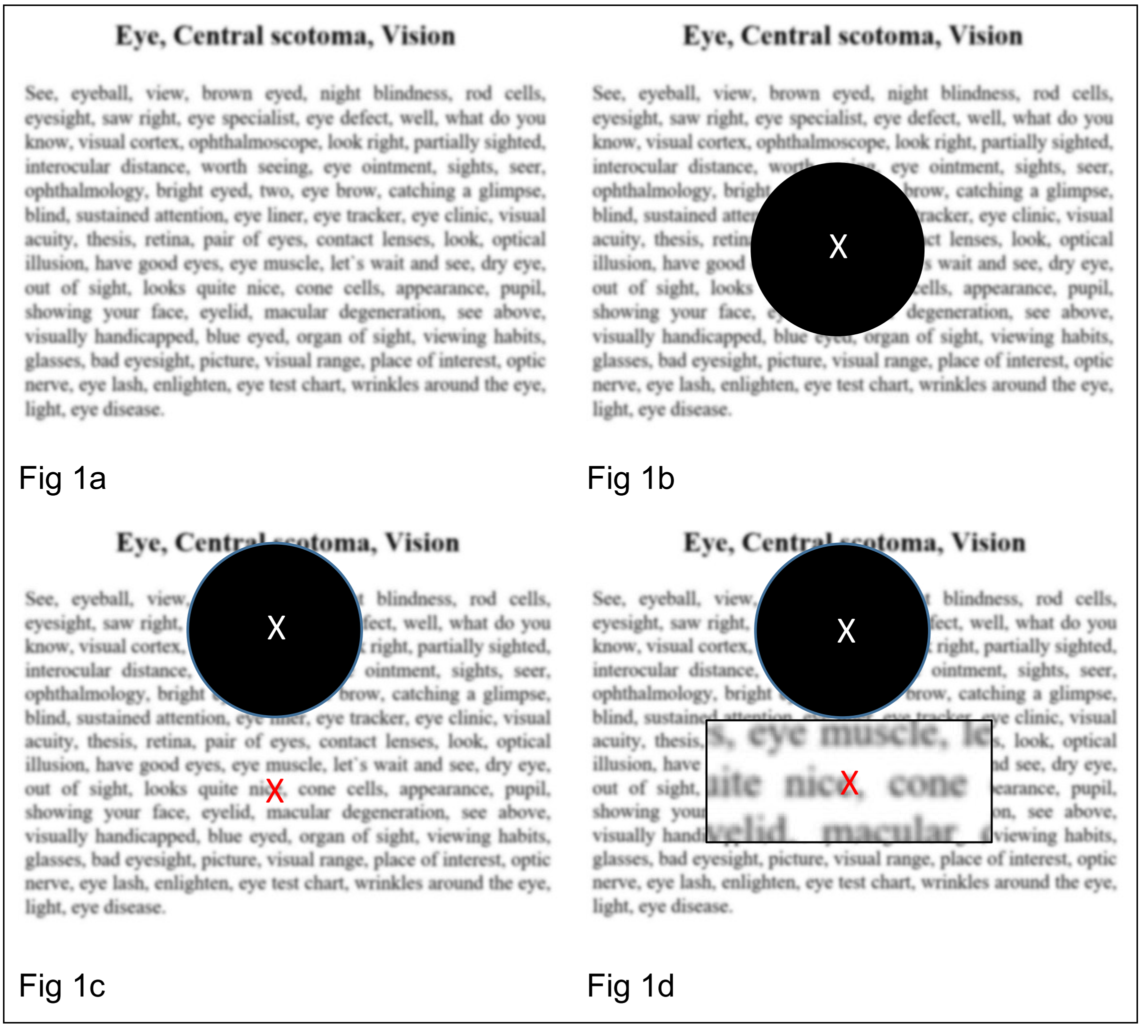


Fig 1a

Fig 1b

Fig 1c

Fig 1d

Fig 1a schematically illustrates how a normally sighted participant sees; Fig 1b shows the view for a patient with a foveal central scotoma (the white cross marks the center of the foveal area); Fig 1c shows the same patient shifting the focus of attention and subsequent point of fixation (red cross), and Fig 1d shows the same patient shifting attention in the same way and using a magnifying tool.
(Modified after: Trauzettel-Klosinski & Tornow, 1996)

1.4. Preferred retinal locus, sustained attention and their interrelation

1.4.1 Preferred retinal locus (PRL)

As described above, patients with macular degeneration and a corresponding loss of foveal vision need to compensate their vision by an intact part of the retina.

They use an eccentric preferred retinal location (PRL) for fixation (Von Noorden & Mackensen, 1962; Timberlake et al., 1987; Trauzettel-Klosinski & Tornow, 1996; Fletcher et al., 1997; Altpeter et al., 2000). The PRL can be a single, or multiple, circumscribed non-foveal loci and develops after central visual loss. Many experiments have been designed to determine where patients with central scotoma develop their PRL, how the fixation stability develops, as well as which reading habits and what kind of cortical adaptation are most beneficial (Nilsson et al., 2003; Crossland et al., 2005; Fine et al., 1999; Fletcher & Schuchard, 1997; Guez et al., 1993; Sunness, 1996; Trauzettel-Klosinski & Tornow, 1996). To date, however, the mechanism for a specific placement of the PRL is not fully understood. In the following paragraph some hypotheses will be discussed.

Localization of the PRL

In addition to good reading ability, mainly three different aspects are necessary for a suitable localization of the PRL (Trauzettel-Klosinski, 2018):

- Resolution:

Patients with macular degeneration might adopt a strategy such that the image falls onto a peripheral location on the retina which still has a sufficient resolution (Trauzettel-Klosinski & Tornow, 1996; Trauzettel-Klosinski, 2018; Baker et al., 2005,2008; Masuda et al., 2008). Cheung & Legge (2005) proposed three hypotheses as to the localization of the PRL. One possibility is a performance-dependency, which proposes that the PRL is more likely to develop at a retinal location that can increase performance of visual attention. For example, normally sighted participants have been reported to have higher attentional resolution in the lower central visual field (He, Cavanagh & Intriligator, 1996). This would suggest that the PRL in macular degeneration patients is also localized more often in the lower central visual field. Most of the patients with macular degeneration developed the PRL to the left or below fixation (Fletcher & Schuchard, 1997; Guez et al., 1993; Sunness, 1996; Trauzettel-Klosinski & Tornow, 1996; White & Bedell, 1990). Normally sighted participants with simulated scotomas had highest reading speed in the lower central visual field (Fine & Rubin, 1999; Petre, Hazel, Fine & Rubin, 2000). In many studies the horizontal meridian (PRL to the left or to the right of fixation) is described as being represented a lot more detailed in the human brain than the vertical meridian (Curcio & Allen, 1990; Galletti, Fattori, Gamberini & Kutz, 1999; Van Essen, Newsome & Maunsell, 1984).

- Sufficient size of the visual field:

The remaining central visual field in patients with macular degeneration needs a sufficient size. This applies also to peripheral parts on the retina which were chosen as a PRL. The minimum reading central visual field is 2° to the left and right of the fixation (Trauzettel-Klosinski, 2018) see Figure 2. Normally sighted participants can reach during one fixation the total ‘perceptual span’ of 1.3-2° to the left and even up to 5° to the right (McConkie & Rayner, 1975).

- Sustained attention and the PRL

Altpeter et al. (2000), described that normally sighted participants and patients with macular degeneration showed similar results in performance of visual attention, and that both groups had a better performance in the lower hemifield. Earlier in this dissertation, different types of visual spatial attention were already mentioned. Now sustained attention and its importance for the present study will be described in more detail. Sustained attention is necessary to actively maintain visual attention at an eccentric area of the central visual field such as the PRL. Based on the results from Altpeter et al. (2000), a sustained attention test (MacKeben) was used in the present study to investigate attentional capabilities of normally sighted participants. In the current study sustained attention was examined in normally sighted participants with a simulated central scotoma. A correspondence between the evaluated sustained attention fields and the subsequently measured placement of the PRL was evaluated (Barraza-Bernal et al., 2017).

Knowledge of the relationship between initial attentional capabilities and a subsequently well-placed PRL could help patients with low vision to regain their ability to read. They could receive, maybe even in advance, an attentional or PRL training to establish an optimal location for their PRL.

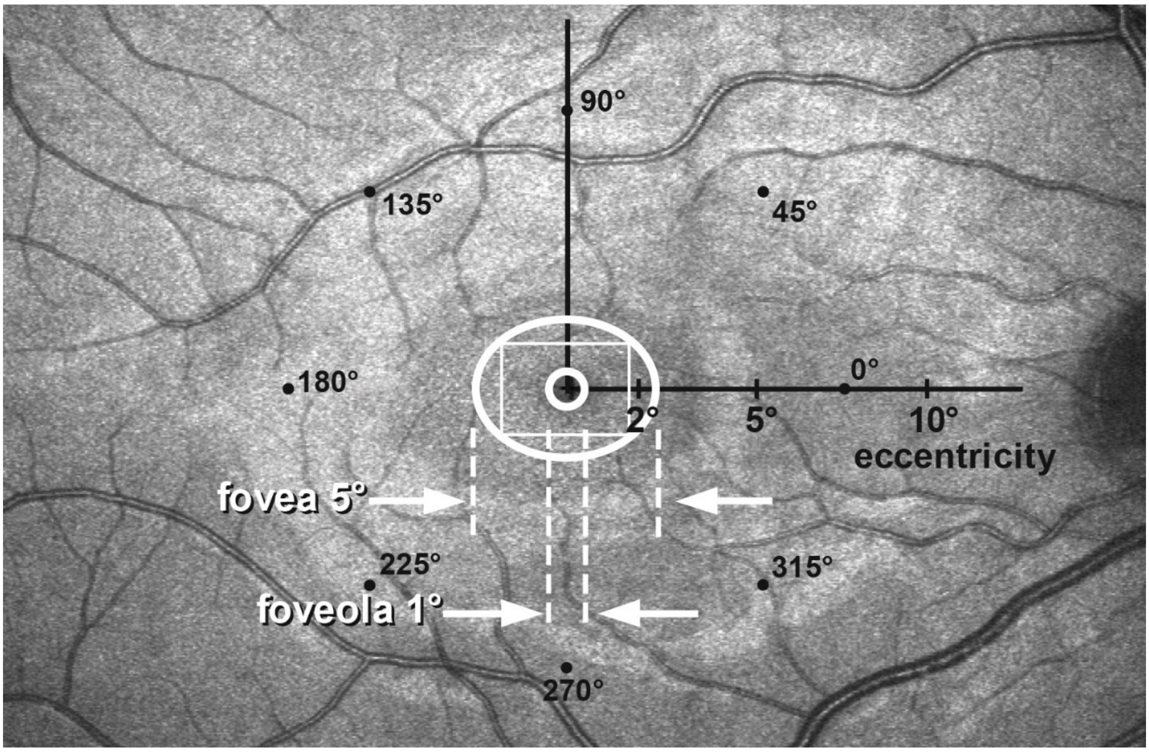


Fig 2: Fundus image. The foveola (1°diameter, inner circle) and the fovea (5° diameter, outer circle) determine the minimum reading central visual field (rectangle). The reading central visual field consists of approximately 2° to the left and right of fixation and 1° above and below fixation. The eight peripheral locations tested in the current study (0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°) are shown at 8° eccentricity.
(Modified figure: Trauzettel-Klosinski, 2010)

1.5. The importance of visual rehabilitation

Preserving daily living tasks, most importantly the ability to read, is often the strongest wish of patients suffering from central vision loss. Maintaining the ability to read for these patients means independence, social interaction, communication, mental agility and quality of life (Trauzettel-Klosinski, 2010; Nguyen et al., 2011; Trauzettel-Klosinski, 2018). A study by Mielke et al. (2013) showed that patients with age-related macular degeneration, who received optimal magnifying aids, had fewer secondary depressions and had higher cognitive and social abilities compared to the control group without visual aids. Therefore, over the last years considerable efforts in visual rehabilitation have been undertaken. Research testing the outcome of providing appropriate optical devices, from simple optical magnifiers to high-magnification video magnifiers, and special training, showed good results. A study by Laubengaier et al. (1997) showed that, before patients with a central scotoma received optimal visual magnifying aids, only 13% had the ability to read a newspaper, whereas after they were provided with the visual aids, 94% of the patients could attain this goal. A study by Nguyen and Trauzettel-Klosinski (2009) reported an improvement of reading speed by 45 words per minute.

Most of the patients have great benefit from visual rehabilitation, especially if the time is taken for individualized counseling, for example, by adapting the appropriate magnifying tool. In the future the high and increasing demand in visual rehabilitation will be a big challenge.

1.6. The aim of the current study

AMD is still the most common cause of severe visual impairment in the Western world, making this topic so important, especially in light of an increasing age in the general population. Over 15 years ago, MacKeben (1999) and Altpeter et al. (2000) did research on applying knowledge on sustained attention on maculopathies. One of the goals was to help patients who developed a central scotoma find their way back to a better quality of life. These, and further studies, found no differences in performance of visual attention between patients with maculopathies and normally sighted participants, suggesting that the same topographic variations in performance of visual attention found in normally sighted participants are valid after acquiring a macular scotoma. For those patients and their participation in daily life, it is important that they can shift attention away from the central scotoma. Pattern recognition outside the central scotoma requires a permanent shift of attention to an intact location on the retina which is only possible by using sustained attention. The study of Altpeter et al. (2000) included normally sighted participants and patients who already suffered from a central scotoma caused by juvenile macular degeneration. The authors investigated whether there would be a position, preferable over others, for shifting the attention to, which could subsequently be suitable as a PRL. They compared results between locations within participants, and results between participants. Results showed that eight out of nine patients with an eccentrically fixating eye and the development of a PRL showed good results in performance of visual attention in a similar position in the other, still healthy, eye.

In the present study we captured and measured eye movements by using an eye tracker. Additionally, we simulated a central scotoma within the same sample of normally sighted participants in a follow up study. Here, the ability to simulate a central scotoma in normally sighted participants, allowed the opportunity to first measure sustained attention and, in a following study, to compare the locations for the placed PRL within the same person. This was set up to investigate the hypotheses of Altpeter and colleagues, that a location of good attentional capabilities can be a candidate for a future PRL-location.

1.6.1 Primary research question

The aim of the study was to evaluate the hypothesis that a locus of high attentional capability can be a candidate for a future PRL, as assumed by the study of Altpeter et al. (2000). Due to the possibility to simulate a central scotoma in normal participants, it was now possible to first examine the attentional field and then evoke eccentric fixation by a simulated scotoma in the same participants.

This dissertation examines the attentional fields of these normal participants and compares the current results with those of the previous, Altpeter et al. (2000) study, with the added possibility of using eye tracking to control fixation stability during stimulus presentation. In a following study, the measured data for the preferred locations for sustained attention were used to investigate the development of the PRL by simulating a central scotoma in the same participants, and reported in a common publication (Barraza-Bernal et al., 2017).

2. Methods

2.1. Equipment

In the current study, objective refraction was measured with the i.profiler (ZEISS International, Germany).

Visual acuity was tested with a standard Snellen chart (OCULUS Optikgeräte GmbH, Germany), with a minimum contrast of 90% under a minimum luminescence of 300 cd/m^2.

The sustained focal attention test was implemented in a MATLAB based computer program, based on MacKeben's (1999) paradigm. The program ran on a MacBook (Apple, USA). The MATLAB based software was written in combination with the PsychToolbox (Brainard, 1997; Pelli, 1997). The VPixx 3D (VPixx Technologies, USA/Canada), at a resolution of 1920x1080 pixels and a refresh rate of 100 Hz, was used to display the stimuli. Eye movements were recorded and monitored using the eye tracker Eyelink 1000 Plus (SR Research, Ltd., Ontario, Canada), in combination with the Eyelink Toolbox (Cornelissen, 2002).

2.2. Participants

Fifteen individuals (nine female and six male) participated in the study and had a visual acuity of at least 1.0. They were all novice except for the author of this dissertation. The participants had to be consenting adult volunteers who did not have any eye diseases. Their age ranged from 20 to 32 years (mean: 24.9 years). The inclusion criteria were 1) males and females between 20 and 35 years old, 2) to be normally sighted and 3) to be informed of the nature of the study and to give their written informed consent.

Exclusion criteria were 1) inability to sit in one position for about 15 minutes, 2) difficulties being in a dark room for 60 minutes, 3) eye diseases and 4) wearing contact lenses or glasses. The study was performed in accordance with the declaration of Helsinki and was approved by the Ethics Committee of the University of Tuebingen (642/2015BO2).

2.3. Study design

This study introduced a new manner to measure sustained attention with the help of a gaze control system. The paradigm of Altpeter et al. (2000) was replicated, as described below. In addition, the gaze was recorded with an eye tracker. If participants failed to fixate on the cross they received an auditory feedback and the trial was repeated.

Each participant had his/her own identification number. The comparison of the identification number and the personal data were stored in separate files.

2.4. Stimuli

The objective refraction and the visual acuity test were measured in an optimally illuminated room. The sustained attention test was performed in a dark room with no distraction (see 2.5.2 and 2.5.3).

2.5. Procedure

The procedure of the study can be seen in detail in the Appendix, Participants Sheet. Here first the dominant eye was determined (see below). Then the objective refraction and the visual acuity were measured. The presentation time and size of the Snellen E from the pretesting were written down. After each test, there was enough space on the sheet for more notes if necessary.

Preliminary testing:

Before the sustained attentional testing started, two preliminary tests were performed, in accordance with Altpeter et al. (2000). The reason for those preliminary tests was to make sure that the differences in the performance of visual attention capabilities where indeed due to the characteristic of sustained attention. The procedure was the same for the two preliminary tests and the following sustained attention test.

In the first test, the optimal size and presentation time of the stimuli for the study (cues and targets, as described below) was determined for each participant.

The starting size of the target was 34 arcmin, while the starting time was 60 ms. Speed increased in steps of 20 ms up to 200 ms. Hereafter, size increased from 34 arcmin to 40 arcmin, beginning with 60 ms again.

This procedure was repeated, until each individual had 75% or more correct responses in at least two of the eight tested locations. The target sizes were always above threshold at the tested eccentricity (MacKeben, 2009; Westheimer, 1982; Weymouth, 1958; Strasburger et al., 2011).

In the second test, the participants had to discover the stimulus, at the predetermined size, in all eight positions, shown for 1 s, to make sure that they could see in all directions and no spatial resolution would limit their performance. After all responses were correct, the preliminary testing was finished and the sustained attention test could begin.

Sustained visual attention test:

The sustained visual attention test was performed in the same way as in the study of Altpeter et al. (2000). Participants had to keep fixation on the central cross in the middle of the screen. A white circle of 18 degrees visual angle surrounded the visual area, in which all cues and targets would appear. Then, a red square appeared as a cue at an eccentricity of 8° for one second, indicating the location at which the target was to be presented. The size of the shown red square was either 34 arcmin or 40 arcmin, depending on the results of the preliminary tests. The locations tested were placed at 8° eccentricity along different meridians, in 45° increments from 0° to 315°. Showing the participants a red cue led to activate the sustained visual attention and therefore enabled the participants to reach higher performance results (MacKeben, 1999). Participants had to maintain fixation at the cross in the middle of the screen and While shifting their attention to the marked location the participants had to fixate the cross in the middle of the screen. At the cued location, the target appeared after an incidental time of 2.5 to 4 seconds. The targets used were Snellen E's in four orientations, opening either to the right, left, upward, or downward (see Fig 3). The size of the Snellen E was 34 arcmin for 13 participants and 40 arcmin for 2 participants, and the target presentation time ranged from 80 ms to 160 ms, depending on the results of the preliminary testing. While the Snellen E was presented, seven distractors were shown at all other locations. Finally, to avoid afterimage effects, at each of the eight locations masks were shown for 100ms (Altpeter et al., 2000). The participants had to report in which of the four possible directions the Snellen E was open, by using the arrow keys. The trials continued until the target was presented 12 times at each location (in total at least 96 trials). During the trials, the eye tracker monitored the eye movements. If the participant failed to keep fixation on the central cross, the trial was canceled and repeated again after the whole trial was completed. The sequence of events for one trial is shown in Fig 5 (see chapter 2.5.4 below).

			
Fig 3a	Fig 3b	Fig 3c	Fig 3d

Fig 3 shows the four different targets, so called Snellen E, used in the tests. In Fig 3a the E opens to the right, 3b opens downward, 3c opens upward, and 3d opens to the left.

2.5.1 Determination of the dominant eye

The dominant eye was determined using a pinhole test. The participants had to look through the hole without holding or touching it. The eye they spontaneously chose to look through was taken as their dominant eye. The other one was the follow-eye.

2.5.2 Objective refraction

The objective refraction was measured with the i.profiler (ZEISS International, Germany). Participants with a spherical ametropia higher than ±0.75 diopters, or with an astigmatism higher than -0.50 diopters could not participate in the study.

2.5.3 Visual acuity test

Visual acuity was tested with a standardized Snellen chart. The participants were seated five meters away from the wall where the Snellen chart hung. They had first to cover their left eye and read the lines from the top to the bottom and from the left to the right; then they covered their right eye, reading again from the top to the bottom but from right to left to minimize a memory effect. Finally they read with both eyes from top to bottom and from the left to the right. The participants had to fulfill at least a visual acuity better or equal to 0.0 logMAR.

2.5.4 Study set-up

Set-up for the preliminary testing and the sustained attention test.

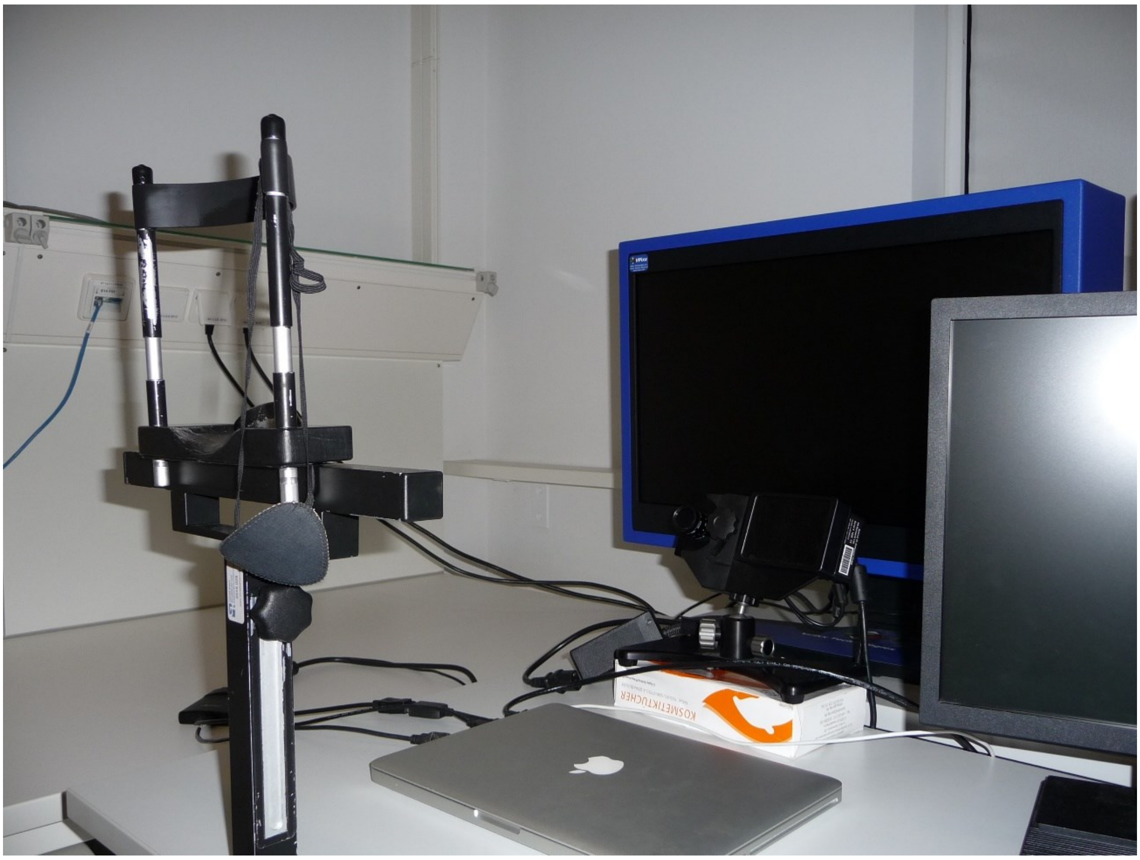


Fig 4: Setup for the pretesting and final testing
On the left side is the chin and forehead rest and the eye-patch. In a distance of 66.6 cm, the VPixx 3D monitor was installed. The pretesting and testing programs were presented on the monitor with the blue frame. The sustained focal attention task ran on the MacBook. The eye tracker Eyelink 1000 plus was installed in between the blue framed monitor and the MacBook. The monitor on the right was used to check on the correct calibration of the eye.

The participant's head was stabilized using a chin and forehead rest, 66.6 cm away from the monitor.

A demonstration of the program was presented to make sure that all the participants understood their task. After that, the non-dominant eye was covered. For the pretesting the participants had to fixate a cross in the middle of the monitor with their dominant eye. The calibration for the Eyelink was done on a separate monitor. After the pretesting, the real test began. The eye tracker was first recalibrated. Then the participant had to fixate the black central cross. The red square appeared. Next, the Snellen E target was presented. The participants had to report the opening of the Snellen E by pressing the correct button on the keyboard. The kind of response is a difference to the procedure described by Altpeter et al., (2000), in which the participants gave a verbal response.

The procedure represents a four-alternative forced-choice task, because participants did not have the option of not pressing any button when they were not sure of seeing the Snellen E correctly. Chance level is thus 25%. The sequence of events in a trial is shown in Fig 5.

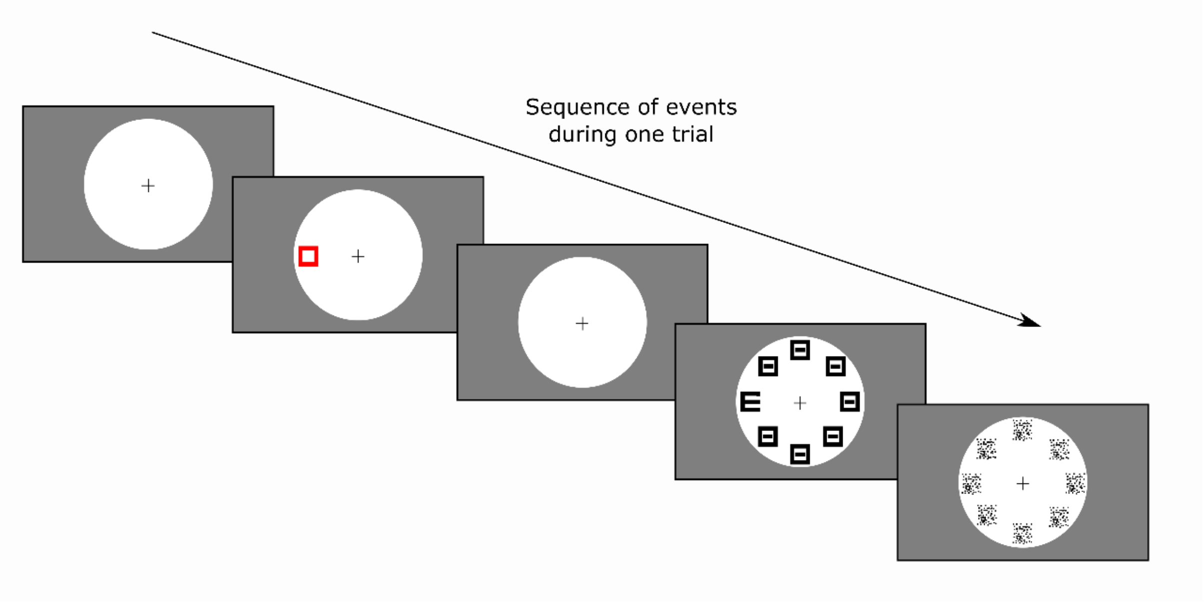


Fig 5: Sequence of events during one trial. All stimuli were presented in a distance of 8° eccentricity.

1. *Participants had to fixate a cross in the middle of the monitor.*
2. *A red square appeared in one of the eight possible positions for 1 second.*
3. *The red square disappeared.*
4. *A Snellen E was presented at the cued location and seven distractors in the other positions for the previous measured duration time of each participant between 80 to 160 ms.*
5. *Finally, masks were shown in all eight positions for 100 ms. Then the participant had to report the opening of the Snellen E by pressing the arrow keys.*

(Modified figure: Barraza-Bernal et al., 2017)

During the trial, eye movements were monitored to ensure that participants kept fixation on the central cross. If the participants did not fixate properly on the monitor, an auditory feedback was given and the trial had to be repeated. In total, the stimulus was shown 12 times at each location. The positions were tested at 8° eccentricity and eight orientations: 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°, giving a total of 96 trials per participant. At the end of the measurement, the program gave the sustained focal attention topography; an example is shown in Fig 6 below.

2.6. Data analysis

The percentage of correct responses was calculated for each location.
A t-test for independent samples was used to compare the results of the correct responses in all eight directions for all participants individually. Then Fisher's exact test was used to quantify whether there is a contingency (i.e., an association) over all positions in correct and incorrect answers. Ratio 1 corresponds to the ratio of correct responses across the horizontal meridian, i.e., the ratio of the percentage of correct response at the 90° and the 270° orientation. Ratio 2 corresponds to the ratio of correct responses in the three upper positions divided by the three lower positions. Ratio 3 corresponds to the ratio of correct responses across the horizontal meridian, i.e., to the ratio between the percentage of correct response at the 0° and the 180° orientation. Ratio 4 corresponds to the ratio of correct responses in the three positions on the left over the three positions on the right. The ratios are thus

$$\text{Ratio 1} = \left(\frac{per(90)}{per(270)}\right) = \text{r1}$$

$$\text{Ratio 2} = \left(\frac{per(45)+per(90)+per(135)}{per(225)+per(270)+per(315)}\right) = \text{r2}$$

$$\text{Ratio 3} = \left(\frac{per(0)}{per(180)}\right) = \text{r3}$$

$$\text{Ratio 4} = \left(\frac{per(0)+per(45)+per(315)}{per(135)+per(180)+per(225)}\right) = \text{r4}$$

where *"per(φ)"* denotes percent-correct at the respective orientation.

Participants were divided into three groups; Participant Group (PG) one until three according to their relative performance in the upper vs. lower central visual fields. The groups were defined as follows: PG 1: better performance in the sustained attention test in the lower compared to the upper central visual field, PG 2: , better performance in the upper compared to the lower central visual field and PG 3: similar results in the upper and lower central visual field. The group separation was done on the basis of the ratio r1, resulting from the performance levels at the 90° and the 270° locations. For comparability to previously reported results, this group separation method was performed using the methods of Altpeter et al. (2000).

PG_one: $r1 < 0.95$ lower performance in the lower visual field.
PG_two: $r1 > 1.05$ lower performance in the upper visual field.
PG_three: $1.05 \geq r1 \geq 0.95$ comparable performance in the upper and lower visual fields.

Further, the ratio r2 was used to compare the upper three with the lower three locations. Again, three groups were defined:

PG_one*: $r2 < 0.95$ lower performance in the upper visual field.
PG_two*: $r2 > 1.05$ lower performance in the lower visual field.
PG_three*: $1.05 \geq r2 \geq 0.95$ comparable performance in the upper and lower visual fields.

For r1, PG_one/ two/ three and for r2, PG_one*/ two*/ three* were built to allow for a better graphical representation of the results, shown in Figures 8 and 9. Polar diagrams were further plotted from these results for each of the groups, PG_one/ two/ three and PG_one*/ two*/ three*, and compared with the polar diagrams for each individual out of these groups.

For a closer look at the data of r1 and r2, a further ratio, r5, was defined. For calculating r5, four locations were used for r1, on the respective two oblique meridians above and below the horizontal meridian that were not considered in r1. It was of interest to see whether results would differ if the two locations 90° and 270° were left out of the calculation:

$$\mathrm{r5} = \left(\frac{per(45)+per(135)}{per(225)+per(270)} \right)$$

For the statistical analysis of the data, the software package SPSS 22 FP 2 was used under MacOS 10.11. In addition, graphical representations were created in Excel 2016.

3. Results

3.1. Comparisons between locations of good performance of visual attention within participants

The main goal was to investigate whether there is a difference among all participants in the eight tested locations (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) at 8° eccentricity.

3.1.1 Statistical evaluation

To start with the interpretation of the results, a null hypothesis was formulated. As in Altpeter et al.'s work (2000), the null hypothesis proposed that only by chance could all participants see at all eight positions with no restrictions. With 100% correct responses in all eight directions, the polar diagrams would look like regular octagons (see the 100% line in the polar diagram in Fig 6).

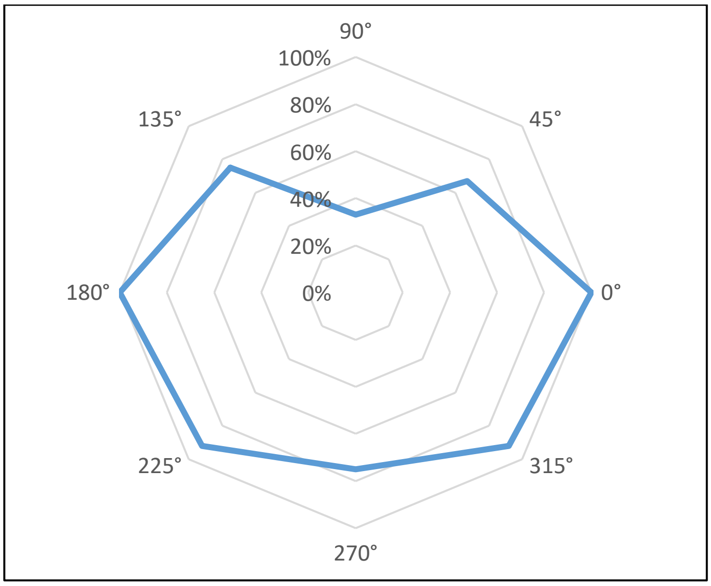


Fig 6: Example polar diagram (Participant 2)

The outer octagon represents 100% correct responses at all eight locations (0° - 315°) throughout the twelve trials. Each smaller octagon represents 20% less recognition performance, with 0% recognition in the middle. As an example, results from one participant are shown as a polar diagram. The blue line connects neighboring blue dots of correct answers. Each attentional field is specific for one participant (See Fig 7 for a polar diagram for each participant).

Table 1: Data collected from 15 participants

Participant No.	Sex	Age	Dominant Eye	Visual Acuity(in dominant eye)	Target		Test results (% correct) & standard error	% correct	%correct	% correct	% correct	% correct	% correct	% correct
					Size (arcmin)	Duration (ms)	0°	45°	90°	135°	180°	225°	270°	315°
1	M	27	OD	1.25	34	100	100	58±14.2	58±14.2	67±13.6	92±0.8	67±13.6	75±12.5	83±10.8
2	F	30	OD	1.25	34	140	100	67±13.6	33±13.6	75±12.5	100	92±0.8	75±12.5	92±0.8
3	F	24	OD	1.0	34	160	100	92±0.8	50±14.4	83±10.8	100	83±10.8	67±13.6	83±10.8
4	M	28	OD	1.0	34	120	75±12.5	67±13.6	42±14.2	67±13.6	75±12.5	83±10.8	75±12.5	58±14.2
5	F	20	OD	1.25	34	120	83±10.8	67±13.6	42±14.2	67±13.6	75±12.5	58±14.2	58±14.2	33±13.6
6	M	20	OD	1.0	34	140	92±0.8	100	67±13.6	83±10.8	67±13.6	83±10.8	83±10.8	58±14.2
7	F	32	OD	1.0	40	140	92±0.8	92±0.8	92±0.8	67±13.6	92±0.8	83±10.8	58±14.2	83±10.8
8	F	23	OD	1.25	40	120	100	67±13.6	17±3.73	58±14.2	100	83±10.8	75±12.5	100
9	M	23	OS	1.25	34	160	100	100	75±12.5	92±0.8	92±0.8	58±14.2	75±12.5	100
10	M	22	OS	1.0	34	80	83±10.8	67±13.6	50±14.4	58±14.2	75±12.5	58±14.2	67±13.6	67±13.6
11	F	29	OS	1.0	34	120	83±10.8	100	42±14.2	75±12.5	75±12.5	75±12.5	67±13.6	92±0.8
12	F	24	OD	1.25	34	140	100	100	58±14.2	75±12.5	92±0.8	75±12.5	83±10.8	100
13	F	25	OD	1.25	34	140	83±10.8	83±10.8	83±10.8	75±12.5	67±13.6	50±14.4	42±14.2	83±10.8
14	M	25	OD	1.0	34	140	100	83±10.8	75±12.5	83±10.8	92±0.8	92±0.8	67±13.6	75±12.5
15	F	22	OS	1.0	34	140	100	75±12.5	67±13.6	92±0.8	100	67±13.6	92±0.8	100

Table 1: From left to right: Participant number, sex, age, dominant eye (OD = oculus dexter, right eye; OS = oculus sinister, left eye), visual acuity (1.0 = 6/6), target: Snellen E target height (in arcmin); target duration (in ms), test results: for all eight positions the percentage of correct responses and corresponding standard errors

To verify the null hypothesis that only by chance all participants could recognize the target orientation at all eight positions, with no restrictions (100% correct responses), a one-sample, one-tailed t-test was used, separately for each participant and for each position, comparing the percentage of correct responses to the expected value of 100%. The level of significance was chosen at 5%. With a p-value of $p < 0.05$ a difference between the expected and the observed results was considered significant. Table 1 shows the percentages of correct responses and the corresponding standard errors, for each participant and position. Within the fifteen participants, two to eight positions deviated significantly from 100% correct responses (mean: 4.27; S.E.: 1.73).
In addition, the null hypothesis of the two-tailed Fisher exact test assumes that all participants have an octagonal attentional field looking like an octagon. We received for each participant one p-value, calculating it out of all results out of all eight locations. The null hypothesis could be rejected for eight out of fifteen participants (p-values between 0.000 and 0.550 see Table 2).

Participant No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
p value	0.122	0.000	0.019	0.550	0.108	0.172	0.292	0.000	0.012	0.031	0.046	0.018	0.166	0.451	0.019

Table 2: Results of Fisher's exact test for deviation from perfect performance. Top row: participant number, bottom row: participants' corresponding p-values.

3.1.2 Polar diagrams

All results are shown graphically in Fig 7, as polar diagrams. The percentage of correct answers is shown as length of the vectors on each meridian (as a reminder, the octagons show the achieved percentage). The outer ring represents 100% correct answers and each smaller ring shows 20% lower performance until 0% recognition. The ends of neighboring vectors are connected to form an area that is referred to as the "attentional field" (Altpeter et al., 2000).

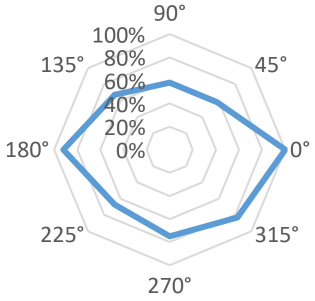
The “attentional field” quantifies the results and allows a graphical comparison of different locations for each participant.

The polar diagrams thus allow an overview of the results for each participant. Participants have preferred locations to which they can better shift sustained attention. Looking at the attentional fields, it seems that most of the participants are more successful at shifting their attention to the lower part than shifting their attention to the upper part of the pericentral visual field.

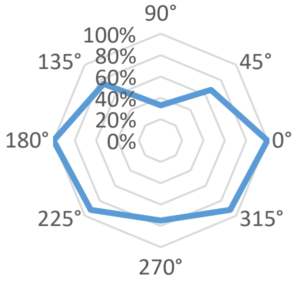
3.1.3 Polar diagrams of all fifteen participants

For a better graphical overview, in this section all polar diagrams are shown for comparison with each other.

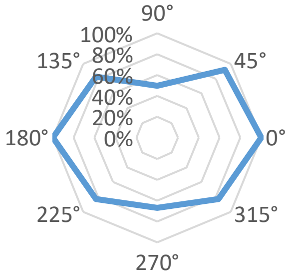
Participant 1



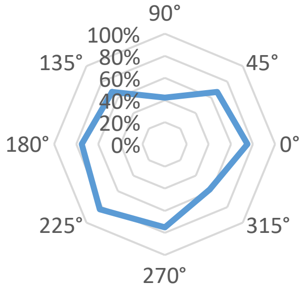
Participant 2



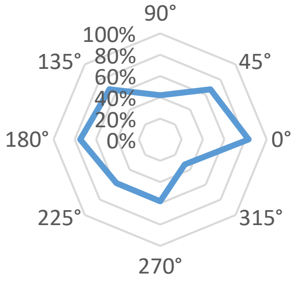
Participant 3



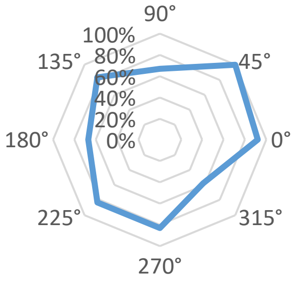
Participant 4

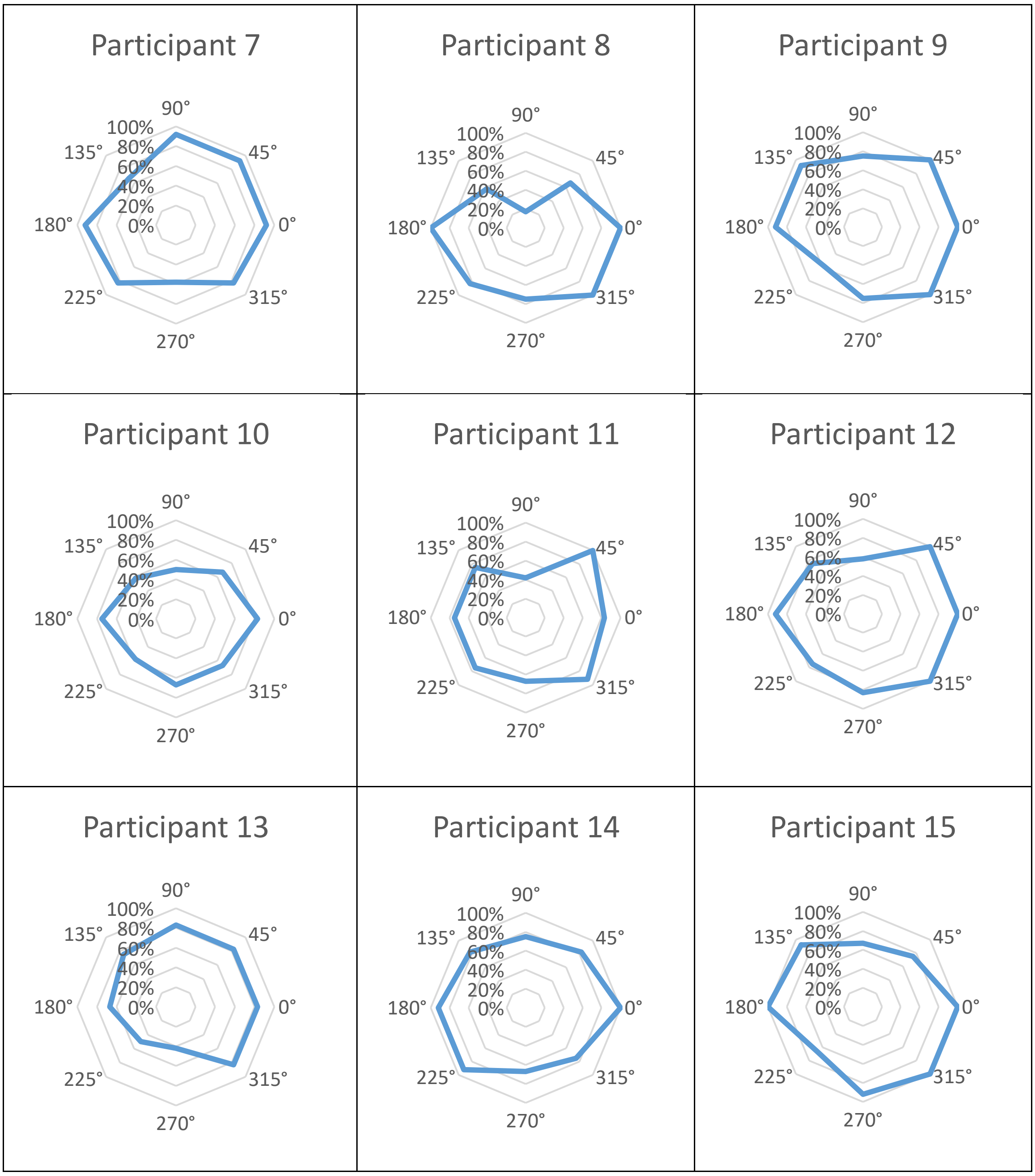


Participant 5



Participant 6





Participant 7

Participant 8

Participant 9

Participant 10

Participant 11

Participant 12

Participant 13

Participant 14

Participant 15

Fig 7: Polar diagrams for the attentional fields of the fifteen participants

The percentage of correct responses is shown in all eight directions (0° – 315°) at 8° eccentricity. Each participant has an own individual attention field within the blue line. The gray lines and the numbers 0% – 100% stand for the percentage of correct answers.

3.1.4 Ranking of discrete angular positions

To make results comparable over all participants, we assigned rankings to the tested positions. Thus, we could see which locations had higher performance results than others. Rankings were assigned from Rank 1 (best) to Rank 8 (poorest) based on the average percent of correct responses across all participants for each position. Fractional over ordinal ranking was chosen to assign equal ranking to locations with equal measurement results. For example, when two positions had the same percentage of correct answers, both would receive the middle out of the two ranking positions; e.g. if 2 positions had the second rank, they then each received a ranking of 2.5.

Fig 8 shows the ranking per location (i.e., orientation in degrees). It can be seen that the location at 90° (i.e. on the upper vertical meridian) has the poorest overall rating (i.e., highest rank). Positions at 0° and 180° are the best overall tested positions, indicating that the best attentional capability is mainly found on the horizontal meridian. Along the vertical meridian, the comparison of the positions at 90° and 270° indicates a higher percentage of correct responses in the lower than in the upper central visual field.

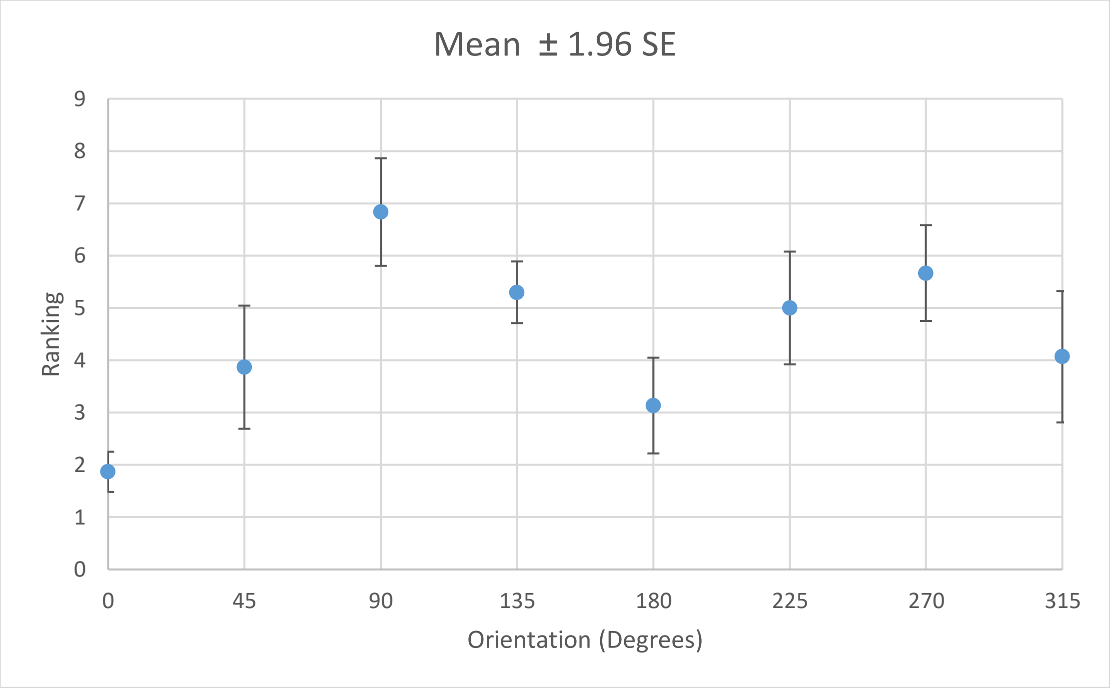


Fig 8: The diagram shows the ranking per tested orientation, averaged over all fifteen participants. On the x axis are the orientations of the meridians for all eight locations, from 0° to 315°. On the y axis are the ranking positions, where Rank 1 indicates the best response and Rank 8 the poorest result. Positions 0° and 180° have very good results for shifting attention to these locations, whereas 90° shows the poorest performance. In this figure, it can be seen that the dots on the left are rising higher than on the right, showing that attentional capabilities in the lower central visual field (180° to 315°, right half of figure) are better than in the upper field (0° to 135°, left half of figure).

3.1.5 Comparing opposing directions

In Fig 9 the horizontal and the vertical meridians were compared as follows:

Ratio 1: ratio per(90) over per(270), (upper vs. lower)

Ratio 3: ratio per(0) over per(180) (right vs. left)

Ratio 2: ratio ((per(45)+per(90)+per(135) / (per(225)+per(270)+per(315)), (upper vs. lower)

Ratio 4: ratio ((per(0)+per(45)+per(315) / (per(135)+per(180)+per(225)) (right vs. left).

Ratios 2, 3 and 4 (r2; r3; r4) show an almost equal result with a ratio close to one (i.e., no performance difference). Ratio 2 has a mean of m = 0.95. Ratio 3 has a mean of m = 1.06 and Ratio 4 a mean of m = 1.07. Thus, there is no relevant difference on the horizontal meridian nor over the entire upper vs. entire lower visual field. However, Ratio 1 has a mean of m = 0.75. Here it can be said that there is a difference in the central visual field. The participants had better attentional capabilities on the lower vertical meridian.

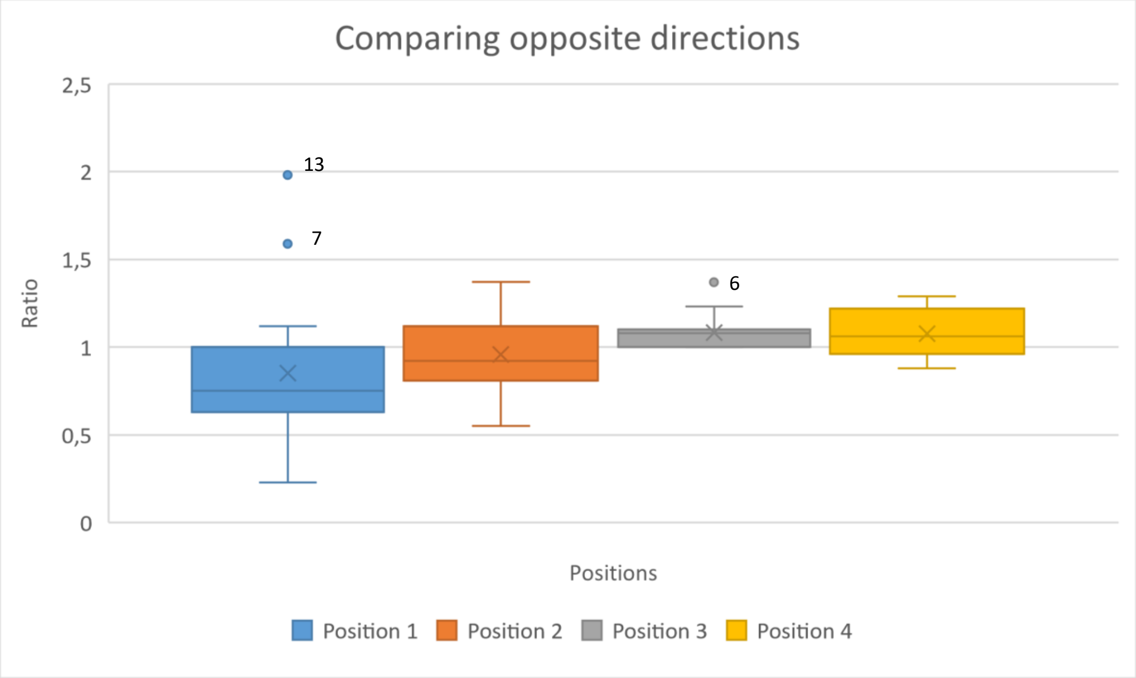


Fig 9: Comparing opposing locations and opposing quarters.
Position 1 is the ratio 90° over 270° (r1) with two outliers (participants 7 and 13). The mean of the box is m = 0.75 (represented with a cross) Position 2 is the upper quarter divided by the lower one,r2 = ((per(45)+per(90)+per(135) / (per(225)+per(270)+per(315)) with m = 0.95. Position 3 is 0° over 180° (r3) on the horizontal meridian, i.e. right vs. left, with m = 1.06 with one outlier (participant 6). Position 4 is the right field divided by the left field, r4 = ((per(0)+per(45)+per(315) / ((per(135)+per(180)+per(225)) with a mean of m = 1.07. On the y axis is the mean ratio for each position across all participants.

3.2. Comparisons between participants

3.2.1 Dividing the participants into groups

Most of the participants had a reduced performance at either one or both locations on the vertical meridian. Ratio r1 was calculated as the ratio of the

percentage of correct responses in the 90° location divided by that in the 270° location. The results allowed three groups to be defined: participants with at least a 5% reduced performance in the upper hemifield, with a reduced performance in the lower hemifield, and with similar performance in both the upper and lower hemifield. By these criteria, eleven out of the fifteen participants were in the first group, with a better performance in the lower central visual field (Participant Group one (PG_one) with a mean r1 ratio of 0.64 ± 0.17. Three participants were in the second group (PG_two) with a better performance in the upper central visual field, and a mean r1 ratio of 1.56 ± 0.43. The third group (PG_three) comprised only one out of the fifteen participants who showed similar performance in both vertical locations (90° and 270°), with an r1 ratio of 1.00. In Fig 10 the results of the r1 ratio are shown for each participant. The two lines separate the participants into three groups. Eleven participants underneath the 0.95 line on the y axis composed PG_one. Three participants above 1.05 composed PG_two. The one participant with a value in between the lines 0.95 and 1.05 was the only member in PG_three.
The three polar diagrams (see Fig 10) represent the mean performance of the three groups PG_one, PG_two, and PG_three, respectively.

The grand mean over all fifteen participants for r1 is
m (90° / 270°) = 0.85 ± 0.44 (SD).
In sum, the results show that most participants have much better performance in the lower central visual field at the vertical meridian than in the upper central visual field.

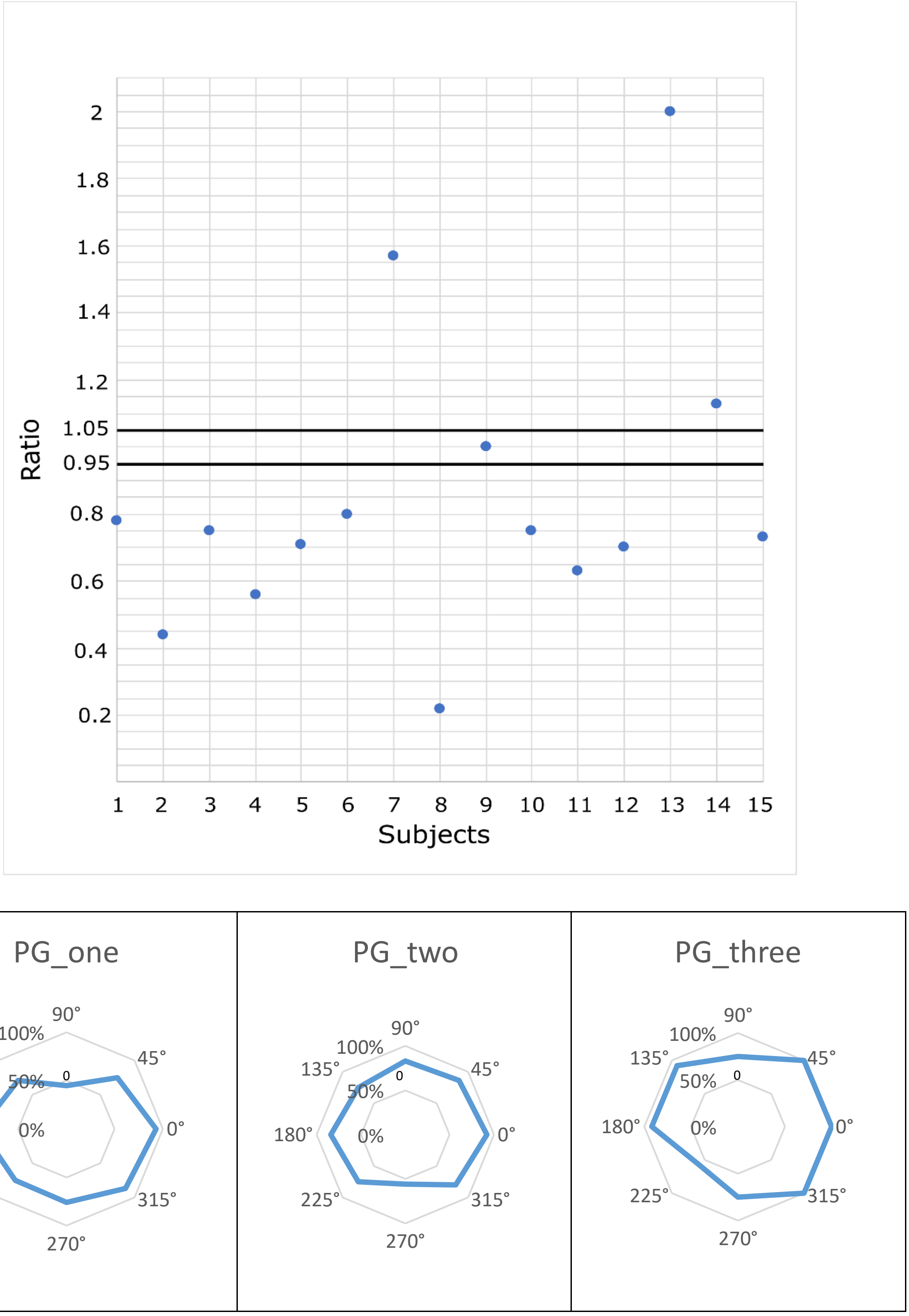


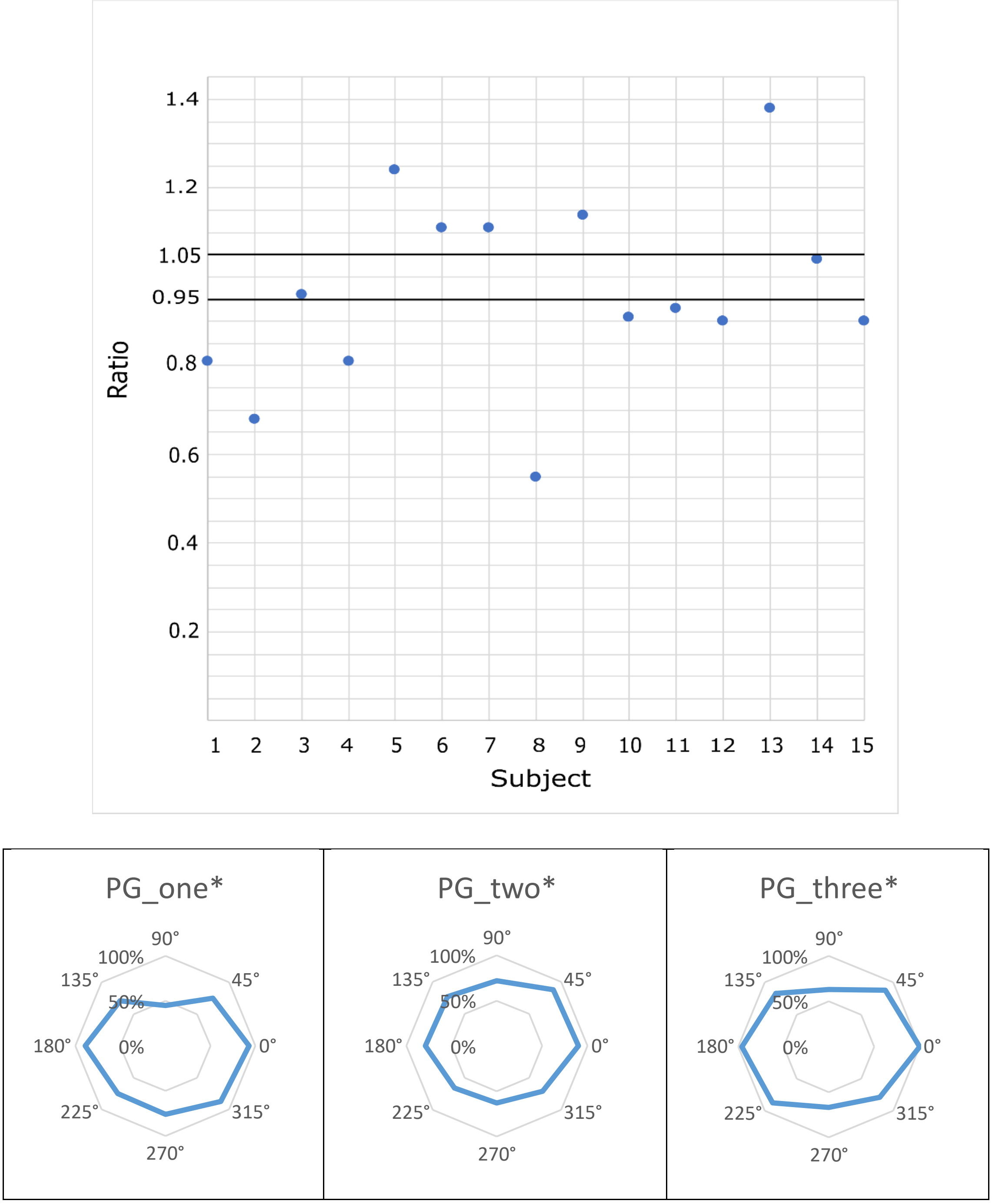
Fig 10: Dividing the participants into groups.
The diagram on top shows the ratio r1 between 90° and 270° for the percentage of correct responses for each participant. The two lines are drawn at a 5% deviation above and below a ratio of 1 and separate the participants into three groups.

Below are three polar diagrams, showing the mean percentage of correct responses in all eight locations (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) for the three groups. PG_one (n = 11), PG_two (n = 3), PG_three (n = 1). The blue line is formed of the percentage of correct responses for the eight possible directions building the attentional field.

Ratio r2 was calculated to further specify the results for r1. Ratio r2 is the performance ratio of the upper three and lower three locations. Again, the participants were divided into three groups. The first participant group (PG_one*), with a better performance in the lower central visual field, comprised eight participants, with a mean ratio r2 of 0.81± 0.13. The second group (PG_two*), with a reduced performance in the lower field, consisted of five participants and a mean ratio r2 of 1.18 ± 0.11. Finally, the third group (PG_three*) contained two participants (90° and 270°) and a ratio r2 of 0.99 ± 0.04. In Fig 11, the results of the upper quarter (per(45)+per(90)+per(135)) over the lower quarter (per(225)+per(270)+per(315)) for each participant are shown. The two lines separate the participants into the three groups. The eight participants below the 0.95-ratio line on the y axis comprise PG_one*. The five participants above 1.05 are PG_two*. The two participants in between the lines 0.95 and 1.05 are PG_three*. A 5% deviation was used in each direction to build the three different groups.

The three polar diagrams in the lower part of Fig. 11 represent the group means for the three participant groups, PG_one*, PG_two*, PG_three*, respectively.

The mean over all fifteen participants for the ratio r2 is m = 0.96 ± 0.2 (SD). While this is below 1, it is very close, indicating no relevant preference for the upper compared to the lower quarter, or vice versa, across all participants when considering a larger part of the visual hemifields.



In Fig 11: Dividing the participants into groups by the upper and lower hemifield (r2).
The data are comparable to Fig 10. The diagram shows participants on the x axis. On the y axis is the performance ratio of the upper (per(45)+per(90)+per(135)) over the lower (per(225)+per(270)+per(315)) quarter. The two lines show a 5% deviation above and below a ratio of 1. The polar diagrams show the group mean percentage of correct responses at all

eight locations. PG_one (n = 8), PG_two* (n = 5), and PG_three* (n = 2). The blue line encircles the attentional field.*

While a better performance is clearly seen for 270° compared to 90° in Fig. 8, this is not confirmed with the larger area underlying the ratio r2. Ratio r2 is very neutral, showing a nearly balanced proportion between the upper and lower field. To explore why that is the case, the four oblique angles not considered in *r1* (positions 45°, 135°, 225° and 315°) were explored by the ratio r5. The mean over all fifteen participants for that ratio is m = 1.03 ± 0.22. This is slightly better in the upper than in the lower hemifield, in the opposite direction of the r1 proportion. Thus, on the vertical meridian there is a strongly reduced performance in the upper central visual field, but moving further on the horizontal meridian to the sides, the differences vanish with even an inversion in the proportion from below to above 1.

3.2.2 Comparing horizontal versus vertical meridian

Furthermore, the vertical (v = 90° & 270°) and the horizontal (h = 0° & 180°) meridian were compared. The ratio *(h/v)* was used, where *h* corresponds to the mean percentage of correct responses on the horizontal meridian and *v* to that on the vertical meridian. The mean ratio was *h/v* = 1.44 ± 0.28 which suggests that the participants had much better performance of visual attention on the horizontal than on the vertical meridian.

3.3. Pretesting results

Out of the fifteen participants, eleven had a right-dominant eye and four a left-dominant eye. Refractive error and astigmatism were assessed with a ZEISS i.profiler. All fifteen participants had a refractive power on their dominant eye between -1D and +1D for the sphere. For results see Table 3.

3.3.1 Objective refraction and visual acuity

Results from the objective refraction – sphere, cylinder, axis, and visual acuity – are shown in Table 3 for each participant. In the visual acuity test, all participants had an acuity of at least 1.0 on their dominant eye. The pretesting results were important to ascertain that only normally sighted participants would participate in the study.

Participant No	Dominant Eye	Sphere (Diopters)	Cylinder (Diopters)	Axis (Degrees)	Visual acuity (dominant eye)
1	OD	- 0.07	- 0.03	119	1.25
2	OD	- 0.06	- 0.58	160	1.25
3	OD	+ 0.32	- 0.14	131	1.0
4	OD	+ 0.43	- 0.23	3	1.0
5	OD	+ 0.15	- 0.3	146	1.25
6	OD	- 0.69	- 0.81	103	1.0
7	OD	- 0.94	- 0.44	92	1.0
8	OD	- 0.69	- 0.27	115	1.25
9	OS	+ 0.92	- 0.5	13	1.25
10	OS	- 0.09	- 0.99	3	1.0
11	OS	- 0.55	- 0.63	12	1.0
12	OD	- 0.39	- 0.34	162	1.25
13	OD	+ 0.39	- 0.53	104	1.0
14	OD	+ 0.80	- 0.25	167	1.25
15	OS	- 0.79	- 0.29	161	1.0

Table 3: Objective refraction. Participant, dominant eye and results from the objective refraction for each participant on their dominant eye. (OD: oculus dexter, right eye, OS = oculus sinister, left eye).

3.3.2 Pretest for target duration, size determination and spatial resolution

Two different types of pretests were performed (see also 2.5.4). First, a suitable presentation duration and size for the Snellen E targets was determined per participant. Second, it was checked that no spatial resolution limited the participants' performance. After that, it was ensured that all participants could see in all directions and have 100% correct responses. The results for the duration and size of the Snellen E are shown in Table 1 above. According to those results for the sustained attention measurement, the Snellen E size was set to 34 arcmin for thirteen participants, while two participants needed a slightly larger size of 40 arcmin (see 2.5.4). The mean presentation time evaluated in the preliminary testing required over all participants was 130.7 ± 20.5 ms (SD).

4. Discussion

4.1. Sustained attention and the development of the preferred retinal locus (PRL)

One of the earliest descriptions of patients with a central vision loss adopting a peripheral preferred retinal locus (PRL) was in 1922 by Fuchs. Since then, many studies have been conducted because age-related macular degeneration (AMD) is such an important topic and will become even more important with an aging population, especially among Caucasians. Therefore, the identification of an optimal PRL will also become increasingly important. Cheung & Legge (2005) postulated three different ideas to answer the main question of what helps to install an optimal PRL a) a function-driven, b) a performance-driven, or c) a retinotopy-driven explanation. The function-driven hypothesis argues that a PRL in the lower field would help the patients most in their daily business and orientation and has the greatest visual benefit. The central scotoma would be shifted upward, leaving the functional retina located below as well as to the left and to the right. 87.5% of 51 AMD patients reported they could not read because of their reduced vision (Timberlake et al., 1987; Trauzettel-Klosinski & Tornow, 1996; Trauzettel-Klosinski, 1997; Rovner & Casten, 2002). Giving them the ability to read again would help them tremendously. If the patients develop a PRL to the left of the scotoma they will have difficulties reading text from left to right, because saccades will often end in the area where no vision is remaining. A PRL to the right causes trouble in retracing, i.e. finding the beginning of the next line, as shown in patients with hemianopia (Trauzettel-Klosinski & Brendler, 1998). Similar outcomes were described (Fine & Rubin, 1999 & Petre et al., 2000) for results in reading. An improvement in reading speed was found when the patients used the lower central visual field. These findings argue against the function-driven hypothesis. The performance-driven explanation dependent on the size of the perceptual span supports two different options. The PRL is either located at a peripheral area that has high visual acuity or a good performance in visual attention (Cheung & Legge, 2005). The third explanation is based on the retinotopic hypothesis. In previous studies, patients had better results at the border of the central scotoma. Either perceptual learning or cortical remapping could be the reason for this improved performance. In animal studies, a readjustment of neurons in V1 was found after they were capped. The neurons spontaneously reorganized to signals coming from retinal areas close to the scotoma (Cheung & Legge, 2005).

In the present study, fifteen normally sighted participants were measured with respect to their performance of visual attention at the border of the macular region (8° eccentricity). Eleven out of the fifteen participants had a better performance in the lower vertical meridian (270° position), three a better performance on the upper vertical meridian, and one participant had a similar performance on the upper and lower vertical meridian.

A follow-up study (Barraza-Bernal, M., et al., 2017) compared the performance of visual attention of the three groups of healthy participants and the placement of their PRL with an artificial scotoma, based on the data measured for sustained attention in the present study. 'Barraza-Bernal and colleagues show that, for nine out of thirteen participants, the location of the PRL was close to the measured location for good attentional capabilities shown here (2017).' Altpeter et al. (2000) had suggested that there could be a correspondence between the two chosen locations. The difficulty was that only the centrally fixating eye could be compared with the other, eccentrically fixating, eye in patients with an already adjusted central scotoma (Barraza-Bernal et al., 2017). With the possibility of using an eye-tracker and the simulation of a central scotoma in the cohort of the here presented patients, Barraza-Bernal et al. (2017) were able to determine the evoked PRL and to correlate it to the before assessed attention fields within the same participants.

4.2. Implementation of the study and its results

4.2.1 Comparison to the results of previous studies

As in Altpeter et al., 2000, the participants could be divided into groups. For the biggest group of the participants, eleven out of fifteen, it was difficult to shift the attention into the upper part of the central visual field (PG_one).For another three out of fifteen participants it was difficult to shift the attention into the lower part (PG_two). One out of fifteen participants had trouble to shift attention to the upper or lower part of the central visual field (PG_three). The two cut-offs to differentiate the groups was chosen at 5%. This cut-off resulted in only few participants being included in the third group. In a larger group of participants, it would be possible to widen the range to 8 or 10%. As well as Altpeter et al., 2000; MacKeben (1996; 1999; 2009) referred to similar results in his experiments.

Horizontal - vertical asymmetry (HVA)

The results of the current study demonstrated horizontal and vertical asymmetries in the performance of sustained visual attention. Good attentional capabilities were better represented in the lower central visual field than in the upper central visual field.

Two previous studies corroborate those results.

In Altpeter et al.’s study (2000), 57% of all participants with mostly juvenile maculopathies had a better result in the lower hemifield. In the upper hemifield 16% reached better results, and 27% of all participants had comparable results in the upper and lower hemifield.

A study by MacKeben (1999) with twelve normally sighted participants, in which the sustained component of attention was used with a letter recognition paradigm, reported comparable results. Fifty percent of the participants showed better results in the lower hemifield, 33.3% had a better performance in the upper hemifield, and 16.6% had similar results in the upper and lower hemifield.

In this present study, fifteen normally sighted participants were measured. 73.3% had a better performance in the lower hemifield, 20% in the upper hemifield and 6.7% in both hemifields. One reason that these current results were better than in previous studies could be that we were able to use a new method. By using an eye tracker we were able to control fixation stability during the presentation of the stimuli. This could lead to the conclusion that the results were measured more precisely. In addition, the three upper locations were compared with the three in the lower hemifield. 53.3% showed a better performance in the lower central visual field, 33.3% showed a better performance in the upper central visual field and 13.3% had similar results in both hemifields. In total it can be said that the lower visual hemifield achieved better results in this study than the upper visual hemifield. Yet the reason for the better performance in the lower central visual field is not clarified. The advantage in the lower field could be either explained by visual field constraints or differences in attentional resolution (Kraft et al., 2007).

One other possible explanation could lead to the conclusion that we learned from environmental influence to improve our lower central visual field and pay attention in this area for e.g., walking down a staircase. In contrast, we do not need our upper central visual field so often because naturally no danger awaits us there. For movements, a benefit in the lower visual hemifield has been found. In evolution, tasks that required fine motor skills like things we do with our hands or paws such as eating, working with tools or recognizing objects also require a better integrity of the lower central visual field. Fine colour or contrast determination are also necessary. In addition, it is the region that immediately surrounds our body, making it all the more integral to working with our bodies in our physical environment (Previc, 1990; Dessing et al., 2013).

Previous studies have also found evidence for better horizontal compared to vertical visual performance, similar to our current findings. Carrasco et al. (2001) reported that visual acuity and performance at eccentric locations are better on the horizontal than on the vertical meridian. Not only visual acuity but also the results in the performance of sustained attention showed a superiority on the horizontal meridian (MacKeben, 1999; Altpeter et al., 2000). Fuller et al. (2008) described similar circumstances: “It is known that visual performance is better on the horizontal than the vertical meridian, and in the lower than the upper region of the vertical meridian”.

In contrast sensitivity, there is a smaller decrease in log sensitivity in both eyes on the horizontal compared to the vertical meridian. Further, the contrast sensitivity on the vertical meridian is greater in the lower meridian compared to the upper meridian (Baldwin, Meese & Baker, 2012).

Horizontal and vertical limitations in letter recognition

Above, the main results of the study, i.e., better performances on the horizontal than on the vertical meridian and better performances in the lower than in the upper central visual field, were discussed. Those results are comparable with previous studies. To be able to help patients with their daily activities, the aim is further to see if the results can be integrated in daily routines. For example, reading and the improvement of reading speed of English text has been a topic in several studies over the last years. The speed and correctness for recognizing letters and words is higher when they are adjusted horizontally and not vertically (Husk & Yu, 2017). Letter recognition is limited by three different types of sensory components, a) acuity, b) crowding, and c) mislocation. Acuity declines to peripheral parts of the retina. The spatial resolution for each individual’s retina determines the size of letters that still can be recognized correctly. Crowding, which in contrast to acuity increases with eccentricity, is related to recognizing letters which do not stand on their own. The letters that stand before or after the target letter can impair correct letter recognition. Finally, mislocations, in which the participant does not know the precise position of correctly recognized letters, can additionally limit reading ability. Reading performance decreases again with eccentricity. The three components are all important for correct letter recognition, but crowding seems to be the most important component (Husk & Yu, 2017). According to this, in this study every participant was pretested for the individually required size of the target (Snellen E) at either 34 or 40 arcmin. It was therefore certain that no spatial resolution problems could limit the performance. Because the location the target would appear at was always precued, mislocation was almost impossible. Here it was more important to hold the shifted attention in the correct position. Lastly, the most important factor the crowding was irrelevant in this study because in each trial only one target appeared and had to be analyzed.

For clinical routine, it might help patients with central vision loss to leave extra space between letters in a text.

4.3. Factors possibly influencing the results

4.3.1 The visual pathway and brain interaction and their possible influence on the results

Retinal factors

It might be argued that the results of this study are due to differences in the detection of stimuli rather than recognition. In order to explain why we think differently, it is necessary to describe the distribution of various types of photoreceptor cells across the retina. Vision, one of our most important senses, begins with different classes of photoreceptors. Photoreceptor cells change light into signals. The signals set up from the photoreceptors pass bipolar cells and ganglion cells and can be further used for brain interaction. Finally, we understand what we see and can interact with nature. Three different types of photoreceptor cells exist. Photosensitive retinal ganglion cells, which are not directly necessary for seeing but understood so far as being important for the circadian rhythm and the pupillary reflex (Foster et al., 1991). Rod cells which work best in less intense light, e.g. night vision and Cone cells which are used for color vision, work best in bright light and identifying fine details. There are many more rod cells than cone cells. Most of the cone cells are in the fovea centralis, a 0.35 mm (= 1.25° eccentricity) diameter area, where no rod cells are found. In the current experiment, the measurement was at 8° eccentricity, i.e. in the perifovea and still in the macular region which has an outer radius of around 2.5 mm corresponding to 8.5° eccentricity (Polyak, 1941; cf. Strasburger et al., 2011). Here the proportion of cones to rods is 1:1. In this area, we have the best working conditions because both cell types are available. The different distribution reported by Curcio et al. (1990), i.e. that more cones are found in the superior retina than in the lower hemifield and more on the nasal than on the temporal side is not relevant in this case, because they described the differences for peripheral parts of the retina, beyond 8° eccentricity.

The stimuli used were presented markedly above threshold. So, it is certain that the results measured were due to recognition and not only detection by the participants. Further it is unlikely that the differences in the performance of visual attention capabilities are due to differences in the distribution of the photoreceptor cells (Altpeter et al., 2000).

Attentional fields

The individual attentional fields of our participants reported in Fig 7 show quite a range of different topographies. The recognition performance under sustained attention was never 100% correct at all eight locations. The common feature of all these attentional fields between all participants was a performance dip on the upper vertical meridian.

Choice of participants

In the present study, participants between 20 and 35 years were analyzed. No significant differences were found in the study on sustained attention fields with age (MacKeben, 1990). The twelve participants who took part in the study were aged either between 18 to 34 (m = 23.8 years) or 51 to 58 (m = 54 years).

Working-memory influences on attention

In the present study, the Snellen E was used as a target and distractors were shown at the other seven locations, followed by masks in all eight locations. In previous studies, a working memory effect on identification performance was found (Cosman & Vecera, 2011; Han, 2015). External noise created by distractors and masks, can be reduced by shifting attention, thereby increasing accuracy and sensitivity to the attended target (Dosher & Lu, 2000; Shiu & Pashler, 1994). Pan et al. (2016) suggested that "working-memory driven attention enhances the target signal at early perceptual stages of visual processing".

Because our brain has a processing capacity limit, sensory inputs are filtered by selective attention. Thus, selective attention plays a highly important role on information processing. Desimone & Duncan (1995) assumed that working memory ‘decides’ on which stimulus attention should be assigned. Already known stimuli in the central visual field are preferred (Downing, 2000; Han & Kim, 2009).

4.3.2 Sustained and transient attention

In this study, sustained attention was measured. A red square appeared and, after that, the Snellen E was presented at the same location. In contrast, transient attention is much faster, and operates in a briefly flashing, stimulus-driven manner (Nakayama & MacKeben, 1989; Ling & Carrasco, 2006).‘For sustained and transient attention mostly right-lateralized brain regions were identified including dorsomedial, mid- and ventrolateral prefrontal cortex, anterior insula, parietal areas, and subcortical structures’ by Langner & Eickhoff, 2013.

For sustained and transient attention, an increased contrast sensitivity for a target stimulus can be achieved even when there is no additional external noise, like distractors or masks. In the case of a signal enhancement mechanism, the results that Ling & Carrasco obtained can be explained for a clean noise display (Ling & Carrasco, 2006). In addition, a participant performs better if the spatial uncertainty is reduced by showing a cue before stimulus presentation. Tse et al. (2003) reported better results for sustained attention at cued positions, and even at positions located between the fixation cross and the peripheral cued position. In this study, a cue was presented before the stimulus was presented. Altpeter et al. (2000) measured the attentional field differences with and without a previously shown cue. They reported that sustained attention was only activated with a previously shown cue, otherwise transient attention was measured. The polar diagrams with the attentional fields differed a lot when comparing transient and sustained attention. MacKeben (1998) mentioned the same results. The current results show a much stronger similarity to the polar diagrams of sustained attention in previous studies.

Transient attention can be performed by signal enhancement even under low external noise terms; for sustained attention signal enhancement can be achieved under low noise conditions. Further, “transient attention apparently works with a combination of contrast gain and response gain, whereas sustained attention only operates by a contrast gain” (Ling & Carrasco, 2006).

4.4. Possible future benefit

The number of patients with age-related macular degeneration will increase in the next years in the whole western world, with one obvious cause being that people get older (Kanski, 2017). The results of the present study, which characterizes spatial attention in the macular region, together with those of the follow-up study by Barraza-Bernal et al. (2017) that shows the relevance for the choice of a PRL, give us the possibility to select patients in early stages of this disease and determine their attention field as a predictor for their future PRL. In case of a functionally unfavorable PRL, these patients could receive a preventive attentional training for the later development of a functionally good PRL, especially below the scotoma. Such a selective training could save costs and even more importantly, improve patients' quality of life.

5. Conclusion

In the present study, fifteen normally sighted participants were tested on their performance of sustained visual attention. For each participant the individual field of attention was determined according to their personal testing results. Those individual fields of attention were compared with each other. 73.3% had a better performance in the lower hemifield, 20% in the upper hemifield and 6.7% in both hemifields. In addition, it could be seen that the participants showed better results on the horizontal meridian compared to the vertical meridian. These results were compared with the results of a previous study, by Altpeter et al. (2000), with the current version of the respective test and fixation control by an eye tracker. The study question was whether we would obtain similar results and confirm the hypothesis that areas of good performance of visual attention can be a candidate for a future PRL after development of an absolute central scotoma. Overall, the presented results corroborate and extend those of Altpeter et al. (2000). Furthermore, current patient data were required to connect this study with a following one (Barraza-Bernal et al., 2017) so that we could test the same eye of the respective participant and simulate a central scotoma within that eye. The results of the follow-up study (Barraza-Bernal et al., 2017) showed that there is a correlation between the here measured locations for the best attentional capabilities and the development of a PRL. Will there be a way in the future to provide new, more focused ways to establish a PRL and can they be trained? In light of the continuous increase of central scotomata in the general population, mainly triggered by age-related macular degeneration (AMD), the focus of interest is on this topic. In absolute central scotoma, patients need to learn to use other areas on the retina for scrutiny of detail. They could receive an attentional training, maybe even earlier in terms of a preventive attentional training. It allows patients to regain their ability to a normal life, such as, for example, reading. Furthermore, that ability helps them maintain self-confidence on daily basis. We know from a clinical point of view that there is a connection between low vision, or the loss of vision, and secondary depression because of its tremendous impact on daily life

(Timberlake et al., 1987; Trauzettel-Klosinski & Tornow, 1996; Trauzettel-Klosinski, 1997; Mielke et al, 2013, Rovner & Casten, 2002).

6. Zusammenfassung

In der vorliegenden Studie habe ich mich mit dem Thema der anhaltenden Aufmerksamkeit (sustained attention) auseinandergesetzt. Aus den hier durchgeführten Messungen wurde für jeden der fünfzehn normalsichtigen Probanden ein individuelles sogenanntes Aufmerksamkeitsfeld ermittelt (Abb. 7). Die unterschiedlichen Aufmerksamkeitsfelder wurden miteinander verglichen. Ein Großteil der Probanden (73%) favorisierte für die Ausrichtung der Aufmerksamkeit den unteren Teil des makulären Gesichtsfeldes. Außerdem konnte festgestellt werden, dass der horizontale dem vertikalen Meridian bei der Aufmerksamkeitslenkung vorgezogen wurde. Neunzehn Jahre nachdem sich Altpeter et al. (2000) ebenfalls schon diesem relevanten Thema widmete, konnte mit Hilfe der nunmehr gängigen technischen Methode der Augenbewegungsmessung („Eye Tracker") die damals ermittelten mit den nun vorliegenden Ergebnissen verglichen werden. Die Ergebnisse der vorliegenden Studie sind mit denen von Altpeter et al. (2000) vergleichbar. Zusätzlich war die Erfassung neuer Daten für anhaltende Aufmerksamkeit (sustained attention) für eine sich auf diese Arbeit aufbauenden Studie notwendig (Barraza-Bernal et al., 2017). Dabei wurde das gleiche Auge der identischen Probanden zeitnah gemessen und mit Hilfe neuer Techniken ein Zentralskotom simuliert, um anschließend auch diese Daten miteinander vergleichen zu können. Es zeigte sich, dass es tatsächlich ein Zusammenhang zwischen den hier dargestellten Ergebnissen und den ausgewählten PRLs durch die Probanden besteht. Es gibt Stellen auf der Netzhaut für den PRL, die aus klinischer Erfahrung besser geeignet erscheinen als andere, dies z.B. für das exzentrische Lesen oder andere Tätigkeiten des Alltags. Diese Erkenntnis bestätigt die Notwendigkeit eines frühzeitigen Beginns für eine individuell angepasste visuelle Rehabilitation bei Patienten mit sich entwickelndem oder bereits bestehendem Zentralskotom. Da auch in den letzten Jahren die Zahl der Patienten mit einem zentralen Gesichtsfeldverlust (Zentralskotom), hauptsächlich bei altersbedingter Makuladegeneration (AMD), ansteigt, ist es unabdingbar, weiterhin zu erforschen, wie diese Patienten bei den Aktivitäten des täglichen Lebens Unterstützung erfahren können.

7. Appendix

Sustained attention and the development of the PRL

Participant Number	

1. **Objective Refraction** Date/time (______/______)

1st measurement

	Sph	**Cyl**	**Ax**
OD			
OS			

2nd measurement

	Sph	**Cyl**	**Ax**
OD			
OS			

3th measurement

	Sph	**Cyl**	**Ax**
OD			
OS			

Comments

____
____
____
____

2. **Visual Acuity** Date/time (______/______)

OD	
OS	
BIN	

Comments

____
____
____
____

3. **Attention measurement** Date/time (______/______)

Comments

____
____
____

Sustained attention and the development of the PRL

4. Central scotoma simulation

Session I		Date	Comments
Sub-session 1			
Sub-session 2			
Sub-session 3			
Sub-session 4			
Session II		Date	Comments
Sub-session 1			
Sub-session 2			
Sub-session 3			
Sub-session 4			

Participants sheet:
1) Objective Refraction: In total three measurements for the right (OD) and left (OS) eye. Sph (sphere), Cyl (cylinder), Ax (axis).
2) Visual acuity for both eyes and binocular
3) Attention measurement
4) Central scotoma simulation (for the following study)

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9. Erklärung des Eigenanteils

Die Arbeit wurde in der Klinik für Augenheilkunde des Universitätsklinikums Tübingen, Forschungseinheit für Visuelle Rehabilitation unter Betreuung von Frau Prof. Dr. med. Trauzettel-Klosinski und dem ZEISS Vision Science Lab unter Betreuung von Herrn Prof. Dr. rer. nat. Wahl durchgeführt.

Die Konzeption der Studie erfolgte durch Frau Prof. Dr. med. Trauzettel-Klosinski, in Zusammenarbeit mit Herrn Prof. Dr. rer. nat. Wahl und Frau Barraza-Bernal.

Die Versuche wurden nach Einarbeitung und in Betreuung durch Frau Barraza-Bernal, zum größten Teil von mir durchgeführt.

Die statistische Auswertung der Daten erfolgte, nach Beratung durch Frau Naumann, des Instituts für Biometrie, eigenständig durch mich.

Ich versichere, diese Dissertation selbstständig nach Anleitung durch Frau Prof. Dr. med. Trauzettel-Klosinski verfasst zu haben und keine weiteren als die von mir angegebenen Quellen verwendet zu haben.

Tübingen, den 18.01.2020

Svenja Nill

Veröffentlichung

Teile der vorliegenden Dissertationsschrift wurden bereits in der folgenden Publikation veröffentlicht:

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