Determination of stereoacuity thresholds and their inherent test retest reliabilities at various eccentricities with a monitor-based two-rod-test

Thesis

by

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Declaration of authenticity

I hereby declare that I have written this thesis independently without unauthorized assistance. No other than the declared sources have been used and have been quoted either literally or by content from the used sources. This thesis has never been published or provided to another examination office before.

Aalen, 2016-04-15 ___________________________

Abstract

Purpose

To determine the stereo threshold and inherent variability with a monitor-based two-rod test at various eccentricities of the visual field. Additionally, to evaluate the duration of this procedure.

Subjects and methods

A pilot trial was conducted in five ophthalmologically normal subjects (2 male and 3 female) aged 21 – 23 years. Two black rods on white background, which appeared under an angle of 1° were presented in a viewing distance of 5.0 meters. The right rod was stationary, whilst the left rod appeared under a stereoscopic parallax, with an either proximal or distal displacement to the image plane. Threshold determination was assessed at seven eccentricities of the visual field by a staircase method. Eccentricities were 0° centrally, 5° to the right and left, 10° to the right and left and 15° to the right and left of the visual field. Proximal and distal displacement as well as the sequence of eccentricities were presented in random order. Stereo acuity was measured in two different sessions for four subjects and in five different sessions for one subject. For all sessions the duration was recorded. All sessions were separated by a time interval of at least 24 hours and no longer than 7 days. Evaluation was made by Wilcoxon test and Kruskal Wallis test at the 95% confidence level (CI) and the median was assessed for all thresholds.

Results

Stereo acuity declines with increasing eccentricities of the retina similar to visual acuity. While at 0° eccentricity thresholds were found to be lowest with (median) 5.0 seconds of arc (’’) and the CI (0.5’’, 30.5’’) for all measurements, they increased to 112.2’’ at 15° eccentricity to the left in proximal displacement. Distal it was 19.9’’ centrally and 112.2’’ to the right at 15° eccentricity with CI (0.5’’, 30.5’’) for all measurements.

Repeatability of the threshold determination was found to be best at 0° eccentricity with proximal displacement showing the exact same result in the repetitive session and poorest repetition was found at 15° eccentricity to the left with distal displacement. Distal repeatability was worse than proximal. Median and CI of duration time was 5.3 (3.2, 8.3) minutes.

Conclusion

Stereo acuity thresholds are repeatable however increase with increasing eccentricity. Repetitions of the threshold determination do not vary considerably. The duration of these measurements indicates the monitor-based two-rod test as a fast procedure, that can be applied in future studies. The test program is limited by an imperfect algorithm and the stereoscopic images evoke cues, this should be reworked.

Keywords

Two-rod test, stereotest, stereopsis, stereoacuity threshold, repeatability, eccentricity

Zusammenfassung

Ziel

Ziel der Studie ist es, mit einem zwei Stäbchen Test am Monitor, die Schwellenwertbestimmung an verschiedenen Exzentrizitäten des binokularen Gesichtsfeldes und deren Wiederholbarkeit durchzuführen. Weiter soll die Dauer der einzelnen Messungen festgehalten und ausgewertet werden.

Methode

Die Explorative Studie wurde mit fünf Probanden im Alter von 21 bis 23 Jahren (2 männlich und 3 weiblich) durchgeführt. Zwei schwarze Balken auf weißem Hintergrund, welche unter einem Winkel von 1° bei einer Beobachtungsentfernung von 5.0 Metern erscheinen, bildeten das Stereobild. Der rechte Balken diente als ortsfester Vergleichsbalken, während der linke Balken zu beurteilen war und durch die stereoskopische Parallaxe, entweder nach vorne oder hinten versetzt erschien. Die Schwellenwertbestimmung erfolgte in sieben Exzentrizitäten zu beiden Seiten des Gesichtsfeldes (0° zentral, 5° rechts/links, 10° rechts/links und 15° rechts/links). Die Darbietung und Abfolge der Bilder mit proximalen und distalen Verschiebungen in den verschiedenen Exzentrizitäten erfolgte randomisiert. Die Bestimmung der Grenzwinkel wurde für 4 Probanden in zwei Sitzungen und für 1 Proband in fünf Sitzungen durchgeführt, wovon bei jeder die Zeit festgehalten wurde. Alle Sitzungen waren mindestens 24 Stunden und längstens 7 Tage voneinander getrennt. Die Auswertung erfolgte durch das bilden von Median und den statistischen Tests von Wilcoxon und Kruskal Wallis mit einem 95% Konfidenzintervall (CI).

Ergebnisse

Peripheres Stereosehen verläuft ähnlich abfallend zur Sehschärfe. Während zentral kleinste proximale Winkel von median 5.0 Winkelsekunden (‘‘) und einem CI (0.5‘‘,30.5‘‘) gefunden wurden, stiegen diese auf 112.2‘‘ in 15° Exzentrizität nach links bei proximaler Darbietung. Distal waren es 19.9‘‘ zentral und 112.2‘‘ in 15° nach rechts. Die Wiederholbarkeit der Grenzwinkelbestimmung war zentral und proximal am genauesten, während in 15° nach links und distal die schlechteste Wiederholbarkeit entdeckt wurde. Zwischen den einzelnen Messungen wurden signifikante Unterschiede der Messdauer gefunden. Die Messdauer liegt bei 5.3 (3.2, 8.3) Minuten.

Schlussfolgerung

Stereogrenzwinkel weichen bei Wiederholungen nicht stark voneinander ab. Mit zunehmender Exzentrizität nehmen die Grenzwinkel zu. Durch die Dauer der Messungen, erscheint der zwei Stäbchen Test am Monitor als schnelle Messmethode die für zukünftige Studien hergenommen werden kann. Jedoch ist der Algorithmus, wie auch die Stereoskopischen Bilder fehlerhaft und sollte überarbeitet werden.

Schlüsselwörter

Two-rod test, stereotest, stereopsis, stereoacuity threshold, repeatability, eccentricity

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Table of Contents

List of abbreviations

Abbreviation	Meaning
2AFC	Two alternative forced choice
3D	Three dimensional
CA	Coefficient of agreement
CI	Confidence interval
cm	centimeter
CR	Coefficient of repeatability
DAR	Display aspect ratio
dB	Decibel
dpt	Diopter
e.g.	Exempli gratia, for example
FPR	Film-type pattern retarder
IQR	Interquartile range
L	Left
m	meter
mm	millimeter
p	Pupillary distance
ppi	Pixel per inch
PSE	Point of subjective equality
px	Pixels
R	Right
s	seconds
VAS	Visual analog scale

List of symbols

Symbol	Meaning	Unit
Δ_a	Discrimination of depth	mm
a_d	Distance of displacement distal, behind	mm
a_p	Distance of displacement proximal, in front of	mm
°	Eccentricity	degree
“	seconds of arc	seconds of arc
y_p	stereoscopic parallax	mm
ϑ	Theta, Stereoscopic angle	seconds of arc
a	viewing distance	m

1. Introduction

1.1 Motivation

Vision, especially its mechanisms and the perception of depth, have been a subject of human interest for thousands of years. The basic interest in eyes was laid by Egyptians (1500 BC) and Greeks (600 – 300 BC) (Crone 1992). Euclid (c. 323 – 285 BC) wrote theorems about geometry and light, of which the majority are still valid today (Gulick and Lawson 1976). Several centuries later it was Ptolemy (c. AD 100 – 175) who further investigated perception and binocular vision amongst optics in general, which was not acknowledged at first, but received attention a few centuries later and again in the 20th century. Finally in the 19th century Gerhard Vieth and Johannes Müller found the theoretical horopter to be a circle and first impressions on stereopsis were discovered (Howard and Rogers 2012). In 1838, Sir Charles Wheatstone invented stereoscopes which laid the foundations to today's understanding of stereoscopy and the empirical horopter (Howard and Rogers 2012).

Stereoscopic vision (also stereopsis, stereovision) is the highest level of binocular vision which describes the perception of three-dimensional (3D) depth due to lateral retinal disparity (Goersch 2000). Stereopsis allows the detection of 3D-structures and breaking of camouflage. Even though stereopsis is not solely necessary for perception of depth (Reading 1983), it is advantageous for guidance of movements such as those needed to solve fine motor tasks, as well as detecting direction and speed of approach (e.g. catching a ball) (Howard and Rogers 2011).

Screening stereopsis is crucial as it provides further details of sensory and motor development and therefore can help detect problems in binocular vision (Kaufmann and Steffen 2012). Many tests have been developed to fulfill examination demands for infants, adolescents and adults. However not all tests lead to identical results, which makes them not interchangeable (Antona et al. 2015).

Westheimer deems the Howard-Dolman two-rod test (Howard 1919) as one of the best clinical tests for stereopsis (Westheimer 2013). On this basis, further stereo tests for distant vision such as the Kolling test (Schiefer et al. 1989) have been developed. The Kolling test is a real depth test and shows two test objects which are either placed in front of, behind or exactly next to a central reference bar. However, the positional changes of the test objects are concomitant with differences in size, shadow and other monocular cues. Taking these confounding factors into account, an improved stereo test for distant vision following the Kolling test is under construction at Aalen University. Real depth stereo test equipment is usually large in size. Since 3D monitor techniques are improving and available at affordable costs, a monitor-based stereo test was used in this exploratory pilot study. Tests that are developed for the purpose of screening, should be repeatable to a certain degree to correctly interpret changes of the results (Adams et al. 2009). Thus there should be no difference in repetition of the monitor-based two-rod test with regard to stereo acuity thresholds. Furthermore, the duration of the test should not differ when it is repeated.

1.2 Purpose

This thesis aimed to determine stereoacuity thresholds at various eccentricities of the visual field with a monitor-based two-rod test.

Furthermore the repeatability and the duration for each given eccentricity of test results was assessed in order to correctly interpret changes (Adams et al. 2009) to either be clinically significant or due to other factors. The threshold for each eccentricity was compared to central fixation threshold to find whether there are differences throughout the retina. Finally, the examiner’s ratings of the test procedures were obtained by using visual analog scales (VAS).

2. Stereopsis: Physiological and (neuro-) anatomical basics

Subsequently the state of the art of stereopsis on the basics of physiological and anatomical aspects is described below. Furthermore, commonly used stereoscopic tests are itemized.

2.1 Stereopsis

2.1.1 Panum's fusional area

The binocular visual field contains both (right and left) monocular visual fields. It contains an overlapping area of about 144° and monocular sectors on its boundary of about 36° (Howard and Rogers 2011). To see objects within this field as single, binocular fusion is necessary. Fusion occurs, when both eyes fixate the same object and their images on the retina fall on corresponding retinal points. Each spot of the retina is associated to a point on the retina of the other eye, these are known as corresponding retinal points (Kaufmann and Steffen 2012). All objects triggering the same directional perception, hence corresponding points, in both eyes are on an imaginary circle known as Vieth-Müller circle. Due to non-ideal spherical shapes of the eyes, the Vieth-Müller circle is better known as the empirical horopter (a curved line rather than a circle) (Berke 2009, Howard and Rogers 2012). The horopter is imaged in Figure 2.1.

Objects outside the horopter fall on non-corresponding points (Howard and Rogers 2011). Images on these points are disparate as they show a certain distance to corresponding points, which can be horizontal, vertical or both. Images on exact corresponding points only exist in theory as both eyes are in constant movement (e.g. microsaccades). Therefore each retinal spot belongs to an area, Panum's fusional area (named after Panum (1858)), in which images can be seen as single (Berke 2009).

Depending on the point of fixation, objects or images within Panum's area are either behind (distal) or in front of (proximal) the horopter, hence they show horizontal (lateral) disparity. As these images can be fused they can be perceived three dimensional. Panum's fusional areas increase with eccentricity and differ with size and spatial frequency of the object (Berke 2009).

2.1.2 Stereoacuity

Stereoacuity describes the smallest angle of binocular disparity, of which perception of depth still is possible. It represents the threshold, where the distance between a fixated and a variable stimulus is detected. The distance of the lateral disparate image to the corresponding retinal point is expressed as stereoscopic parallax (Goersch 2000). The connection between the angle ϑ and stereoscopic parallax y_p as illustrated in Figure 2.2 is pointed out by the equation:

$$\tan\vartheta = \frac{y_p}{a} \tag{1}$$

ϑ = angle of stereo acuity
y_p = stereoscopic parallax
a = viewing distance

2.1.3 Crossed and uncrossed disparities

Figure 2.1 illustrates crossed (a) and uncrossed (b) disparity. When O is fixated and an object (P2) is in front of it (proximal), the images of P2 on the retina have convergent disparity and there is an increased need of vergence of the eyes to fuse the images. Thus the image received by the right eye appears to the left and vice versa. This is known as crossed disparity. If an object (P1) is behind (distal) O, its images have divergent disparity and the eyes have to decrease the angle of vergence to fuse the images. This is also known as uncrossed disparity were the image received by the right eye appears to the right and the one received by the left appears to the left (Howard and Rogers 2012).

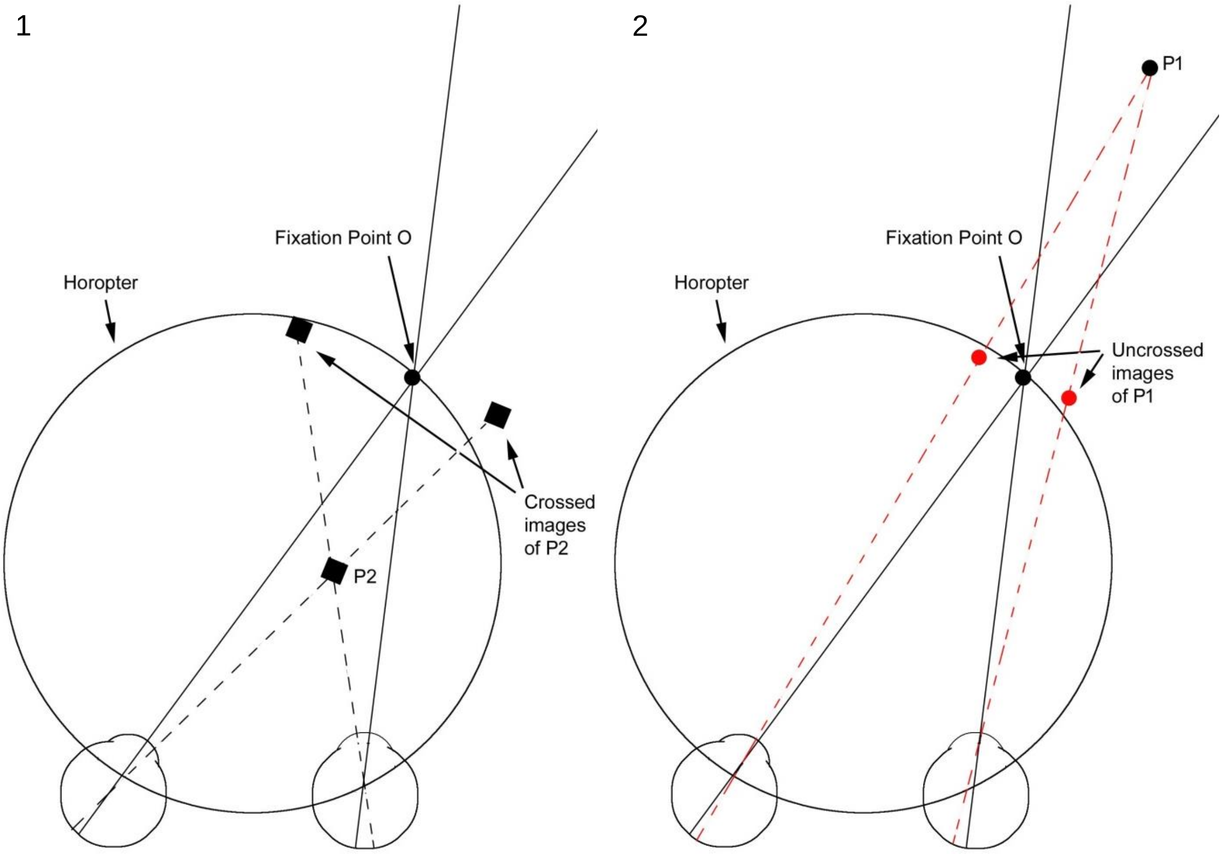

Figure 2.1: **(1) The object P2 is in front of the fixation point O which lies on the horopter. This produces crossed disparity; (2) The object P1 is behind the fixation point O which lies on the horopter. This produces uncrossed disparity (adapted from Howard and Rogers 2011)**

2.1.4 Perception of depth

Stereopsis is the perception of three dimensional depth due to lateral retinal disparity (Goersch 2000). It is easily distinguished from fusion as the latter is satisfied with one object and stereoscopic vision needs at least two objects (Kaufmann and Steffen 2012).

Due to the requirement of images within Panum's fusional area, both retinal images have to be of almost equal quality to allow fusion. Various diseases and optical factors, which lead to different images on the retina, impair stereoscopic vision. When the difference of defocus in both eyes is greater than 2 dpt, stereopsis is abolished (Berke 2009).

There are some terms associated with stereopsis. *Fine stereopsis* is the ability to perceive stereoacuity of 10 seconds of arc or less when both stereoscopic images are alike and can be fused. Stereopsis does not only occur with binocular single vision (Helmholtz 1864) as perception of depth can be evoked by diplopic images with large disparities, which is known as *coarse stereopsis (Giaschi et al. 2013).*

Local Stereopsis is the term for analyzing horizontal disparities in individual features, where no other reference to the retinal field is necessary (Fricke and Siderov 1997). As humans seldom need stereopsis in individual features such as single lines or dots, *global stereopsis* combines several groups of features. This leads to the perception of three-dimensional figures laid out on the surface (Kaufmann and Steffen 2012).

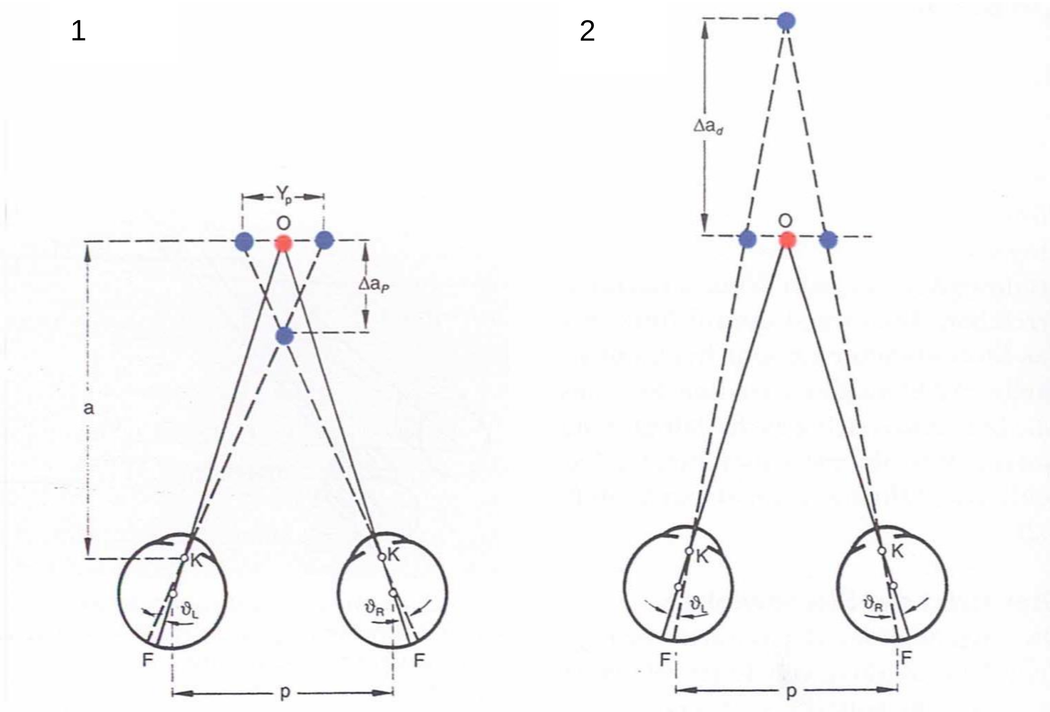

Figure 2.2: Geometry of stereoscopic vision. With the stereoscopic parallax y_p, viewing distance a and pupillary distance p. F indicates the foveae; (1) The blue object is in front of the fixation point O, its depth is proximal Δa_p; (2) The blue object is behind the fixation point O, its depth is distal Δa_d; The images of the blue object appear crossed (1) or uncrossed (2) to the right and left eye with the angle $\vartheta=\vartheta_R+\vartheta_L$ (Berke 2009)

The equation for discrimination in depth Δa (Figure 2.2) can be distinguished for proximal Δa_p and distal Δa_d displacement:

$$\Delta a_p = \frac{a * y_p}{p + y_p} \tag{2}$$

$$\Delta a_d = \frac{a * y_p}{p - y_p} \tag{3}$$

Δa_p = discrimination in depth proximal
Δa_d = discrimination in depth distal
a = viewing distance
y_p = stereoscopic parallax
p = pupillary distance

The equation 4 combines the before mentioned equations 1, 2 and 3:

$$\vartheta = \frac{p * \Delta a}{a^2 \pm \Delta a} \tag{4}$$

Δa = discrimination in depth (either Δa_p or Δa_d)
ϑ = angle of binocular disparity
a = viewing distance
p = pupillary distance

From equation 4 it is obvious that the pupillary distance p influences stereoacuity ϑ. In Figure 2.2 it is unambiguous that p also serves as the base to stereoscopic vision. From the geometry, individuals with a wider pupillary distance should show better stereoacuity than individuals with smaller pupillary distances (Dodgson 2004).

2.1.5 Anatomical basis

As mentioned in section 2.1.1 monocular visual fields have to overlap to a certain degree for the existence of stereopsis. Some organisms like humans are characterized by two eyes which evolutionary moved horizontally from the temple into the face which qualifies the binocular visual field (Howard and Rogers 2012).

The procession of visual information depends heavily on the optic chiasm, in which partial decussation of medial fibers, that is optic nerve fibers run either crossed (nasal hemiretina) or uncrossed (temporal hemiretina), provides input from both retinas to the visual cortex (Howard and Rogers 2012). Cells of the primary visual cortex (V1) are organized in horizontal layers and vertical columns which are specified to certain functions (e.g. movement, color etc.). Stimulated receptive fields arouse cortical cells which are connected to binocular neurons, which again are specified to various disparities (Kaufmann and Steffen 2012). Depending on the visual information, it is processed to higher areas (V2 to V5) where it is decoded. Procession of stereoscopic information were found in neurons of V1 and V2 (Poggio 1995).

2.2 Stereoscopic tests

There are many tests for stereoscopic vision. All tests need to create different retinal images, which can be distinguished when viewed monocular or binocular (Berke 2009). These different retinal images are achieved by presenting two similar pictures (one for each eye) simultaneously to both eyes under slightly different angles, two pictures of the same object under slightly different perspectives or the same pictures side by side. This will be explained more detailed for each test in the following sections. The tests can either be made of contour stereograms, random-dot stereograms or real depth. Some of them separate the images for the right and left eye by polarization or red and green filter (Howard and Rogers 2012). The following examples are some of the most common tests for distance and near fixation, which are used in subjects who are able to respond to verbal instructions.

2.2.1 Contour Stereograms

Distance tests

Polatest

The Polatest is a universal instrument for many monocular and binocular vision tests. It also contains two versions of differentiating stereo tests showing various symbols. One is made of a single row with every symbol being disparate to a different order and the second one is made of five rows (Figure 2.3) with one symbol of each sequence being disparate. Disparities vary between 4 to 0.5 minutes of arc and the test is built for a viewing distance of 5.0 or 6.0 m (Goersch 2000).

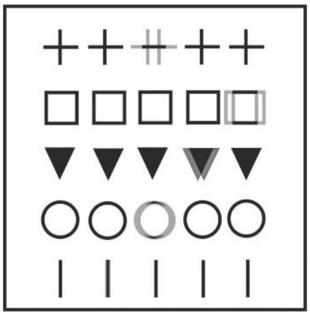

Figure 2.3: Five row differentiated stereo test, showing different disparate symbols (Goersch 2000)

Freiburg Stereoacuity Test

The Freiburg Stereoacuity Test (Figure 2.4) is suitable for the measurement of stereoacuity over a wide range of disparities (between 1 and 1000 seconds of arc) without presenting monocular cues. The stereo target consists of a vertical rod, which is presented randomly either behind or in front of a random black and white squared frame. It is computer generated, requires crystal shutter glasses for separation and is designed for a viewing distance of 4.5 m. Proportions of the rod and frame are held constant relative to the disparity and the rod is randomly displaced to the right or left. (Bach et al. 2001).

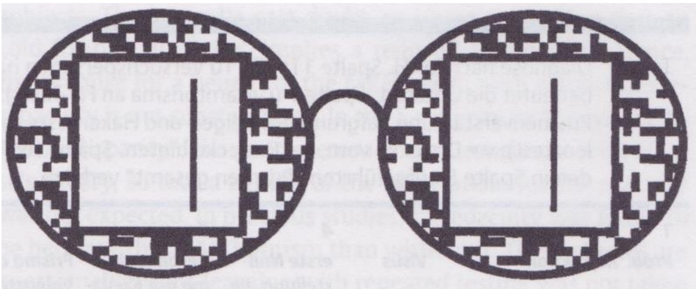

Figure 2.4: Freiburg Stereoacuity Test with two images of a vertical rod in a random black and white squared frame, which are disparate (Bach et al. 2001)

2.2.2 Random-Dot Stereograms

Near tests

TNO Test

The TNO test (Figure 2.5) is made of red and green anaglyphs, thus red and green filter glasses are required. It is detectable even in subjects with anomalies of color perception and also suitable for children. The test consists of six plates with various figures showing disparities of 480 to 15 seconds of arc and is designed for testing in 40.0 cm. As there are no monocular cues within these plates, stereoacuity is necessary for the detection of the figures. There is one additional plate containing three circles arranged next to each other. The middle one is smaller than the outer ones and subjects have to detect the biggest circle, which will indicate the leading eye (Berke 2009).

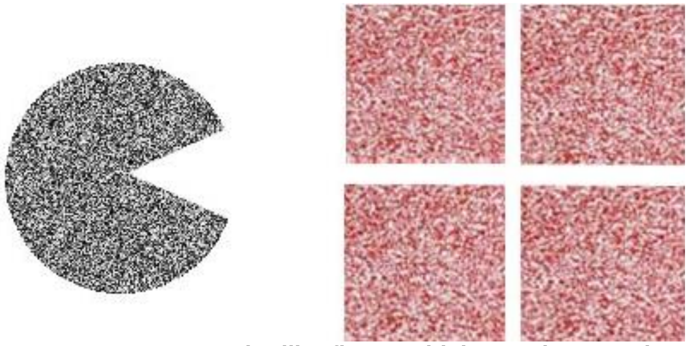

Figure 2.5: TNO test, cake like figure which may be seen in the red fields when stereopsis exists

Lang Stereo Test and DeKa-Test

Both tests, the Lang Stereo tests and the DeKa-test, are made of cylinder raster cards and have a test distance of 40.0 cm. The impression of depth is enabled due to the slightly different angles both of the eyes observe through lenticular lenses that are vertically arranged above the image. All three cards show figures that are suitable for the testing in children. The Lang Stereo test is made of two cards. Lang I (Figure 2.6) contains disparities of 550 to 1200 seconds of arc and Lang II shows 200 to 600 seconds of arc in figures like cars or animals. To gain the attention of children, the Lang II test contains an additional non-stereoscopic figure (a star) which can be seen monocular. The DeKa-test contains two cards with similar figures and disparities from 1000 to 1800 seconds of arc (Berke 2009).

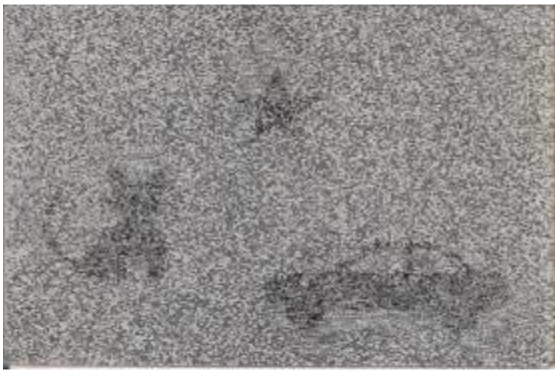

Figure 2.6: Lang Stereo Test I with three figures to induce a stereoscopic impression (Kaufmann and Steffen 2012)

2.2.3 Real Depth

Tests with real depth objects do not require separation of the eyes and are less artificial. Real depth tests have been found to have better results when pupillary distance is greater due to increased stereo base and therefore disparity (Howard and Rogers 2011).

Near tests

Two-Pencil Test after Lang

A qualitative testing of stereopsis at a distance of about 40.0 cm is the Two-Pencil Test after Lang. The subject has to tap the end of a pencil on the top of another one, held by the examiner (Figure 2.7). The examiner observes the subject's eyes and the accuracy of the closing process as well as the strictly vertical movement of the pencils. This test affords monocular and binocular testing as subjects with stereopsis are not able to solve the task monocularly. Disparities are similar to the Titmus Fly (section 2.2.1) (Kaufmann and Steffen 2012).

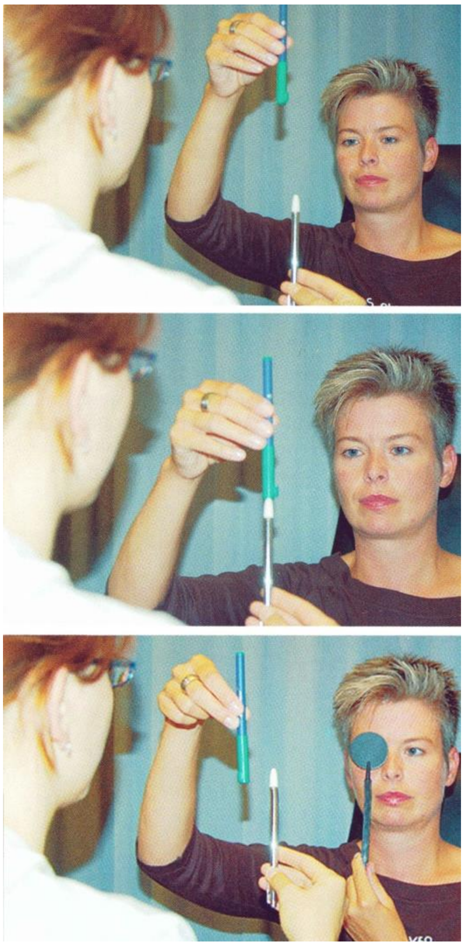

Figure 2.7: Two-Pencil Test after Lang with the subject trying to tap the pencil on the top of the examiners pencil when viewing binocular or monocular (Kaufmann and Steffen 2012)

Frisby Stereo Test

The Frisby test (Figure 2.8) is designed for testing stereopsis at a distance of 40 cm. Three clear plastic plates differing in thickness contain 4 test fields. Each of these fields consists of randomly arranged dots or other small figures. In one field, some are printed on the front and some on the reverse side of the plate. When the front side is being looked at, these figures will appear nearer than the others and build a circle, which indicates the disparity of either 495, 250 or 85 seconds of arc. Figures will appear more distant when the reverse side is being looked at. Motion parallax depicts a monocular cue though it can easily be avoided by controlling the subject's movements of head or plate. This test is well-accepted in children as it is easy to understand and does not need viewing devices (Kaufmann and Steffen 2012).

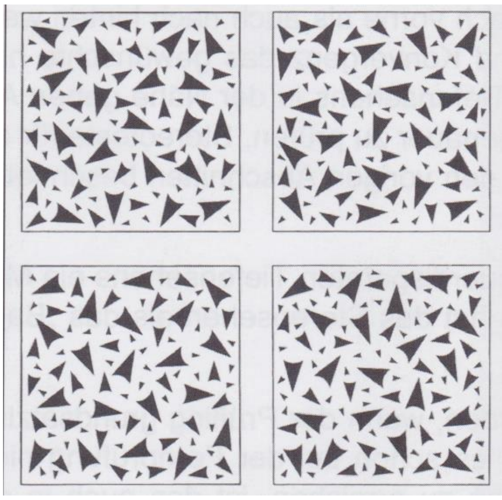

Figure 2.8: Frisby test made of four test fields. Each test field is made of randomly arranged triangles printed on one side of the plate. One of the fields also has triangles printed on the reverse side, which evokes the stereoscopic impression (Howard and Rogers 2012)

Distance tests

Howard-Dolman Test / Helmholtz apparatus

The Helmholtz apparatus (Figure 2.9) contains three rods inside a white painted box with a small opening which is illuminated not to cast shadows. The small opening covers the edges and ends of the rods, which reduces cues. One of the rods can be moved in front of or behind the others. This movement usually is covered by a screen so there is no cue of direction. From a viewing distance of 5.0 or 6.0 m the subject is forced to decide in which direction the rod was moved.

The apparatus can be varied easily by changing the rods into figures or using two rods instead of three. The Howard-Dolman Test is such a variation with only two rods.

Both designs enable to test disparities in a wide range, even up to a few seconds of arc, depending on the dimensions of the box and rods (Diepes 2004, Howard and Rogers 2012).

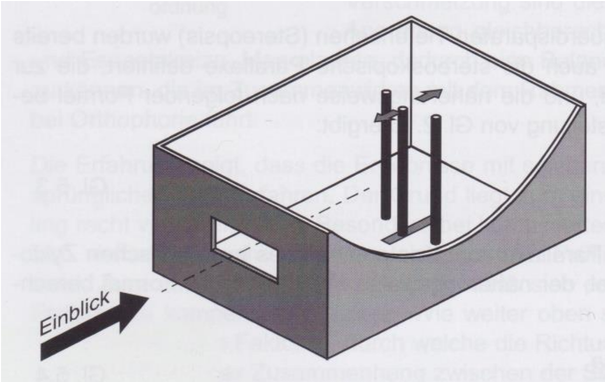

Figure 2.9: Three rod apparatus after Helmholtz (Diepes 2004)

Stereo test after Kolling

Based on a modification of Helmholtz' three-rod apparatus, the Kolling test (Figure 2.10) contains shifted car figures. Subjects have to decide whether the cars located in a device are behind or in front of a stationary strip. It is designed for distant vision (viewing distance of 4.0 m), does not give monocular cues, does not require separation and has been found to be fast, easy to understand, practice orientated and reliable (Schiefer et al. 1989).

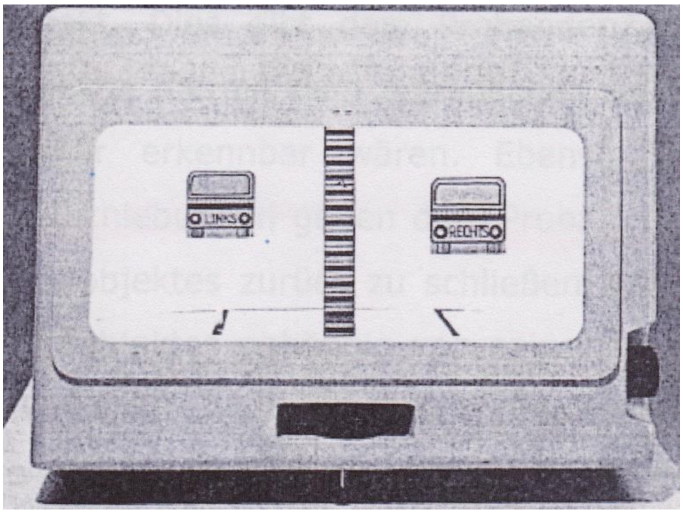

Figure 2.10: Kolling test with two movable cars and a stationary strip (Schiefer et al. 1989)

3. Subjects and methods

3.1 Subjects

Participants (2 male and 3 female) were recruited from Aalen University students and were in the age range of 21 – 23 years (mean 21.6, SD 0.80). All participants were given written information regarding the subsequent examination, the course and purpose of the study (see Appendix for the related documents). Informed consent was obtained by all participants. All data of the subjects were pseudonymized and the assigned subject-IDs were used during the study. Subjective refraction data of all participants are listed in Table 3.1. Subject 2 was the only participant wearing spectacles (Table 3.2) in daily life. Even though the subjective refraction of subject 1 and 5 reflect the need of spectacles, their visual acuity without correction was better than the inclusion criteria (see section 3.1.1) and no spectacles were worn during the study.

Table 3.1: subjective refraction with sph = sphere and cyl = cylinder in dpt = diopters, A = Axis in degree, VA = decimal visual acuity cc = cum correctione and sc = sine correctione of all subjects

Subject ID	Subjective refraction	Sph [dpt]	Cyl [dpt]	A [°]	VA cc monocular	VA cc binocular	VA sc monocular	VA sc binocular
1	R	+0.50	-1.25	100	1.25	1.60	0.80	1.25
	L	0.00	-0.75	80	1.25		1.25	
2	R	+1.75	-0.25	180	1.25	1.25	1.60	1.60
	L	+3.50	-1.75	180	1.25		0.50	
3	R	0.00	0.00		1.60	2.00	2.00	2.00
	L	0.00	0.00		1.60		2.00	
4	R	0.00	-0.25	120	1.60	2.00	1.60	2.00
	L	0.00	-0.25	0	1.60		1.60	
5	R	+0.50	-1.25	95	1.25	1.60	0.80	1.25
	L	+0.75	-1.25	90	1.25		1.00	

Table 3.2: Strength in dpt = diopters, sph = sphere, cyl = cylinder and A = axis of the worn spectacles of subject 2 with monocular and binocular visual acuity VA

Spectacles subject 2	Sph [dpt]	Cyl [dpt]	A [°]	VA cc monocular	VA cc binocular
R	+2.50	-0.50	176	2.00	2.00
L	+3.25	-1.50	3	1.60	

3.1.1 Subsequent examination

A subsequent examination was conducted to screen suitable participants. Pupillary distance was measured with a pupilometer (PD 500, Mailshop GmbH Augenoptik, Mühlacker/Germany), refraction and visual acuity were measured with VISUCAT (VISUCAT argus individuell optic GmbH, Putzbrunn/Germany). Stereo acuity was measured with two commonly used stereo tests: the TNO test (Laméris Ootech, Ede/Netherlands) and Polatest (Zeiss, Oberkochen/Germany) (see section 2.2 for details of the tests). Additionally, a history form concerning the in- and exclusion criteria, history of the eyes and general health was completed. In- and exclusion criteria for this study were as follows:

Inclusion criteria

- Age: ≥ 18 years
- Informed consent
- Spherical refractive error: + 5.00 diopters (dpt) to – 5.00 dpt
- Astigmatism: 2.50 dpt or less
- Decimal visual acuity with or without spectacle correction in both eyes: 0.80 or better.
- If correction had to be worn: full correction distant spectacles and no contact lenses on the days of measurements

Exclusion criteria

- epilepsy or other psychiatric diseases
- medication to influence reaction time or visual system
- ophthalmic or ophthalmic optics education, except first term
- albinism
- strabismus
- eye movement disorders or nystagmus
- eye injuries
- dry eye syndrome
- history of eye or retina surgery within the last 3 months
- infectious eye disease
- diabetic retinopathy
- glaucoma
- macula disease
- history of diseases or injuries with influence to binocular vision
- amblyopia
- relative afferent pupillary defect
- visual field defects

- Stereoscopic threshold: ≥ 60 seconds of arc, Assessed with the TNO test at 40 cm

All of these measurements were documented in a history and a case report form. Refraction was first assessed with an auto refractometer (HRK-7000A, A. Huvitz BD, Gunpo/South Korea) and then a monocular subjective refraction with subsequent binocular fine-tuning (VISUCAT as listed above) followed.

3.1.2 Questionnaire

To evaluate the subjective experience during the course of the measurement, each participant completed a questionnaire (see Appendix) at the end of each measurement day. The questionnaire consisted of three questions concerning the individual's feelings about the test instructions, that day's measurements in general and the assessment of the presentation while looking straight ahead. The questionnaire was made of a visual analog scale (VAS) as individual feelings cannot be measured directly. The subjects responded to these questions with marking their level of agreement on a straight line by a vertical bar between two specified end points (Sriwatanakul et al. 1983).
The participants were asked to answer the following 3 questions:

1. How do you feel about the test instructions?
2. How do you feel about the measurements of today's session?
3. How do you feel about the evaluation when looking straight ahead on the monitor?

The examiner had to answer one question:

1. How do you feel about the measurements of today's session?

3.2 Setup

The setup for the current study consisted of a table and chair, a forehead and chin rest (HR-A-HR-P, Haag Streit, Koeniz/Switzerland) and a monitor (Figure 3.1 and Figure 3.2). The monitor (for specifications, see Table 3.3) had a luminance level of 298 cd/m² which was assessed with a luminance meter (Minolta Spotmeter LS-110, Minolta Camera Co. LTD, Tokyo/Japan). Separation for the right and left eye was achieved with circular polarized glasses (AG-F310).
The room illuminance level of 338 cd/m² was assessed with a digital luxmeter (PeakTech 5025, PeakTech Prüf- und Messtechnik GmbH, Ahrensburg/Germany).
The observer was placed at a viewing distance of 5.0 m from the monitor (Figure 3.1) and the level of the observer's eyes was adjusted by the forehead and chin rest to the same height of the mid of the monitor (1.19 m).

Table 3.3: Technical details of the 3D monitor and size with W=width, H=height, and D= depth

Model:	LG 32LB650V Smart TV
Resolution (px):	1920 x 1080
Screen size (inch):	32
Display type:	LED
Display aspect ratio:	16:9
Dimensions WxHxD without stand (mm):	731 x 437 x 54.5

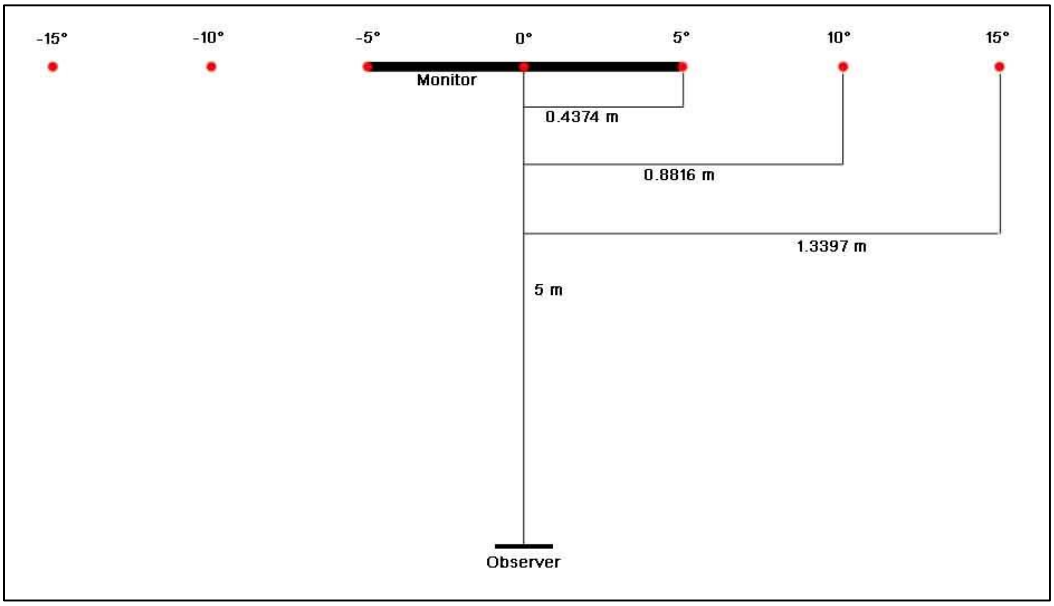

Figure 3.1: Scheme of the setup with a viewing distance of 5 m and fixation points (red dots) in 0°, 5°, 10° and 15° (where – indicates "to the left") eccentricity to the right and left

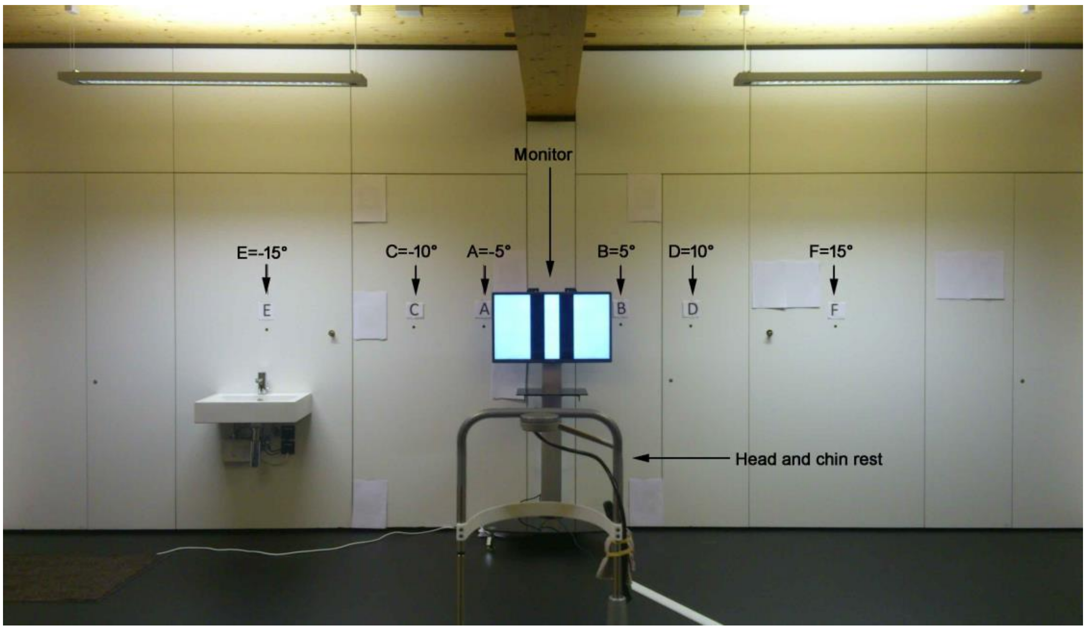

Figure 3.2: Picture of the set up inside the laboratory with fixation points A to E (A=- 5°, C=- 10°, E=- 15° (- = to the left), B= 5°, D= 10°, F= 15°), the monitor with the two rods, and the head and chin rest

The subjects were positioned by the help of the forehead and chin rest. Unless advised otherwise, subjects were required to remain still and maintain fixation. In each session the test program randomized 7 fixation points over 5 repetitions. Randomization occurred by a code of the test program, which runs on every computer. The 5 repetitions were necessary to minimize response bias as there was a 50 % probability of successful guesswork with only 2 possible response options. Fixation points included 0° centrally and eccentricities up to 15° either side at 5° increments (Figure 3.1). Above the markings of those points, letters from A to E were hung up as displayed in Figure 3.2. A, C and E indicated 5°, 10° and 15° to the left of central fixation and to the right it was B, D and F, respectively. The assignment of the letters to each of the fixation point was made by the choice of the examiner. These letters were used to announce the fixation point on turn. After the program chose the point, subjects were instructed to fixate on the accompanying marking of the fixation point, below the letter on the wall. Then the algorithm started with the first image. Subjects had to decide whether the left rod was relocated to the front (in front of, proximal) or back (behind, distal) in relation to the right rod, which was constantly situated on the screen level (see chapter 3.4 for more details on the stereo target). To record the decision, subjects were given an input device (presenter PERIPRO-707, Perixx Computer GmbH, Düsseldorf/Germany) consisting of an up (behind) and down (in front of) arrow to press. The next image was chosen by the program following a 5/3 decibel (dB) thresholding algorithm, which is further discussed in section 3.5. Between each image, a plain white image briefly (140 ms) appeared to cover up the change of disparity. When the threshold for a particular fixation point was determined, the program chose the next eccentricity point. There was a short pause of roughly 5 minutes between each of the five repetitions. This procedure was applied for each of the seven points (eccentricities) in all 5 repetitions at every session.

A repetitive session was carried out in four subjects to evaluate the test-retest reliability. The fifth participant was asked to attend five sessions, to assess an idea of a possible learning effect in this test.

3.3 3D technology

Commonly available 3D monitors use different technologies to achieve 3D images. In the current study, a 3D monitor by LG Electronics was used. LG operates with a film-type patterned retarder (FPR) to achieve 3D images on their monitors (Fernando et al. 2013). FPR is based on circular polarization where two images are presented simultaneously while being separated by a patterned retarder film. Due to the polarized glasses, the right and left images are received from the corresponding eye and are seen as the desired stereoscopic image. As the images are presented simultaneously, there is no shuttering effect with this technology. Despite no flickering being experienced, only half of the horizontal lines are presented to each eye, which therefore reduces the horizontal resolution by half (Su et al. 2012).

3.4 Stereo target

The stereo target consisted of two black rods on a white background (Figure 3.3). Its Michelson-contrast was 0.85 with luminance levels of L_{max} = 298 cd/m² (white background) and L_{min} = 23.47 cd/m² (black rods). The right rod was stationary and the left rod appeared either in front of (proximal) or behind (distal) the image plane. The left rod never appeared in the same image plane as the right rod, thus there were only two response options. The width of each of the rods and their distance between each other was 8.70 cm and the distance between the rod and the horizontal border of the monitor was 22.35 cm. Their height extended vertically from the upper border to the lower border of the monitor, which therefore was 39.85 cm. These dimension made the rods appeared under an angle of 1° at a viewing distance of 5.0 m.

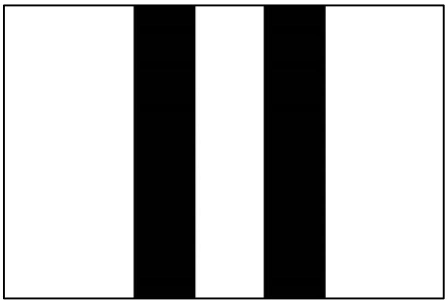

Figure 3.3: Stereo target. Two black rods

Stereo target images ranged from 1 to 1000 seconds of arc for both proximal and distal serving. Within the images, each value was expressed in dB for an easier course of the threshold algorithm (see section 3.5). The following Table 3.4 illustrates the logarithmic conversion of the two units and the accompanying stereoscopic parallax y_p, which arise from the equations 1 (see section 2.1.2) and 5:

$$1.26\ seconds\ of\ arc = 10^{\left(\frac{1dB}{10}\right)} \tag{5}$$

1.26 seconds of arc= lateral disparity

Table 3.4: Conversion of the stereoscopic parallax y_p into the stereoscopic threshold level in dB and the lateral disparity in seconds of arc

Stereoscopic parallax y_p [m]	Stereoscopic threshold level [dB]	Lateral disparity [seconds of arc]
2,42407E-05	0	1.00
3,05172E-05	1	1.26
3,84189E-05	2	1.58
4,83665E-05	3	2.00
6,08898E-05	4	2.51
7,66558E-05	5	3.16
9,65039E-05	6	3.98
0,000121491	7	5.01
0,000152948	8	6.31
0,000192551	9	7.94
0,000242407	10	10.00
0,000305172	11	12.59
0,000384189	12	15.85
0,000483665	13	19.95
0,000608898	14	25.12
0,000766558	15	31.62
0,000965039	16	39.81
0,001214912	17	50.12
0,001529484	18	63.10
0,001925506	19	79.43
0,002424069	20	100.00
0,003051722	21	125.89
0,003841890	22	158.49
0,004836654	23	199.53
0,006088988	24	251.19
0,007665583	25	316.23
0,009650402	26	398.11
0,012149145	27	501.19
0,015294885	28	630.96
0,019255155	29	794.33
0,024240874	30	1000.00

3.5 Threshold determination

Threshold determination is fastest when a bracketing method (also known as the staircase method) is applied. It is a precise procedure for testing the perception of stimuli with varying features such as intensity or direction. With this method a threshold stimulus will be detected by closing in, beginning with a starting value either well above or well below the estimated threshold (García-Pérez 1998). Regarding the observer's response, the following stimuli will be presented above or below the last stimulus with a certain step size. Step sizes should be greater in the beginning and decrease with the number of reversals as large steps miss the point of subjective quality (PSE) and using small steps throughout the whole test cost a huge amount of time. This way the threshold of demand will be stepped over with the reversals of the observer's response (therefore bracketing), although determined fast and precise as the decreasing step sizes close in on the possible stimuli. The thresholds should not be affected by changes in the observer's criterion. Thus a two-alternative forced-choice procedure (2AFC) should be applied. Subjects have to choose one of the two alternatives with every stimulus presented (Howard and Rogers 2012).

Figure 3.4 illustrates these aspects with a 5/3 dB algorithm applied to the monitor-based two-rod test and a chosen starting value of 18 dB. With respect to the observer's response (correct/false regarding distal/proximal) the next stimuli was chosen from the program. The first stimuli changed gradually with 5 dB differences either increasing, when a false response was given (red lines), or decreasing, when a correct response was given (green lines). When the observer's response reversed (star figure), the next stimuli were presented with 3 dB differences in the opposite direction (increasing or decreasing). The algorithm stopped when a second reversal in the observers' response occurred (dots). If the algorithm reached the end of the range of images, it displayed the 0 or 30 dB image next, as there were no images above or below those two values. If there was a reversal in the observer's response on that point, the algorithm either stopped or changed direction as described above. The program evoked failure by presenting the end image as if it was the correct next stimuli according the algorithm and changing direction if it was the first reversal on that point. The following stimulus therefore was presented with a false step size and lead to an artificial threshold value. As a matter of clarity, the flowchart shows only some of the possible courses the measurement can take.

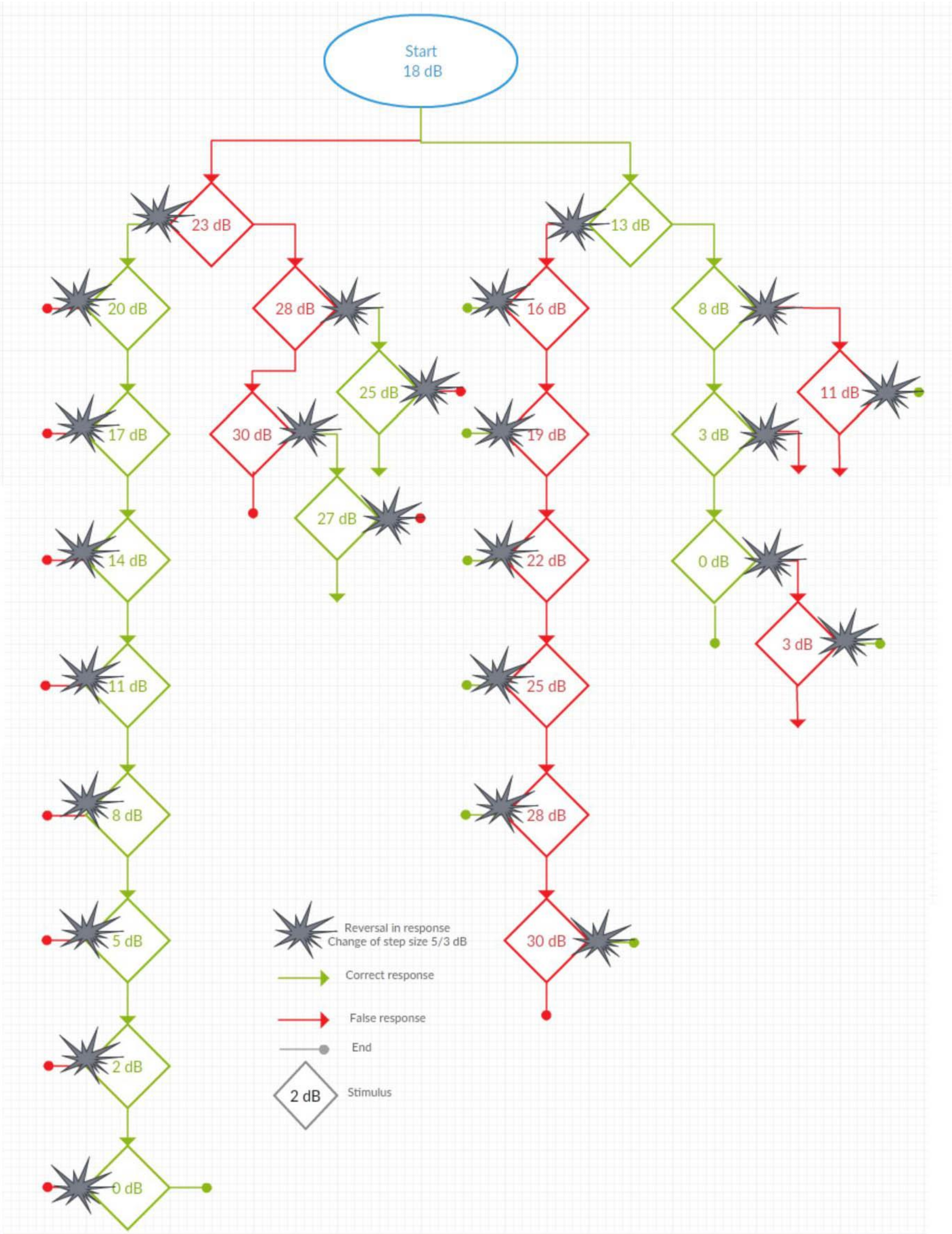

Figure 3.4: Flowchart of possible courses the program could take with a starting value of 18 dB. Correct (green) and false (red) responses lead (arrow) to stimuli (boxes) following the step size of a 5/3 dB algorithm. Reversals (star figure) change direction and step size. Dots symbolize the end of the course

Each image value, its direction (proximal/distal), the observer's respond (true/false) and the reaction time for the response of each presentation were noted. Reaction time is the time of presentation of the image and the time of pressing a button on the input device. The program also gave out the median response (reaction) time, the total time from the beginning of the measurement to the end of each point and its results for the threshold for proximal and distal display (Figure 3.5).

%%%%%%%%%%%%%%%%%%%%%%% STAMMDATEN:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

PatientID	Name	Geschlecht	SequenzNr	Examiner	Älter
4		0	1	JF	21

Eccentricity: -10

%%%%%%%%%%%%%%%% Individuelle Untersuchungsdaten%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Querdisparation	Vorne(+)/Hinten(-)	Detected	Reaction Time
23	-1	false	2703
23	1	true	2234
18	1	false	1734
21	1	true	2203
28	-1	false	1988
30	-1	true	2204
27	-1	false	1953

%%%%%%%%%%%%%%%%%%%%%%% Resultat:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

The median of the response times: 2203.0
Proximal test: Min detected: 21 max missed: 18 Average:19.5
Distal test: Min detected: 30 max missed: 28 Average:29.0
TOTAL TEST DURATION (hh:mm:ss): 00:07:16

Figure 3.5: Example of the original result data of subject 4 session 1 repetition 1 eccentricity -10° (10° to the left), with Patient ID=subject, Geschlecht=sex, SequenzNr=repetition, Älter=age, Querdisparation=disparity=image number, Vorne +1= proximal display, Hinten -1= distal display, false= not seen correct, true= seen correct, reaction and response time measured in milliseconds and all disparity values in dB

3.6 Evaluation methods

Microsoft Excel (Excel 2010, Microsoft Corporation, Redmond, United States of America) and R statistical software (The R foundation, Vienna, Austria, Version 3.2.2, https://www.r-project.org/ 2015-11-25) were used for the evaluation of the collected data.

The following parameters were investigated:

- Threshold (in seconds of arc) for each of the 7 eccentricities in 2 respectively 5 sessions
- Duration (in minutes) of each measurement
- Individual evaluation of the measurement with a visual analog scale

The data were processed as described below.

3.6.1 Threshold determination

Section 3.5 describes the applied method for the determination of the thresholds. Table 3.4 expressed the conversion of the unit dB and seconds of arc.
When the algorithm reached the end of the range of the images, it continued by presenting the end image (30 or 0 dB), regardless if the correct step size was kept (Figure 3.4). This evoked failure in the end results, thus the threshold was determined manually for this study.

Threshold determination was based on the last correctly and last not correctly determined stimulus. The mean of both was built to get the threshold. Figure 3.6 illustrates some examples with a starting value of 18 dB. When 18 dB was seen correct, the next stimulus was 13 dB. In this example 13 dB was not seen correct, therefore the reversal of response evoked a change of step size (from 5 to 3 dB) and direction, which presented 16 dB next. This stimulus was seen correct, thus a second reversal of response happened and evoked the end of the measurement. The last correct seen stimulus was 16 dB and the last not seen correct stimulus was 13 dB. The median of both reveals a stimulus of 14.5 dB.
The next possible course gives a description of reaching the end of images. Each stimulus was seen correct, therefore the next stimulus after 3 dB should be -2 dB which does not exist. The program progressed as described above, however this is not correct. In the manual determination 0.5 dB was notes to indicate the failure of the program.

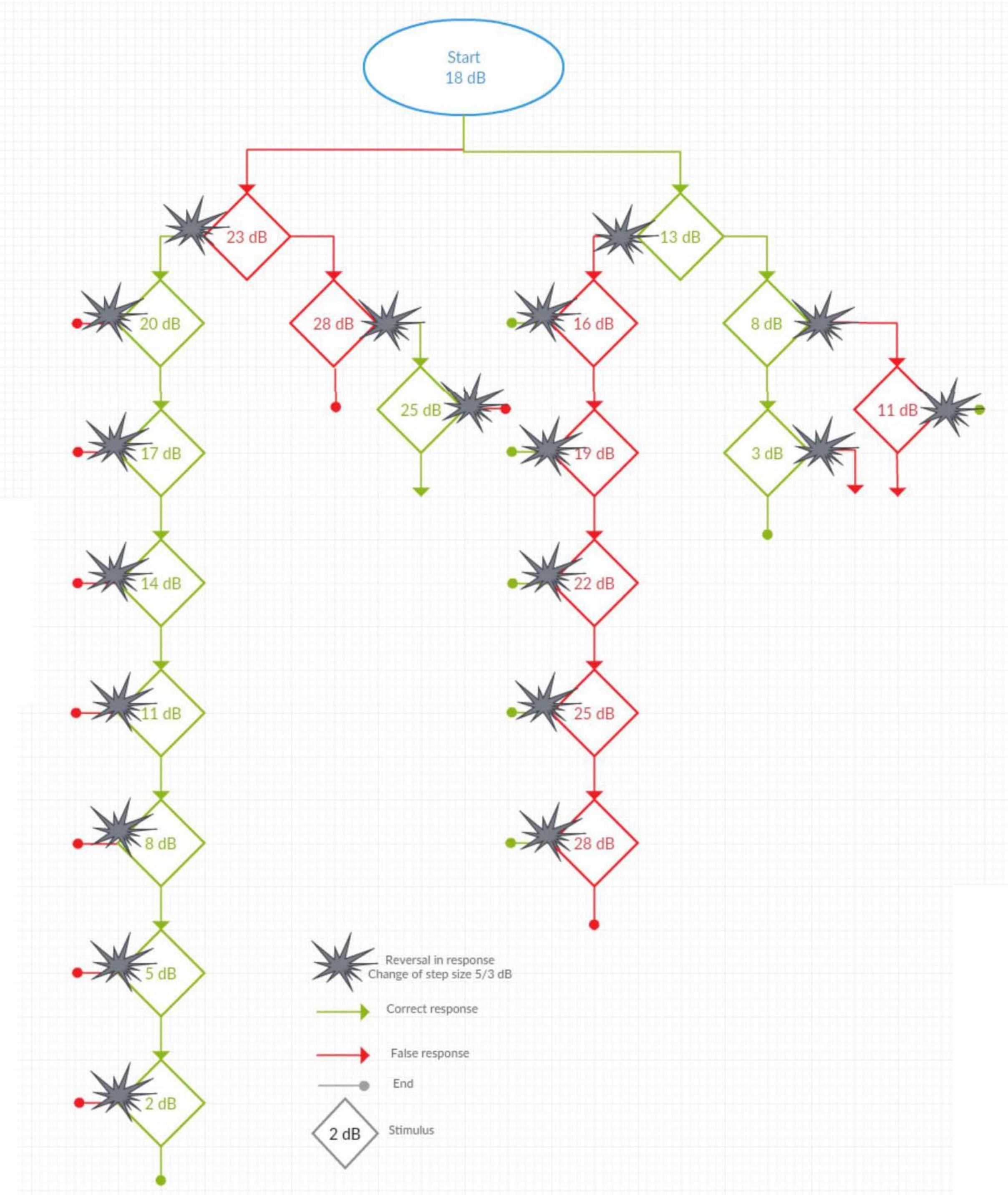

Figure 3.6: Flowchart of the manual determination with the applied 3/5 dB algorithm and a starting value of 18 dB. Correct (green) and false (red) responses evoke the next (arrow) stimuli (box) regarding the step sizes that are changed by reversals (star figure).

Effect of eccentricities

Seven eccentricities were assessed 5 times in *two* sessions (in 4 subjects) or *five* sessions (in 1 subject). The median and confidence interval of all measurements of session 1 and 2 in five subjects was built for each eccentricity proximal and distal.

Significance was tested with the Wilcoxon-test and p-value was set to p=0.05.

Repeatability

Repetition of the test was assessed in four subjects who attended two sessions and one subject who attended five sessions. The median and confidence interval of all results of session 1 and 2 of all subjects was built for each eccentricity. Significance was tested with the Wilcoxon–test with p=0.05. All results were tested in dB unit. For central measurements, there was an additional critical effect size of at least 13 seconds of arc difference between the session 1 and 2 (Antona et al. 2015).

For the subject who attended 5 sessions, each session was correlated to session 1.

3.6.2 Duration

The duration of each measurement of the 5 repetitions at each session was measured and noted as hour, minute, second. To compare the difference between durations of session 1 and session 2, the results were converted into minutes and Wilcoxon test was applied with the p-value set to p=0.05. Therefore, the median and confidence interval of all 5 repetitions of each session for each subject was built. Additionally, the durations of all sessions in subject 5 were compared using the Kruskal Wallis test.

3.6.3 Questionnaires

The questionnaire consisted of visual analog scales and was evaluated by comparing the scale to an additional scale with markings (Figure 3.7). Each scale on the questionnaire had a length of 10 cm. Only the end points were marked. The additional evaluation scale had a total length of 10 cm and every mm had a numbered marking between 0 (negative experience) and 100 (positive experience). By comparing these numbers to the markings of the subjects, their individual feeling about the 3 questions was noted numerically. Even though there was only one examiner, an examiner questionnaire contained one question which was treated the same.

The numerical results of each session were then evaluated with the Wilcoxon-test at p=0.05 and are shown in box plots. Subject 5 is included in the evaluations of sessions 1 and 2, though an additional separated test (Kruskal-Wallis) was used as there were 5 sessions to evaluate in the questions for the subject and the examiner.

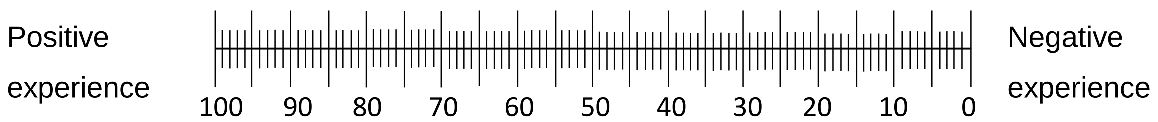

Figure 3.7: Additional reference scale with markings for the evaluation of visual analog scales with 0 being a negative experience and 100 being positive

There was a section for free comments on each questionnaire. When comments were given, these were noted and taken into consideration in chapter 5.

4. Results

Data were collected in numerous sessions and treated as explained in section 3.6.

The original data are enclosed on CD to this thesis.

4.1 Thresholds

Table 4.1 shows the median and the 95% confidence interval (CI) for each eccentricity recorded in session one and two, separated into proximal and distal display. The median of the proximal stereo acuity was better at 0° (centrally) than at the other eccentricities. The median of the distal stereo acuity at 10° to the right was better than in the other eccentricities. Overall distal stereo acuity was better than proximal except in 0° centrally.

Table 4.1: Median and 95% CI of all measured stereoacuity thresholds in dB and seconds of arc and the assigned eccentricities in degrees separated into proximal distal stereoacuity

Eccentricity [degrees]	Proximal stereoacuity (Median (CI))		Distal stereoacuity (Median (CI))	
	dB	Seconds of arc	dB	Seconds of arc
15 left	20.5 (0.5,30.5)	112.2 (1.1,1122.0)	13.0 (0.5,30.5)	89.1 (1.1,1122.0)
10 left	14.5 (0.5,30.5)	28.2 (1.1,1122.0)	7.5 (0.5,30.5)	5.6 (1.1,1122.0)
5 left	13.5 (0.5,30.5)	22.4 (1.1,1122.0)	8.0 (0.5,30.5)	6.3 (1.1,1122.0)
0	5.0 (0.5,30.5)	3.2 (1.1,1122.0)	13.0 (0.5,30.5)	19.9 (1.1,1122.0)
5 right	12.3 (0.5,30.5)	16.8 (1.1,1122.0)	8.5 (0.5,30.5)	7.1 (1.1,1122.0)
10 right	17.3 (0.5,30.5)	53.1 (1.1,1122.0)	4.5 (0.5,30.5)	2.8 (1.1,1122.0)
15 right	20.5 (0.5,30.5)	112.2 (1.1,1122.0)	20.5 (0.5,30.5)	112.2 (1.1,1122.0)

4.1.1 Effect of eccentricities

Figure 4.1 shows the results of the measurements of proximal stereoacuity in the eccentricities to the left and right visual field and 0° centrally. The results of the eccentric fixation points to both sides of the visual field increase with increasing eccentricity. Figure 4.2 shows the results of the measurements of distal stereoacuity in the eccentricities to the left and right visual field and 0° centrally. The results of 0° centrally are worse than those of 5° and 10° to both sides of the visual field, although better than at 15° of both sides. The median are the bold lines and the boxes symbolize the interquartile range (IQR) from 25th (lower border) and 75th (upper border) of the outcomes. The whisker stand for the margin area, in this study the minimum and maximum of the values, and the open dots symbolize the outlier which vary greater in the distal measurements than in the proximal measurements. The medians shown in both figures are listed in Table 4.1. Their increase with the increasing eccentricity is different for proximal and distal stereoacuity. For the proximal measurements the increase is almost regular to both sides. There were no significant agreements of the results when eccentric thresholds and central thresholds are being looked at (p>0.05).

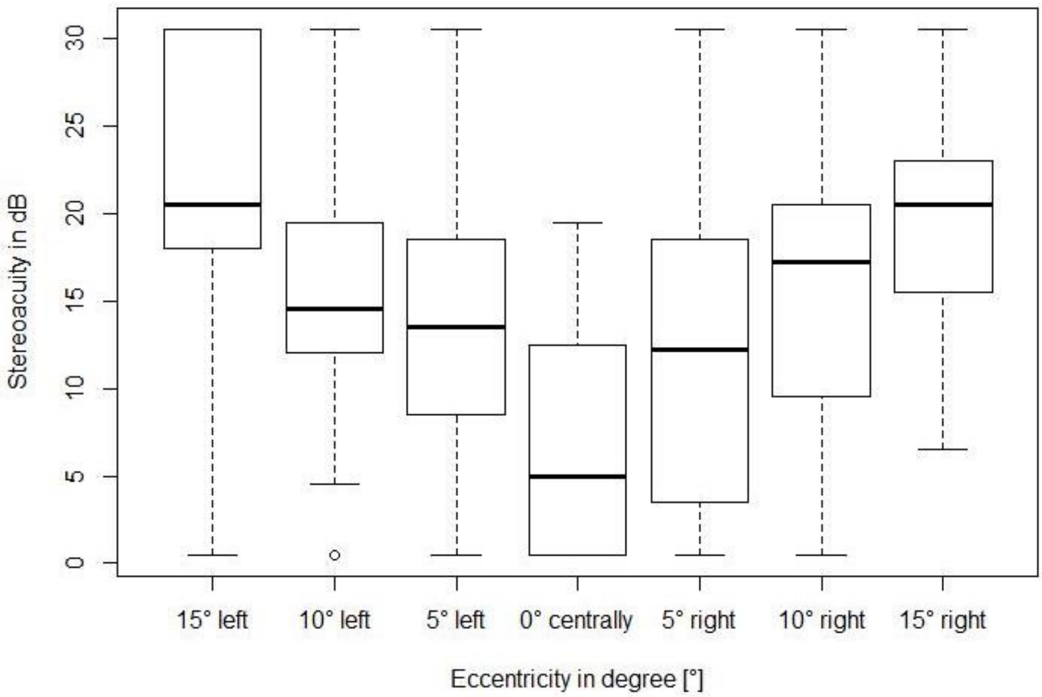

Figure 4.1: **Proximal data of session 1 and 2 of all 5 subjects shown for each eccentricity with the median (bold line), first and third quartile (lower und upper border of the box), interquartile range IQR (box), minimum and maximum values (lower and upper whisker (dotted line)) and the outlier (open dot), (Wilcoxon test p>0.05)**

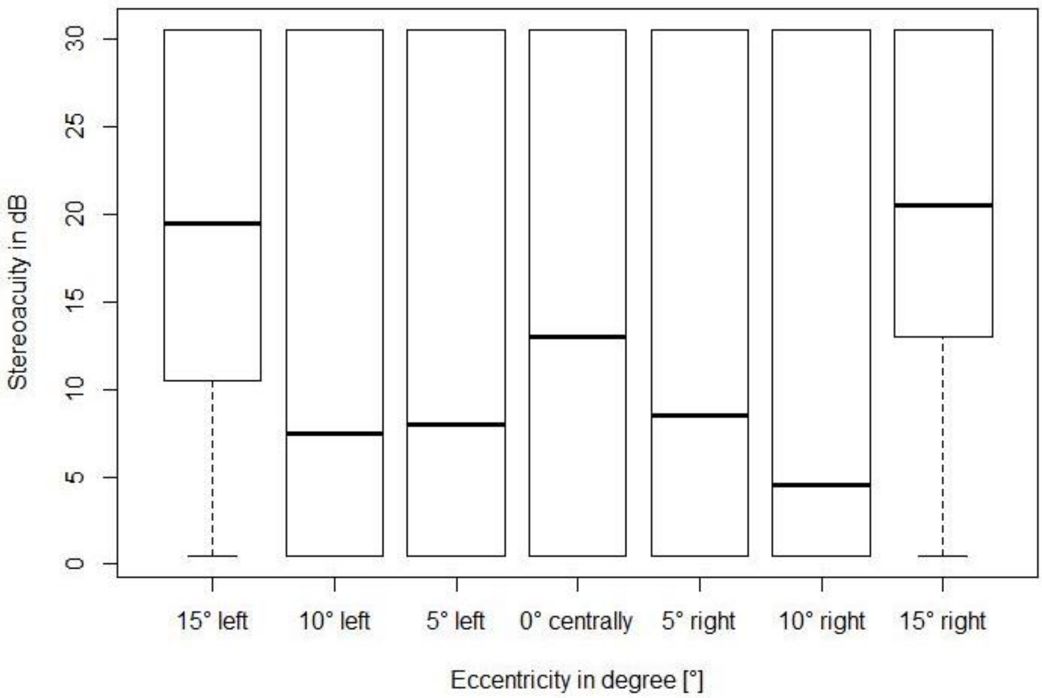

Figure 4.2: **Distal data of session 1 and 2 of all 5 subjects shown for each eccentricity with the median (bold line), first and third quartile (lower und upper border of the box), interquartile range IQR (box), minimum and maximum values (lower and upper whisker (dotted line)) and the outlier (open dot), (Wilcoxon test p>0.05)**

Figure 4.3 illustrates the median stereo acuity in seconds of arc of all available results at sessions 1 and 2 and the distribution of visual acuity which was adapted from Kaufmann and Steffen (Kaufmann and Steffen 2012).

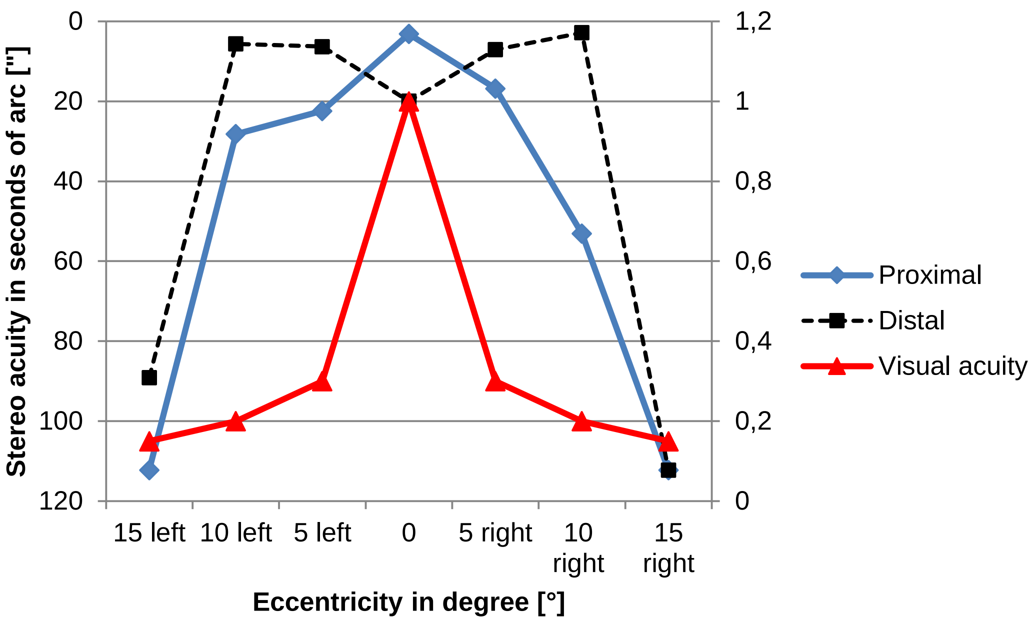

Figure 4.3: Median stereo acuity thresholds in seconds of arc of all subjects of sessions 1 and 2 in various eccentricities and visual acuity distribution (decimal) which was adapted from (Kaufmann and Steffen 2012)

4.1.2 Repeatability

Figure 4.4 and Figure 4.5 show the results for proximal and distal measurements of session 1 and 2 of all subjects.

There were no significant differences (p>0.05) in neither of the proximal or distal repetitive medians (Table 4.2) for each eccentricity.

Table 4.2: Proximal and distal median and CI for each eccentricity at session 1 and 2

	Proximal median (CI)		Distal median (CI)	
	Session 1	Session 2	Session 1	Session 2
15 left	23.0 (0.5,30.5)	20.5 (0.5,30.5)	23.0 (0.5,30.5)	13.0 (0.5,30.5)
10 left	14.5 (0.5,30.5	14.5 (0.5,30.5)	22.0 (0.5,30.5)	7.0 (0.5,30.5)
5 left	13.5 (0.5,30.5)	13.1 (0.5,30.5)	8.5 (0.5,30.5)	4.5 (0.5,30.5)
0	5.0 (0.5,30.5)	5.0 (0.5,30.5)	12.5 (0.5,30.5)	12.5 (0.5,30.5)
5 right	11.0 (0.5,30.5)	13.1 (0.5,30.5)	6.0 (0.5,30.5)	8.5 (0.5,30.5)
10 right	17.0 (0.5,30.5)	17.1 (0.5,30.5)	4.5 (0.5,30.5)	0.5 (0.5,30.5)
15 right	20.5 (0.5,30.5)	18.0 (0.5,30.5)	18.0 (0.5,30.5)	20.5 (0.5,30.5)

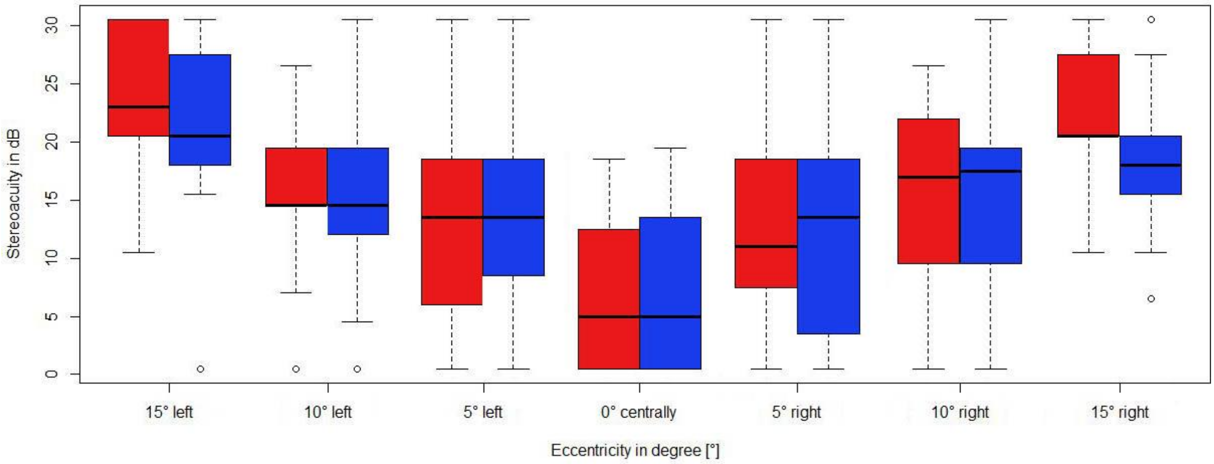

Figure 4.4: **Proximal displacement, Median (bold line), IQR (box), minimum and maximum (lower and upper whisker – dotted line) and outlier (open dot) for proximal stereo acuity measured in dB of all subjects with respect to the eccentricities in degrees at session 1 (red) and 2 (blue) (Wilcoxon p>0.05)**

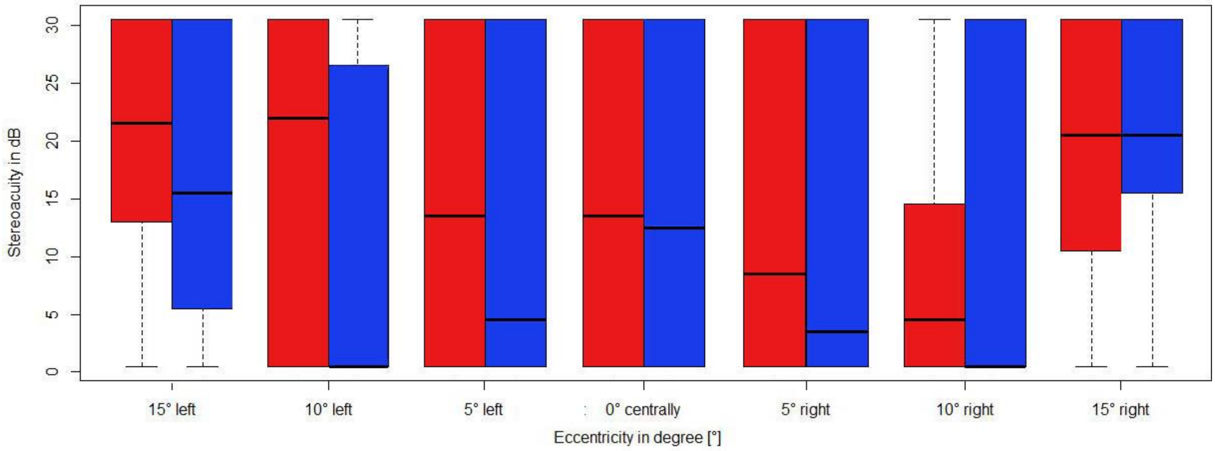

Figure 4.5: **Distal displacement, Median (bold line), IQR (box), minimum and maximum (lower and upper whisker – dotted line) and outlier (open dot) for distal stereo acuity measured in dB of all subjects with respect to the eccentricities in degrees at session 1 (red) and 2 (blue) (Wilcoxon p>0.05)**

Thresholds for each eccentricity of all 5 sessions in subject 5 are shown as median and confidence interval in Table 4.3. There were no significant differences between all sessions with the Kruskal-Wallis test p>0.05.

Table 4.3: Median and CI of stereo acuity thresholds in dB for all eccentricities in each session of subject 5

Subject ID 5	Session 1	Session 2	Session 3	Session 4	Session 5
Eccentricity [degree °]	Proximal stereoacuity [dB] Median (CI)				
15 left	30.5 (15.5, 30.5)	27.5 (0.5, 30.5)	25.0 (3.0, 30.5)	20.5 (3.0, 30.5)	10.5 (0.5, 15.5)
10 left	14.5 (0.5, 19.5)	19.5 (3.0, 30.5)	19.5 (3.0, 30.5)	12.0 (3.0, 14.5)	7.0 (0.5, 9.5)
5 left	6.0 (0.5, 13.5)	8.5 (0.5, 30.5)	0.5 (0.5, 8.5)	3.5 (0.5, 8.5)	3.5 (0.5, 6.0)
0	5.0 (0.5, 12.5)	2.5 (0.5, 7.5)	0.5 (0.5, 3.0)	2.5 (2.5, 7.5)	0.5 (0.5, 5.0)
5 right	3.5 (0.5, 8.5)	0.5 (0.5, 3.5)	0.5 (0.5, 3.0)	0.5 (0.5, 3.5)	3.5 (0.5, 8.5)
10 right	7.0 (0.5, 19.5)	0.5 (0.5, 19.5)	0.5 (0.5, 30.5)	0.5 (0.5, 4.5)	0.5 (0.5, 9.5)
15 right	20.5 (3.0, 30.5)	15.5 (3.0, 20.5)	15.5 (0.5, 30.5)	13.0 (0.5, 18.0)	15.5 (3.0, 20.5)
	Distal stereoacuity [dB] Median (CI)				
15 left	15.5 (3.0, 27.5)	5.5 (0.5, 27.5)	5.5 (0.5, 27.5)	0.5 (0.5, 10.5)	0.5 (0.5, 20.5)
10 left	0.5 (0.5, 19.5)	0.5 (0.5, 3.0)	0.5 (0.5, 8.5)	0.5 (0.5, 3.0)	0.5 (0.5, 3.0)
5 left	3.5 (0.5, 16.5)	0.5 (0.5, 8.5)	3.5 (0.5, 16.0)	0.5 (0.5, 3.0)	0.5 (0.5, 3.0)
0	2.5 (0.5, 22.0)	0.5 (0.5, 3.0)	0.5 (0.5, 7.5)	0.5 (0.5, 3.0)	0.5 (0.5, 7.5)
5 right	3.5 (0.5, 8.5)	3.5 (0.5, 3.5)	3.5 (0.5, 12.5)	3.5 (0.5, 18.5)	0.5 (0.5, 3.0)
10 right	9.5 (0.5, 14.5)	0.5 (0.5, 4.5)	9.5 (0.5, 30.5)	2.5 (0.5, 20.5)	0.5 (0.5, 4.5)
15 right	15.5 (3.0, 20.5)	20.5 (0.5, 24.5)	5.5 (0.5, 20.5)	0.5 (0.5, 5.5)	0.5 (0.5, 3.0)

4.2 Duration

The median and CI of all duration times in session 1 and 2 was 5.3 (3.2, 8.3) minutes.
There were no significant differences (Table 4.4) in median duration between session 1 and session 2 of all subjects.

Table 4.4: Median and CI of the duration (in minutes) of session 1 and session 2 of all subjects. Difference of durations between the sessions was tested with Wilcoxon p>0.05

Subject ID	Session 1	Session 2
Subject 1	6.1 (5.4, 7.5)	5.3 (3.1, 6.4)
Subject 2	5.2 (4.1, 6.4)	3.3 (3.2, 3.5)
Subject 3	6.2 (5.5, 7.5)	5.1 (4.2, 5.2)
Subject 4	6.1 (4.2, 8.3)	5.0 (4.5, 5.2)

Subject 5 attended 5 sessions. Between all five sessions there were no significant (p>0.05) differences in the duration of measurements. Median and CI of the duration times are listed in Table 4.5.

Table 4.5: **Median and CI of the duration (in minutes) of each session (1 to 5) in subject 5. Difference of durations between sessions 1 and 2 tested with t-Test. Between all 5 sessions statistical analysis was conducted with Kruskal Wallis p>0.05**

	Session 1	Session 2	Session 3	Session 4	Session 5
Subject 5	6.1 (5.4, 7.4)	5.2 (4.4, 5.3)	5.0 (4.2, 5.2)	5.3 (5.0, 7.6)	5.1 (4.5, 5.3)

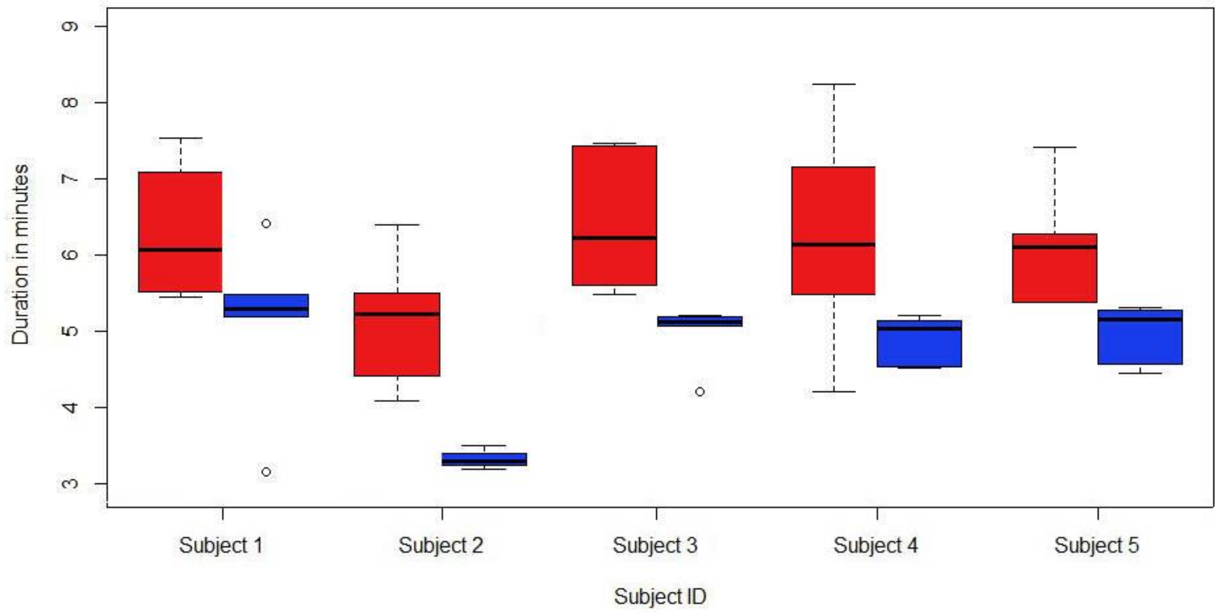

Figure 4.6: **Duration of all measurements of all five subjects on session 1 (red) and session 2 (blue) with the median (bold line), the 25 and 75 quartiles (lower and upper border of the box), the interquartile range (box), minimum and maximum (lower and upper whisker – dotted line) and the outlier (open dot)**

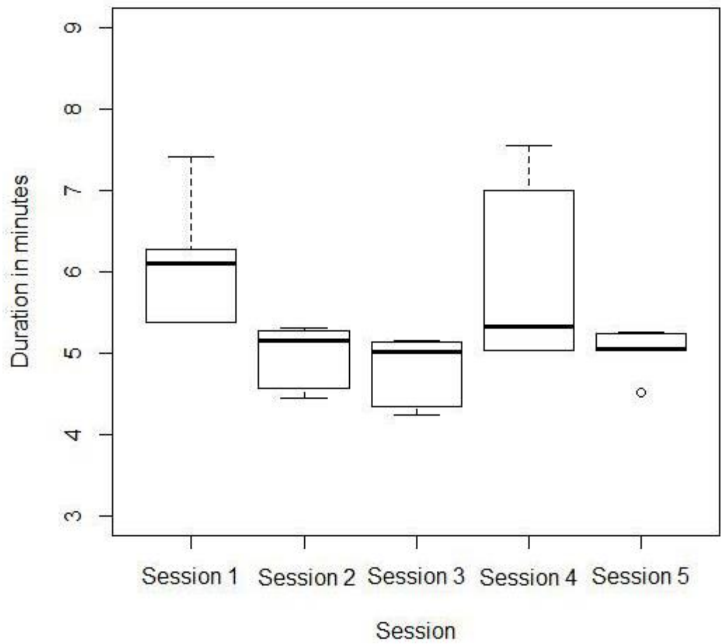

Figure 4.7: **Duration of all measurements of all sessions in subject 5 with the median (bold line), the 25 and 75 quartiles (lower and upper border of the box), the interquartile range (box), minimum and maximum (lower and upper whisker – dotted line) and the outlier (open dot)**

4.3 Visual analog scale questionnaire

Figure 4.8 illustrates each answer on question 1 (How do you feel about the test instructions?) of all 5 subjects on each measurement session, where 4 participants attended two sessions and 1 participant attended five sessions. The median of the answers of all 5 subjects on session one was 94 and on session two it was 99. There was no statistical significant ($p>0.05$) improvement in these experiences (Table 4.6).

Table 4.6: Statistical analysis of all 5 subjects regarding the question "How do you feel about the test instructions?" of the daily questionnaire showing sessions 1 and 2

	Session 1	Session 2	Wilcoxon-Test
N	Median (CI)	Median (CI)	
5	94.0 (92,100)	99.0 (92,100)	p>0.05

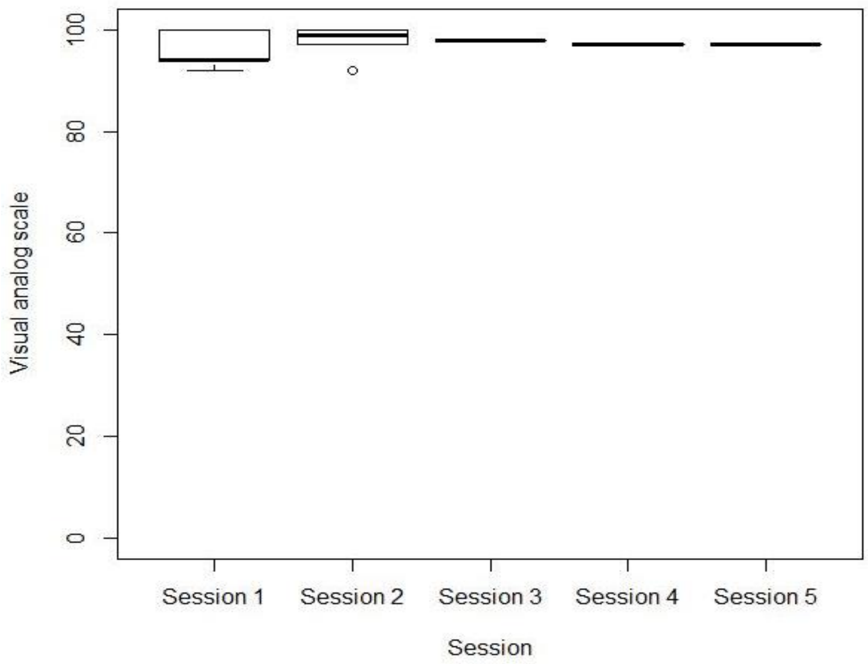

Figure 4.8: Comparison of the individual feeling about the test instructions on each session. Session 1 and 2 with 5 subjects and sessions 3 to 5 with 1 subject, median (bold line), 25 and 75 quartiles (lower and upper border of the box), IQR (box), minimum and maximum (lower and upper whisker – dotted line) and the outlier (open dot)

Answers of question 2 (How do you feel about the measurements of today's session?) differed between session 1 and session 2 with median scores of 71 and 89 (Table 4.7). This however, was not statistically significant. Figure 4.9 illustrates each answer provided by the participants at each session.

Table 4.7: Statistical analysis of all 5 subjects regarding the question "How do you feel about the measurements of today's session?" of the daily questionnaire showing sessions 1 and 2

	Session 1	Session 2	
N	Median (CI)	Median (CI)	Wilcoxon-Test
5	71.0 (39,87)	89.0 (51,100)	p>0.05

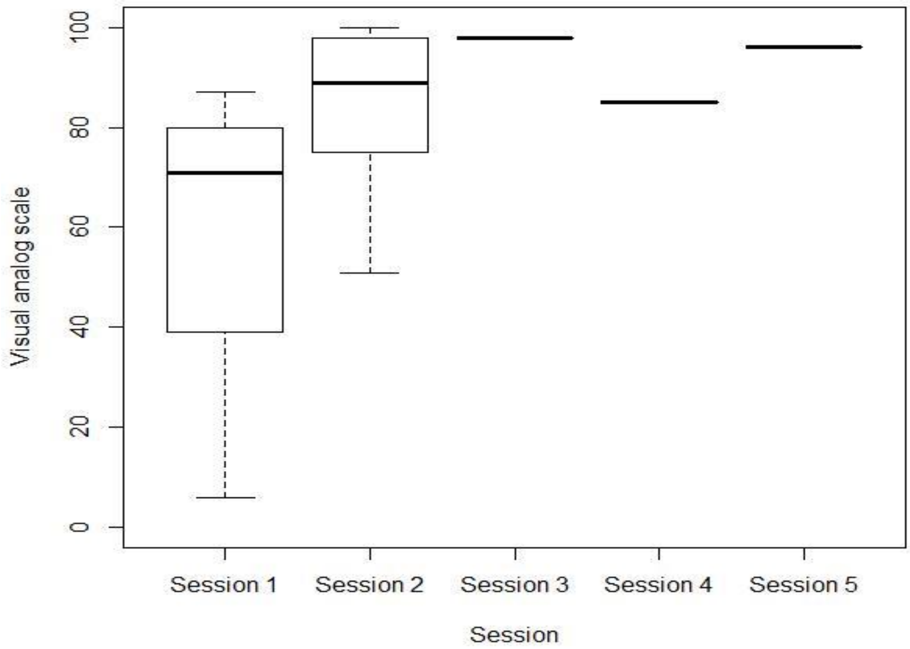

Figure 4.9: Comparison of the individual feeling about the measurement of today's session for each session. Session 1 and 2 with 5 subjects, sessions 3 to 5 with 1 subject, median (bold line), 25 and 75 quartiles (lower and upper border of the box), IQR (box), minimum and maximum (lower and upper whisker – dotted line) and the outlier (open dot)

The subjects answer of question 3 (How do you feel about the evaluation when looking straight ahead on the monitor?) on session 1 had a median score of 36.5. However, the score improved on session 2 to a median of 51.5 (Table 4.8) which was not statistically significant. Figure 4.10 illustrates these findings.

Table 4.8: Statistical analysis of all 5 subjects regarding the third question "How do you feel about the evaluation when looking straight ahead on the monitor?" of the daily questionnaire showing sessions 1 and 2

	Session 1	Session 2	
N	Median (CI)	Median (CI)	Wilcoxon-Test
5	36.5 (11,91)	51.5 (22,92)	p>0.05

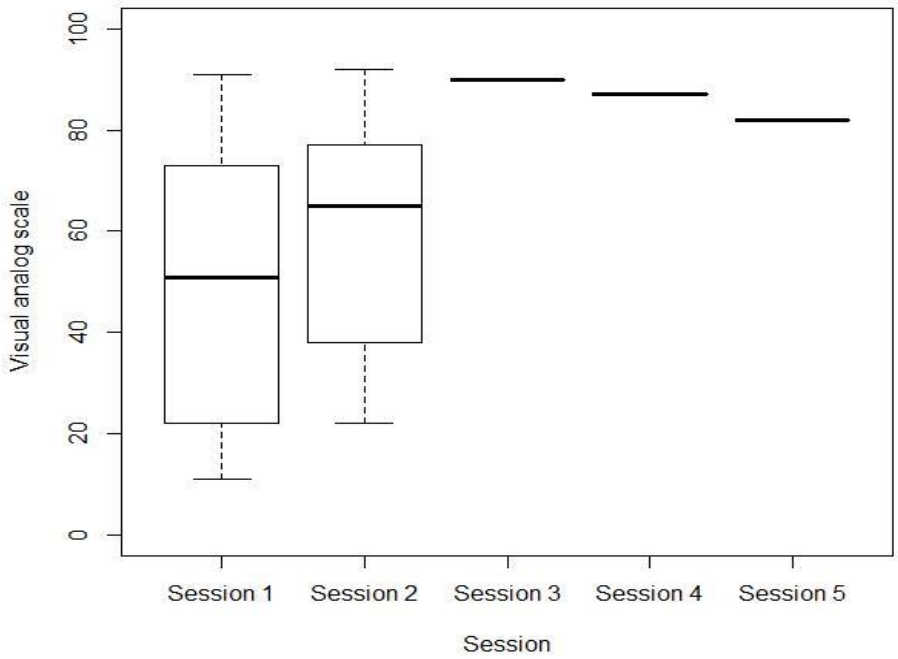

Figure 4.10: Comparison of the individual feeling about the evaluation when looking straight ahead on the monitor for every session. Five subjects on sessions 1 and 2 and one subject on sessions 3 to 5, median (bold line), 25 and 75 quartiles (lower and upper border of the box), IQR (box), minimum and maximum (lower and upper whisker – dotted line) and the outlier (open dot)

In the course of subject 5's five sessions the experience of the test instruction improved slightly with each visit, although not statistically significant (Table 4.9). Similar findings can be found in Table 4.10 on the experience of the session itself.

Table 4.11 shows the answers on the experience with the test while looking straight ahead on the monitor, which did not improve significant.

Table 4.9: Subject 5's response to question "How do you feel about the test instructions?" at all five measurement sessions

Session	1	2	3	4	5	Kruskal-Wallis-Test
Response	92	92	98	97	97	p<0,05

Table 4.10: Subject 5's response to question "How do you feel about the measurements of today's session?" at all five measurement sessions

Session	1	2	3	4	5	Kruskal-Wallis-Test
Response	80	98	98	85	96	p<0,05

Table 4.11: Subject 5's response to question "How do you feel about the evaluation when looking straight ahead on the monitor?" at all five measurement sessions

Session	1	2	3	4	5	Kruskal-Wallis-Test
Response	73	77	90	87	82	p<0,05

The examiner's feeling of the session with each subject on session 1 had a median score of 81 which increased significant to a median score of 91 on session 2 (Table 4.12).
For subject 5's five sessions, there was no significant difference in the examiner's response (Table 4.13).

Table 4.12: Statistical analysis of the examiner question "How do you feel about the measurements of today's session?" of sessions 1 and 2 on all 5 subjects

	Session 1	Session 2	
N	Median (CI)	Median (CI)	Wilcoxon-Test
5	81.0 (44,87)	91.0 (81,96)	p=0,05

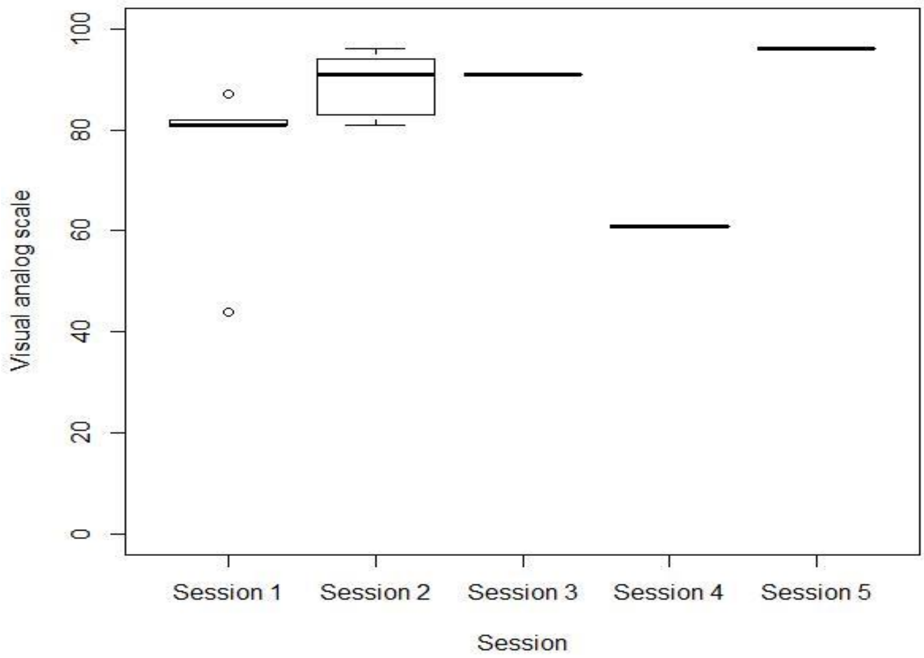

Figure 4.11: Comparison between five sessions on the examiners individual feeling during the measurements of all five subjects. Five on sessions 1 and 2 and one subject on sessions 3 to 5

Table 4.13: Answers of the examiner on the question "How do you feel about today's session?" of all five sessions in subject 5

Session	1	2	3	4	5	Kruskal-Wallis Test
Answer	82	83	91	61	96	p<0,05

4.4 Free comments

Comments are independent of the subject and in randomized order. The available and translated comments are listed in Table 4.14.

Table 4.14: Translation of additional comments on the questionnaire as provided by subjects

Subject ID	Session	Comment
2	1	While looking straight ahead on the monitor it depends on the point next to the monitor → E/F seem easy, A/B difficult Sometimes there are 3 rods (if rods are really close to each other and points E and F)
4	1	Left side was easier. Right side uncertain
4	2	The evaluation was easier on the second day
5	3	Rods that appear towards me are blurred, rods that are far away from the reference rod are hard to interpret as well

The examiner also gave comments on some sessions which can be found in Table 4.15.

Table 4.15: Translated comments of the examiner as given in the questionnaire

Subject ID	Session	Comment
1	1	Takes a lot of time, the image in between rarely appeared, sometimes it was grey
1	2	Bad reaction of the input device
2	1	Input device worked Fast, subject thought to have decoded the algorithm. Seems there is a cue when a lot of images were presented, followed by less
2	2	Very fast
3	1	Takes a lot of time with 5 measurements Image froze at the beginning (Repetition 1: -10°, 10°, 5°) From the view of the examiner, fixation rarely was lost (mostly in -15°)
4	1	Good course of measurement although the input device lost its function several times, meanwhile input was made by hand, then the input device worked again
4	2	Faster than last time, no technical difficulties Interruption during repetition 4 when a person entered the room and the door was left open → light
5	1	Difficulties with fixation Lots of head movements
5	2	Faster than day 1 Subject mentioned double images → Probably in the higher dB values
5	3	Input device was held upside down during repetition 3 point 10°
5	4	Input device without function during repetition 4 and 5 During repetition 1 the last two points were interrupted when a person entered the room

5. Discussion

Eccentricity

This study determined stereo acuity thresholds in various eccentricities of the visual field with a monitor-based two-rod-test. The results of all subjects of sessions 1 and 2 (Figure 4.3) as well as the additional results of three sessions in subject 5 were similar to previous literature on peripheral stereo acuity. Figure 4.3 illustrates the degradation of proximal and distal stereo acuity as well as visual acuity. In central vision both acuities can reach best values although deteriorate rapidly with increasing eccentricity.

In the healthy human eye, stereoacuity has been found to be 30 seconds of arc or better and under optimal conditions can improve to 2 seconds of arc (Coutant and Westheimer 1993). In the current study stereo acuity was found with a median of 3.16 seconds of arc for proximal and 19.95 seconds of arc for distal displacement. However, these findings are not valid all over the retina (Figure 4.3) which confirms the small amount of previous literature (Figure 5.1 and Figure 5.2) on decreasing stereo acuity thresholds in the peripheral field (Berke 2009, Kaufmann and Steffen 2012).

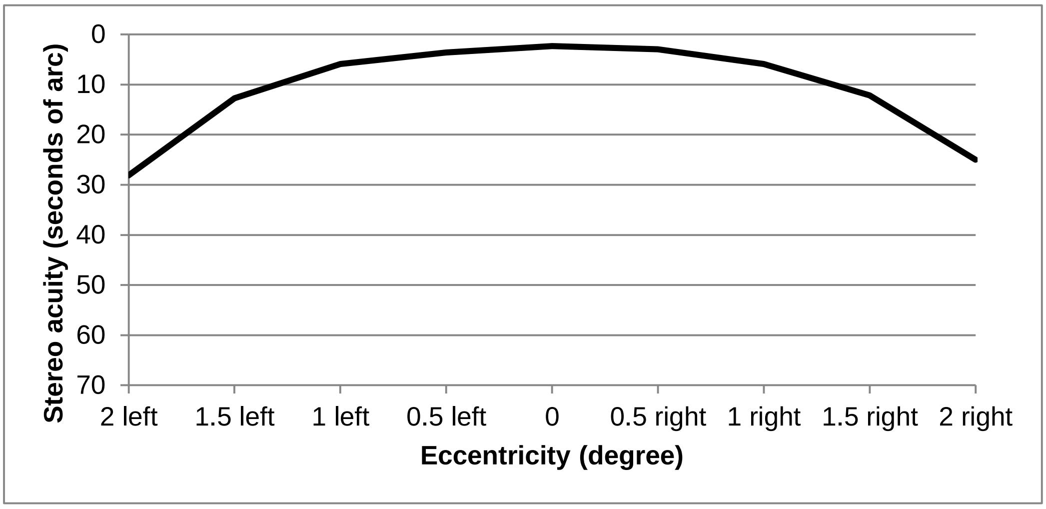

Figure 5.1: **Stereoacuity threshold at various eccentricities of the retina adapted from Münschke, 1989**

The degradation of stereo acuity is similar to the degradation of visual acuity (Fendick and Westheimer 1983). Although there is no evidence of mutual influence between stereoacuity and visual acuity as the former can be found even with low visual acuity and vice versa (Burian 1951).

The current study confirms these findings, however the distal findings seem to disprove them. The varying results of the distal measurements are meaningless as there is a high statistical dispersion besides this study is limited by various bias, which will be discussed in the following.

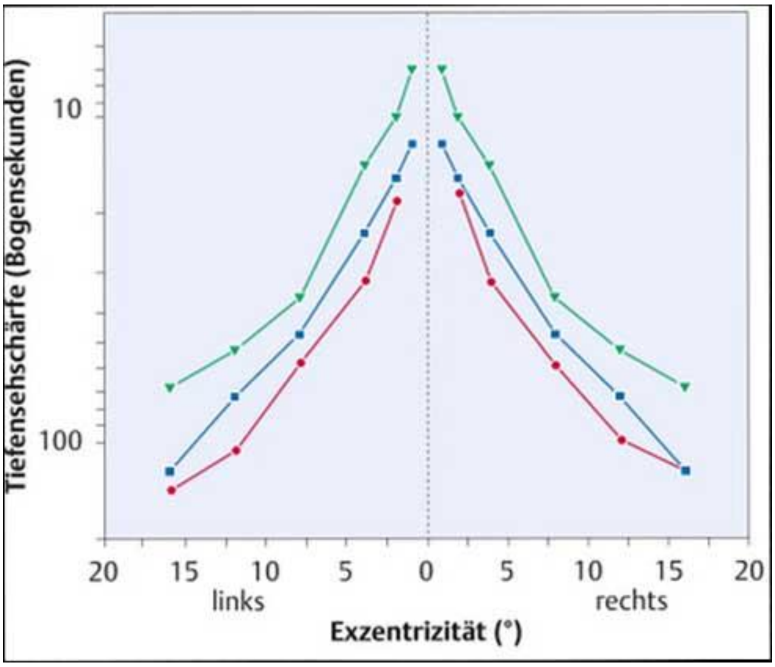

Figure 5.2: **Stereoacuity in various eccentricities. Red and blue line: fixation distance 40 cm, green line 76 cm (Kaufmann, 2012)**

Even though there is hardly any evidence on the degradation being due to the declining visual acuity outside the fovea (Kaufmann and Steffen 2012), the stereo acuity degradation is only slightly steeper than visual acuity degradation (Fendick and Westheimer 1983). Findings on spatial frequency (Siderov and Harwerth 1995) being the underlying reason were disproved by Wardle et al who found early loss of precision in horizontal disparity (Wardle et al. 2012). Other research linked the decreasing stereo acuity in the peripheral field to the magnitude of retinal neurons and cells (Mochizuki et al. 2012). Thus stereo acuity is dependent on the information processed in the human visual cortex. However in the peripheral field perception for uncrossed disparities was found to be better than for crossed disparities (Devisme et al. 2008). The current study found confirming evidence in some of the subjects and eccentricities. Table 4.1 shows that especially in central vision the reverse is true, which is confirmed by ample evidence. Howard and Rogers amongst other researchers, found that crossed (proximal) disparities are detected more precisely than uncrossed (distal) disparities (Howard and Rogers 2011, Schumer and Julesz 1984, Landers and Cormack 1997). This probably is due to evolution as an object with crossed disparity comes towards the observer which triggers the grasping reflex.

Repetition

The findings of central stereo acuity thresholds in the subjects of the current study support other studies in which it has been found to be between 10 and 30 seconds of arc (Berke 2009) and under best conditions had reached 2 to 6 seconds of arc (Howard and Rogers 2011). All subjects in the current study were young adults (age range 21-23 years) and did not show any optical or ophthalmic abnormalities in the initial examination. The inclusion criteria to this study were fulfilled in all subjects and expectation of central stereo acuity thresholds were testified. When the individual results of each measurement were examined, there were great variations for each subject and each repetition. However, this is diminished by building the median over all repetitions. There were no significant differences in repetition of the monitor-based two-rod-test in any of the examined eccentricities. Although repeatability of the test was found, it is different for each of the measured eccentricities (Figure 4.4 and Figure 4.5). These results show better correlation of repetition than the findings of Antona et al who investigated the repeatability of some of the most commonly used stereoacuity tests (for near vision) and found best repeatability coefficient of ±13 and ±12 seconds of arc with the Frisby test and Titmus test respectively (Antona et al. 2015). Schiefer et al, who compared the Kolling distance vision stereo test and commonly used stereo tests, found evidence for better performances in near stereo acuity tests than in distant ones (Schiefer et al. 1989). As this is different to the current findings, the monitor-based two-rod test should be compared to near vision tests in a future study.

Duration

The duration of each repetition of each of the 7 eccentricities was measured (section 4.2). These results show that the applied algorithm was concomitant with fast responses. All subjects except one showed significant reduction in duration between measurements, which probably is due to a habituation to the task. The study did not take especially strict care about a tiring effect, however there were no superficial signs of this. Therefore, it is to assume that the duration of the monitor-based two-rod test is acceptable to examiner and subject.

Limitations of this study

During this explorative study various factors which influenced the test course became obvious. There were technical difficulties with the input device. During four points of measurement in two subjects (4 and 5), the device lost its function. During the loss of device function, the input of those rounds were made by the subjects telling the examiner “in front of” or “behind” and the examiner manually recording the responses. Therefore, there was the possibility of false input through the examiners failure and false response times due the two persons involved. There was no repetition of those rounds in order to not change the numbers of trial and the results of those rounds were not excluded for the same reason. With every other measurement the original device was tested and used in order to maintain the same test conditions for each subject and each point of measurement. Only in the above listed cases the examiner had to make the input by hand and no other device was used.

The input device was a small, flat and rectangular presenter with buttons embossed only slightly. Therefore, in one case (subject 5, session 3, round 3, point 10°) the device was held upside down, which led to false responses in this point. Due to the unusual fast round it was noticed and corrected for the remaining measurement points and did not occur at any other measurement. The results of these rounds however were included in order to not change the number of trials. These and the following issues not only might have influenced duration times, they also could have had major impact on repeatability and determination of thresholds in general.

The test included only a small number of trials which might be a bias. Bomer et al suggest at least 100 trials for an accurate estimation of stereo acuity threshold which has been confirmed by Bach and colleagues (Bomer et al. 1995, Bach et al. 2001). The above mentioned false results might have had minor impact when the test followed Bomers suggestion.

The probability of successful guesswork with only two possible answers was 50 %. Repeating each measurement 5 times was thought to reduce the potential error. With the results greatly varying, it is possible that guesswork was still successful. The best PEST method (Lieberman and Pentland) used by other studies on stereo acuity tests is more accurate, yet as fast as the applied algorithm. Rework of the algorithm regarding accuracy might be appropriate to reduce guesswork and increase the number of trials, which might lead to more stable results of stereo acuity thresholds. Rework of the algorithm with reference to the staircase method and the end of range of images is recommended as well. As described in section 3.6.1 there was a failure in the algorithm when the staircase method reached either one end of images. The range of images ended with 30 dB (respectively 1000 seconds of arc) and 0 dB (1 second of arc). If results were taken from the original data, thresholds near the end of the range were likely to be incorrect as the algorithm changes step sizes and direction in that area. Evaluation by hand resolved that problem, though evoked another failure of missing the correct value.

In two subjects (4 and 5) there was a change of conditions during another four points of measurement when the door was opened and a non-test-related person entered the room. Subjects lost fixation and concentration, though were asked quickly to remain on the fixation point and continue with the measurement. When the door was opened and in one case was left open during the time of disturbance, the light arrangement inside the room was changed. This led to different light conditions due to a different room illuminance level, which influenced level of adaptation, hence contrast sensitivity (Okada et al. 2006, Pestilli et al. 2007). Michelson-contrast of the stereo target was determined to be 0.85 when optimal test conditions (see section 3.2) were secured. This is recommended as the minimum contrast in the determination of visual acuity, so VA is independent of the luminance level (Diepes 2004). Thus even small modifications of light conditions can have considerable influence on the results. Measurements where external disturbances were experienced did not result in the remaining tests to be paused. Pausing would have halted the algorithm and repeating the disturbed points would have led to a different number of trials than in the other sessions and subjects. Albeit being influenced, the results did not show great deviation from the others. As in the case of the upside down input device mentioned earlier, these measurements were included and might have major impact to the evaluation of the results.

Loss of fixation could be another potential bias to this study. Due to the course of 7 eccentricities which were measured each 5 times, each session required concentration over the time of one hour. Between each repetition, the session included a pause as long as the subject needed. The pauses were kept as short as possible though. Concentrating and undertaking a monotonous task over a certain amount of time, might be tiring. Attention influences visual tasks and fixation might be lost when attention diminishes (Carrasco 2011). When a stereo test is set up, the effect of fatigue should be kept in mind. In the current study subjects were asked to place their chin and forehead in a chin and head rest, so head movement was minimized. Head movements would lead to different viewing angles and different positions for each subject. Therefore, the measurements would not be comparable and a repetition would not be possible as it is not secured that the position is the same. Furthermore, in a test construction with real depth objects, this would lead to cues and influence the outcomes. Participants also were instructed to always fixate the directed fixation point on the wall and not move their eyes unless told otherwise. The examiner observed head and eyes of the subjects though it was not possible to discern each movement. If a major movement was detected, subjects were advised not to move the head or eyes. Especially in the first couple of measurements subjects were observed to move the head as performing the test in eccentricities above 5° were perceived to be difficult. Each movement changed the angle of gaze and therefore it cannot be entirely assured that the test results belong to the scheduled 0°, 5°, 10° and 15° of the right and left visual field. Fixation might be lost due to other stimuli in the visual field such as the other markings on the wall (Figure 3.2). Each fixation point was presented constantly during the period of measurement and might have served as stimulus to lose fixation. The input device as described above might also have distracted from fixating the points as one might be tempted to follow one’s fingers to the correct button on the device. A less distracting input device should be used or constructed for future tests. It is possible to construct a device, especially made for the input of only two possible responses. Furthermore, subjects might have tried to please the examiner or wanted to achieve the best result, which might lead to glances on the monitor. Nevertheless, in this explorative study it was sufficient to assume there were no failures in gaze direction and all results were able to be evaluated.

Monocular and binocular cues to solve the test were thought to be non-existent. However, two subjects (2 and 5) did mention differences in color and shape of the rods when certain images were displayed. These two participants also mentioned that more than two rods were visible in some images, which made the assessment more difficult to determine the direction of the stereoscopic image.
These findings were also detected during the preparations of this study. When stereoscopic images with wider disparities were displayed, color gradients in the left rod and doubling were observed. Both observations can be attributed to the construction of stereoscopic images on a 3D monitor. As this only occurred in images above 18 dB and therefore above 63.10 seconds of arc its influence to the test results were not considered significant prior to the study commencement. However, the start images in the eccentricities and some detected thresholds were above 18 dB. Therefore, these measurements were biased considerably and stereoscopic images should be reworked.

Decentration of spectacle lenses can reduce stereo acuity due to an induced prism effect (Jiménez et al. 2000). Similar effects might have occurred when eccentricities were evaluated with the same instructions as in the current study. As head movements were not allowed, fixation on eccentricity points meant subjects wearing spectacle correction would gaze through peripheral portions of the lenses which might affect stereoacuity. Especially when progressive lenses are worn, this also reduces visual acuity with the distortion areas. Some studies found evidence for decreased stereo acuity when visual acuity was decreased (Roggenkämper 1983, Goodwin and Romano 1985). Glasses that are not fully corrective also evoke reduced visual acuity which makes full correction necessary. In the current study, four subjects did not wear glasses and one did. Results of the subject with glasses did not vary conspicuously from the others and all participants had visual acuity well above the requirements (section 3.1) with and without glasses respectively. A comparison of stereo acuity with and without correction while having visual acuity above 0.8 might be interesting and could be content of a future study. Lee and Koo found decreased stereoacuity in age groups above 40 years in both near and distant stereo tests (Lee and Koo 2005). Age of subjects should be considered in testing stereo acuity as well as refractive error of the subjects.

Learning

Improving stereoacuity can be achieved with a higher number of test sessions (Fendick and Westheimer 1983, Xi et al. 2014). This is attributed to a learning effect, though there are findings by Sowden et al that such an effect does not exist (Sowden et al. 1996). In the study conducted by Fendick and Westheimer, the stereo target was presented within 5° eccentricity to the fovea and improvement of stereoacuity was found after 2000 trials (Fendick and Westheimer 1983). In the present study, observations of a possible learning effect were made only in one subject (subject 5), who attended five sessions. From Table 4.3 an effect might be detected, however it was not significant. In total the subject was presented each eccentricity 25 times over the course of one week. Other studies on practicing stereo acuity tests, mention many more trials (Schmitt et al. 2002). Despite the assumption that there is a learning effect as some thresholds were better at the repetitive sessions (Table 4.2 and Table 4.3), the current study only indicated a possible learning effect and more stimulus presentations are recommended to get meaningful results on this. However, each subject mentioned to be more experienced in the follow up sessions. The answers on the questionnaire were not confirming these experiences, therefore this might be a subjective feeling rather than an actual effect.

Questionnaire

To improve the monitor-based two-rod-test and its real conversion, a questionnaire for examiner and participants was made of visual analog scales. From these, the test instructions seem to be clear and easy to understand. None of the participants had any additional questions and the course of measurements was understood after the first few stimuli. Subjects did not appear to experience improvement between repetitions of the measurement. There were no statistical significant improvements in the response of the second question of the visual analog scale questionnaire. The measurements did not appear to be appealing to the subjects at session 1, assumingly because of the time consuming monotonous task. This improved only slightly in the follow up session, which is probably due to the decreasing duration time.

The third question was about the feeling on the judgment while looking straight ahead on the monitor. Subjects answered it to be rather bad, which did not improve significant on the follow up. Unfortunately, subjects did not explain these feelings with any comments. There might have been an awkward formulation of the question and participants might have interpreted another meaning in it.

The examiner, however seemed to get used to the test course as the answers show significant differences (Table 4.13). During the course of the test, the examiner mainly observed the participant. This assumingly was easier when a few rounds were finished, as it became obvious which movements need to be considered. Furthermore, abnormalities within the measurement course were noticed faster than at the beginning. Participants seemed to get used to the test during the repetitions and were much faster in the repetitive sessions. From the examiners point of view, fixation was lost less in the repetitions than at the beginning.

All persons involved were asked to give free comments on the test, which only some participants did. They felt the test getting easier on the follow up sessions and the assessments at the left visual field to be easier than the right. However, there were no results to confirm these feelings. As mentioned above, there were technical difficulties in the presentation of stereoscopic images, which rarely were noticed by the subjects.

Evidence from the current study is limited due to its pilot character with only five participants. Significant findings can only be made in larger subject cohorts. Therefore, future studies on the monitor-based two-rod test should be made with a larger subject cohort.

6. Conclusion

In conclusion, the determination of stereo acuity thresholds with the monitor-based two-rod test is reproducible, even though proximal values show better repeatability than distal values. It is dependent on the eccentricity of the binocular visual field where measurements of the central stereo acuity are more repeatable than the greater eccentricities.

With increasing eccentricity, the stereo acuity increases and best stereo acuity was found in central vision. The median of central proximal stereo acuity was 3.2 seconds of arc and the central median of distal stereo acuity was 19.9 seconds of arc, whereas the eccentric median was up to 112.2 seconds of arc at 15° to the right and left of the visual field.

Median duration time was 5.3 minutes, which makes the monitor-based two-rod test a fast procedure to measure several fixation points.

Albeit these findings this study was limited by having only 5 subjects, an imperfect algorithm and imperfect stereoscopic images that showed color gradient or doubling. Furthermore, the results were influenced by changed conditions due to disturbances of the measurements.

7. Future prospects

The findings of this study will be of great use to future studies on monitor-based and free-sighted two-rod stereo tests. Currently a free sighted test is under construction at Aalen University. Findings of the current study are supposed to improve the monitor-based two-rod test for future studies and a comparison with the free-sighted version. Improvements on the test have to be done in order to get better results and to get a comparable assembling. First of all, the input device has to be improved to minimize the urge to loose fixation and possible input failures. Next, disturbances during the measurements that change and influence the test conditions and also evoke loss of fixation have to be strictly avoided. The algorithm underlying the test program and its determination of the threshold have to be reworked especially when the end of the range of the stereoscopic images is reached. The program deviates from the correct step sizes of the staircase method which was applied, which evokes failure in the sequence of testes images and therefore failure in the results.

List of figures

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Appendix

Data CD

Probandenaufklärung_ Vs.2016-01-23 (6)
Studien-ID: **2RodMon**
Patienten-ID:____________
Untersuchungsdatum: ⌊ ⌊ ⌊ ⌊⌋-⌊ ⌊⌋-⌊ ⌊⌋

Bestimmung der Tiefenwahrnehmung mit dem 2-Stäbchen-Test am Monitor

a) Das Ziel des Vorhabens ist die Messung der Tiefenwahrnehmung (3D-Sehen) beim Blick geradeaus (0°) und bei seitlichen Blicken (5°, 10° und 15° nach rechts und links) sowie deren Übereinstimmung bei Wiederholungen

b) Messung der Untersuchungsdauer und der probanden- sowie untersucherseitigen subjektiven Einschätzung

Probandenaufklärung

Sehr geehrte Probandin, sehr geehrter Proband,
die oben genannte Studie führen wir durch, um zu messen, inwiefern sich der Betrag der Tiefenwahrnehmung bei verschiedenen Blickwinkeln ändert und wie stark diese Messergebnisse bei einer Wiederholungsmessung schwanken.

Überblick

Die Untersuchung zur Bestimmung der Tiefenwahrnehmung (3D-Sehen) erfolgt mit einem sogenannten 2 Stäbchen Test an einem 3D Monitor. Es werden zwei Balken auf einem Monitor gezeigt, die aus unterschiedlichen, vorgegebenen Blickrichtungen dahingegen beurteilt werden sollen, ob ein links im Bild positionierter „Messbalken" nach vorne (also auf Sie zu) oder nach hinten (also von Ihnen weg) im Vergleich zu einem rechts im Bild positionierten „Vergleichsbalken" befindet (siehe Abbildung 1).

Fragestellung

Teil a) der Studie untersucht die Ergebnisse der Tiefenwahrnehmung (3D-Sehen). Des Weiteren wird hier untersucht, wie gut man die Messmethode wiederholen kann und wie anfällig sie für Störungen und Fehler ist. In Teil b) geht es darum zu ermitteln, wie Sie als Proband mit dem Test zurechtgekommen sind und ob Sie den Test als anstrengend, ermüdend oder ähnliches einschätzen. Neben Ihrer Einschätzung wird auch von dem Untersucher eine subjektive Bewertung erstellt. Zudem werden hier für jeden Test die Durchlaufzeiten festgehalten.

Page 1 of the subject's information

Hochschule Aalen

Probandenaufklärung_ Vs.2016-01-23 (6)
Studien-ID: 2RodMon
Patienten-ID:___________
Untersuchungsdatum: ____-__-__

Hintergrund

Die Tiefenwahrnehmung gilt als die höchste Stufe des beidäugigen Sehens und gibt Aufschluss über die Entfernung zweier Gegenstände zueinander. Verschiedene Teste zur Tiefenwahrnehmung lassen Rückschlüsse darauf ziehen, inwiefern beide Augen am Sehen beteiligt sind. Daher werden diese auch in Geräte zur Messung der Sehfunktionen integriert. Da bei dieser Vorgehensweise lediglich künstlich erzeugte Tiefenunterschiede dargestellt werden können, ist die Übertragung der Ergebnisse auf tatsächliche Gegebenheiten nicht ohne weiteres möglich. Eine spätere Studie wird in einem realen Testaufbau einen „echten" 2-Stäbchen-Test mit dem 2-Stäbchen-Test am Monitor vergleichen. Die Studie „Bestimmung der Tiefenwahrnehmung mit dem 2-Stäbchen-Test am Monitor" soll grundlegende Erkenntnisse für spätere Messungen liefern, die dann zeigen, wie verlässlich die Messung mit künstlich generierten Tiefenunterschieden ist.

Ablauf der Studie im Detail

Allgemein

Bitte versuchen Sie, bei dem Test ruhig auf dem Stuhl zu sitzen. Starke Kopfbewegungen können die Messergebnisse beeinflussen. Um diese zu vermeiden, stützen sie Ihr Kinn und Ihre Stirn bitte in der vorhandenen Kinn- und Kopfstütze ab. Antworten Sie bitte zügig und ohne Ihre Augen zusammenzukneifen. Blicken Sie bitte während des Testes durchgehend auf den Ihnen genannten Punkt, ein Abweichen davon kann die Messergebnisse beeinflussen.

2-Stäbchen-Test am Monitor

Bei dem 2-Stäbchen-Test am Monitor sehen Sie zwei schwarze Balken (Abb. 1). Während jedes Durchgangs sehen Sie mehrere Bilder dieser Darstellung, wobei Ihnen jeweils der linke Balken vor oder hinter dem Bildschirm erscheint. Die Durchgänge erfolgen beim Blick geradeaus und bei seitlichen Blickrichtungen nach links bzw. nach rechts. Es wird mehrere Durchgänge geben die auf zwei Tage verteilt sind.

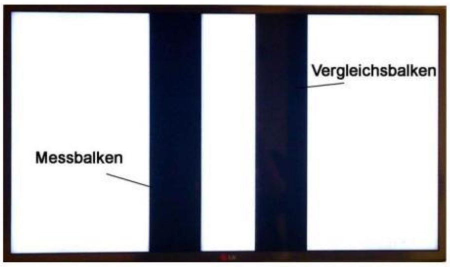

Abbildung 1: 2-Stäbchen-Test am Monitor

Ihre Aufgabe besteht darin, zu beurteilen, ob der linke Balken vor oder hinter der Bildschirmebene und dem rechten Balken erscheint. Blicken Sie dabei stets auf den Ihnen jeweils genannten Punkt und entscheiden Sie sich für eine der beiden Richtungen, auch wenn Sie keinen Unterschied erkennen können. Beachten Sie die Anweisung des Untersuchers, bis der Test beendet ist.

Page 2 of the subject's information

Voruntersuchungen

Vor den Tests werden folgende Voruntersuchungen von Prof. Dr. med. Ulrich Schiefer durchgeführt:

- Augenbeweglichkeitsuntersuchung
- Untersuchung der Augenstellung
- Untersuchung zum Pupillenspiel
- Vergleich der Pupillengröße
- Spiegeln des Augenhintergrundes
- Spaltlampenuntersuchung (vorderer Augenabschnitt)

Folgende weitere Messungen werden durchgeführt:

- Bestimmung der Sehschärfe
- Test des räumlichen Sehens
- Vermessung der getragenen Brille

Nebenwirkungen

Es sind keine Nebenwirkungen durch die Teste bekannt. Sämtliche angewandte Methoden sind nicht invasiv. Das heißt es werden keine Eingriffe vorgenommen oder Untersuchungen getätigt, welche länger anhaltende Beeinträchtigungen mit sich ziehen. Lediglich durch die Spaltlampenuntersuchung kann es zu einer kurzzeitigen Blendung kommen. Daher wird die Fahrtüchtigkeit durch die Teilnahme an dieser Studie nicht eingeschränkt.

Zeitaufwand

Die Untersuchungen finden an drei Terminen statt. Zunächst finden Voruntersuchungen bei Prof. Dr. med. Ulrich Schiefer und die Befragung bezüglich augenbezogener und allgemeiner Erkrankungen statt. Diese Voruntersuchungen werden insgesamt ca. 45 Minuten beanspruchen.

Während der beiden folgenden Termine werden die eigentlichen Messungen zur Tiefenwahrnehmung durchgeführt. Jeder dieser Termine dauert ca. 60 Minuten.

Alle Termine haben einen zeitlichen Abstand von mindestens 24 Stunden und maximal 7 Tagen zueinander.

Beachten Sie bitte, dass an diesen drei Terminen Kontaktlinsen erst nach der Untersuchung/Messung getragen werden dürfen. Tragen Sie vorher und während der Termine Ihre Brille.

Page 3 of the subject’s information

Hochschule Aalen

Probandenaufklärung_ Vs.2016-01-23 (6)
Studien-ID: 2RodMon
Patienten-ID:___________
Untersuchungsdatum: |_|_|_|_|-|_|_|-|_|_|

Das Aufklärungsgespräch hat geführt:

Prof. Dr. med. Ulrich SCHIEFER
ulrich.schiefer@htw-aalen.de

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Hochschule Aalen
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Fax: + 49 - 7071 29 -5038

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www.uni-tuebingen.de

Erklärung der aufklärenden Person:

Hiermit erkläre ich, den/die o.g. Teilnehmer/in am ___________________________ über Wesen, Bedeutung, Tragweite und Risiken der o.g. Studie mündlich und schriftlich aufgeklärt und ihm/ihr eine Ausfertigung dieser Probandenaufklärung sowie der Einwilligungserklärung übergeben zu haben.

____________________________ ____________________________
Ort, Datum Unterschrift Prof. Dr. med. Ulrich Schiefer

Page 4 of the subject's information

Hochschule Aalen

Einwilligungserklärung_Datenschutz_Vs.2016-01-28 (4)
Studien-ID: **2RodScreen____**
Untersuchungsdatum: └┴┴┴┘-└┴┘-└┴┘

Bestimmung der Tiefenwahrnehmung mit dem 2-Stäbchen-Test am Monitor

a) Das Ziel des Vorhabens ist die Messung der Tiefenwahrnehmung (3D-Sehen) beim Blick geradeaus (0°) und bei seitlichen Blicken (5°, 10° und 15° nach rechts und links) sowie deren Übereinstimmung bei Wiederholungen

b) Messung der Untersuchungsdauer und der probanden- sowie untersucherseitigen subjektiven Einschätzung

Einwilligungserklärung zum Datenschutz

Sehr geehrte Probandin, sehr geehrter Proband,
bei wissenschaftlichen Studien werden persönliche Daten und medizinische Befunde über Sie erhoben. Die Weitergabe, Speicherung und Auswertung dieser studienbezogenen Daten erfolgt nach gesetzlichen Bestimmungen. Die Teilnahme an der o.g. Studie setzt folgende Einwilligung voraus:

Hiermit willige ich ein,
dass zum Zwecke der oben genannten Studie folgende personenbezogene Daten von mir erhoben und nur pseudonymisiert (also mit einem Verschlüsselungscode versehen) gespeichert werden:

1. Geschlecht
2. Geburtsdatum
3. Sehschärfe
4. Brillenkorrektion
5. Augenbezogene Befunde (s. Dok. Augenbefund)
6. Augen-/Allgemeinvorgeschichte (s. Dok. Anamnesebogen)

Diese Daten dürfen nur pseudonymisiert auf elektronischen Datenträgern aufgezeichnet und verarbeitet werden. Ich bin auch damit einverstanden, dass die Studienergebnisse in anonymer Form, die keinen Rückschluss auf meine Person zulassen, veröffentlicht werden.

Seite 1 von 2

Page 1 of the declaration of consent on data protection

Hochschule Aalen

Einwilligungserklärung_Datenschutz_Vs.2016-01-28 (4)
Studien-ID: 2RodScreen____
Untersuchungsdatum: ____-__-__

Mir ist bekannt, dass ich meine Einwilligung jederzeit ohne Angabe von Gründen und ohne nachteilige Folgen für mich zurückziehen und einer Weiterverarbeitung meiner Daten mit Wirkung für die Zukunft jederzeit widersprechen und ihre Löschung bzw. Vernichtung verlangen kann.

☐ Ich willige des Weiteren ein, dass meine Kontaktdaten elektronisch gespeichert werden zum Zwecke der Kontaktaufnahme für weitere Studien, für die ich als Proband in Frage käme. Dieser Speicherung und der Kontaktaufnahme kann ich jederzeit widersprechen.

- Name, Vorname:______________________
- Straße & Haus-Nr.:______________________
- Telefon:______________________
- E-Mail:______________________

Ich bevorzuge die Kontaktaufnahme via ☐ Post ☐ Telefon ☐ E-Mail

______________________ ______________________
Ort, Datum Unterschrift des/der Teilnehmers/in

Seite 2 von 2

Page 2 of the declaration of consent on data protection

Hochschule Aalen

Einwilligungserklärung_Vs.2016-01-28 (5)
Studien-ID: **2RodMon__**
Untersuchungsdatum: └┴┴┴┘-└┴┘-└┴┘

Bestimmung der Tiefenwahrnehmung mit dem 2-Stäbchen-Test am Monitor

a) Das Ziel des Vorhabens ist die Messung der Tiefenwahrnehmung (3D-Sehen) beim Blick geradeaus (0°) und bei seitlichen Blicken (5°, 10° und 15° nach rechts und links) sowie deren Übereinstimmung bei Wiederholungen

b) Messung der Untersuchungsdauer und der probanden- sowie untersucherseitigen subjektiven Einschätzung

Einwilligungserklärung zur Durchführung der Versuche

Hiermit willige ich ein,
dass an mir zum Zwecke der oben genannten Studie folgende Messungen/Untersuchungen durchgeführt werden dürfen:

1. Bestimmung der Sehschärfe (mit und ohne Brille)
2. Vermessung der getragenen Brille
3. Test des räumlichen Sehvermögens
4. Spaltlampenuntersuchung (vorderer Augenabschnitt)
5. Spiegeln des Augenhintergrundes (Netzhaut)
6. Vergleich der Pupillengröße R/L
7. Messung zum Pupillenspiel R/L
8. Messung zur Augenstellung
9. Messung zur Augenbeweglichkeit

Ein ausführliches Informationsblatt liegt den Unterlagen bei.

Name:_________________________ Vorname:_______________________

Geb.-Datum: └┴┘ └┴┘ └┴┴┴┘ Geschlecht: weiblich ☐ männlich ☐

_____________________________ _____________________________
Ort, Datum Unterschrift des/der Teilnehmers/in

Seite **1** von 1

Declaration of consent on the test

Hochschule Aalen

Anamnesebogen_Vs 2016-01-28 (5)

Studien ID: 2RodMon______
Patienten ID: ____________
Untersuchungsdatum: ☐☐☐☐ ☐☐ ☐☐

Anamnesebogen

Augenanamnese	Ja	Nein	Falls ja, ab welchem Lebensjahr bzw. wann wurde Erstdiagnose gestellt?	Welches Auge ist betroffen? R/L	Ergänzungen
1. Brillenträger?	☐	☐	☐☐. Lj.		____________ ____________
2. Kontaktlinsenträger?	☐	☐	☐☐. Lj		____________ ____________
3. Sehen Sie auf beiden Augen mit Korrektion gleich gut?	☐	☐			____________ ____________
4. Sind Sie Schwachsichtig? (Amblyopie)?	☐	☐	☐☐. Lj	R ☐ L ☐	____________ ____________
5. Schielen bekannt?	☐	☐	☐☐. Lj	R ☐ L ☐	____________ ____________
6. Doppelbilder?	☐	☐			____________ ____________
7. Augenbewegungsstörungen	☐	☐			____________ ____________
8. Grauer Star (Katarakt)?	☐	☐	☐☐. Lj	R ☐ L ☐	____________ ____________
9. Grüner Star (Glaukom)?	☐	☐	☐☐. Lj	R ☐ L ☐	____________ ____________
10. Netzhauterkrankungen? (z.B. Netzhautablösung,..)	☐	☐	☐☐. Lj	R ☐ L ☐	____________ ____________

Seite 1 von 3

Page 1 of the history form

Hochschule Aalen

Anamnesebogen_Vs 2016-01-28 (5)

Augenanamnese	Ja	Nein	Falls ja, ab welchem Lebensjahr bzw. wann wurde Erstdiagnose gestellt?	Welches Auge ist betroffen? R/L	Ergänzungen
11. Makulaerkrankungen?	☐	☐	☐☐. Lj	R ☐ L ☐	______ ______
12. Schwere chronische Augenentzündungen?	☐	☐	☐☐. Lj	R ☐ L ☐	______ ______
13. Augenverletzungen?	☐	☐	☐☐. Lj	R ☐ L ☐	______ ______
14. Augen-Operationen?	☐	☐	☐☐. Lj	R ☐ L ☐	______ ______
15. Augenmedikamente? (Tropfen/Salben)	☐	☐	☐☐. Lj	R ☐ L ☐	______ ______
16. Sind in Ihrer Familie Augenerkrankungen bekannt? (z.B. hohe Fehlsichtigkeiten, Glaukom [Grüner Star], Katarakt [Grauer Star], Netzhautablösung, Farbsehstörungen,....)	☐	☐			______ ______ ______ ______ ______

Allgemeinanamnese	Ja	Nein	Falls ja, ab welchem Lebensjahr bzw. wann wurde Erstdiagnose gestellt?	Ergänzungen
1. Herz- Kreislauferkrankung?	☐	☐	☐☐. Lj	______ ______
2. Andere Organerkrankung? (z.B. Leber, Niere, Magen,..)	☐	☐		______ ______
3. Neurologische Erkrankungen? (z.B. Schlaganfall, Epilepsie,..)	☐	☐	☐☐. Lj	______ ______

Seite 2 von 3

Page 2 of the history form

Hochschule Aalen

Anamnesebogen_Vs 2016-01-28 (5)

Allgemeinanamnese	Ja	Nein	Falls ja, ab welchem Lebensjahr bzw. wann wurde Erstdiagnose gestellt?	Ergänzungen
4. Stoffwechselerkrankung? (z.B. Blutzucker, Schilddrüse, Fettstoffwechsel,..)	☐	☐	☐☐. Lj	___
5. Seelische Erkrankungen?	☐	☐	☐☐. Lj	___
6. Schwangerschaft?	☐	☐		___
7. Medikamenteneinnahme?	☐	☐	☐☐. Lj	___
8. Medikamente, welche die Reaktionszeit beeinflussen?	☐	☐	☐☐. Lj	___
9. Andere Erkankungen?	☐	☐	☐☐. Lj	___
10. Haben Sie Allergien?	☐	☐		___

Sonstige Anmerkungen:

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Seite 3 von 3

Page 3 of the history form

Hochschule Aalen

Protokoll_Vs.2016-02-04 (5)
Studien-ID: 2RodMon____
Patienten-ID:____________
Untersuchungsdatum: __ __ __ __-__ __-__ __

Untersuchungsprotokoll

Voruntersuchung durch Prof. Dr. med. Ulrich Schiefer

	Intakt/ unauffällig	Gestört/ auffällig	Welches Auge ist betroffen?	Bemerkungen
Augenstellung	Ferne ☐	☐	☐ R	____________
	Nähe ☐	☐	☐ L	____________
Augenbeweglichkeit	☐	☐	☐ R	____________
			☐ L	____________
Pupillen efferenz	☐ In Helligkeit und Dunkelheit isokor ☐ Anisokorie ☐ R>L ☐ L>R ☐ Bei Helligkeit zunehmend (Kontraktionsdefizit) ☐ Bei Dunkelheit zunehmend (Dilatationsdefizit)			____________
Vorderer Augenabschnitt	☐	☐	☐ R	____________
			☐ L	____________
Augenhintergrund (in Miosis)	☐	☐	☐ R	____________
			☐ L	____________
Fixation	R☐ ruhig zentral	☐ exzentrisch		____________
	L☐ ruhig zentral	☐ exzentrisch		____________

Sonstige Anmerkungen

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Seite **1** von **2**

Page 1 of the case report form

Hochschule Aalen

Protokoll_Vs.2016-02-04 (5)
Studien-ID: 2RodMon____
Patienten-ID:____________
Untersuchungsdatum: |_|_|_|_|-|_|_|-|_|_|

Voruntersuchung durch Bachelorand

Autorefraktometer	Sph	Cyl	A
R			
L			

Visus s.c. R: ☐ L: ☐ binokular: ☐

Phoropter	Sph	Cyl	A	Visus monokular	Visus binokular
R					
L					

Getragene Brille/KL	Sph	Cyl	A	Visus monokular	Visus binokular
R					
L					

Pupillendistanz (mm) R: ☐ L: ☐ Gesamt: ☐

Stereowinkel (in “) TNO Test: ☐ 5 Reihen Zeiss Polatest: ☐

Sonstige Anmerkungen:

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Seite **2** von **2**

Page 2 of the case report form

Hochschule Aalen

Fragebogen_Proband_Vs.2016-01-28 (2)
Studien-ID: 2RodMon____
Patienten-ID:____________
Untersuchungsdatum: |_|_|_|_|-|_|_|-|_|_|

Evaluation

Auf der folgenden Seite finden Sie einen Fragebogen zu Ihrem Empfinden während der heutigen Messungen. Zur Beantwortung dieser Fragen steht Ihnen jeweils eine Skala in Form einer Linie zur Verfügung. Markieren Sie die Stelle auf der Linie mit einem Kreuz (×), die Ihrem Empfinden am besten entspricht. Beantworten Sie bitte jede Frage. Bitte schreiben Sie keine Klartextantworten wie z.B. „zu lange".

Nachfolgend ein Beispiel:

Wie geht es Ihnen heute?

Bestens, sehr gut |–×——————————————| Sehr Schlecht

Im Beispiel bedeutet die Antwort, dass es Ihnen heute ganz gut geht, aber nicht bestens.

Beantworten Sie die Fragen bitte nur in Bezug auf die Messungen. Die Frage nach der Ermüdung beispielsweise sollte nicht mit „Ja, absolut" beantwortet werden, weil Sie eventuell aufgrund von Schlafmangel müde sind.

Seite **1** von **2**

Page 1 of the subject's questionnaire

Hochschule Aalen

Fragebogen_Proband_Vs.2016-01-28 (2)
Studien-ID: **2RodMon____**
Patienten-ID:____________
Untersuchungsdatum: ____-__-__

Wie empfinden Sie die Einweisung in den Testablauf?

Verständlich |————————————————| Kompliziert

Wie empfanden Sie die heutigen Messungen insgesamt?

Angenehm |————————————————| Unangenehm

Wie empfanden Sie die Beurteilung beim Blick direkt auf den Monitor?

Einfach |————————————————| Schwer

Anmerkungen:

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Seite **2** von **2**

Page 2 of the subject's questionnaire

Hochschule Aalen

Fragebogen_Untersucher_Vs.2016-01-28 (2)
Studien-ID: **2RodMon____**
Patienten-ID:____________
Untersuchungsdatum: └┴┴┴┘-└┴┘-└┴┘

Evaluation durch Untersucher

Auf der folgenden Seite finden Sie einen Fragebogen zu Ihrem Empfinden während der heutigen Messungen. Zur Beantwortung dieser Fragen steht Ihnen jeweils eine Skala in Form einer Linie zur Verfügung. Markieren Sie die Stelle auf der Linie mit einem Kreuz (×), die Ihrem Empfinden am besten entspricht. Beantworten Sie bitte jede Frage. Bitte schreiben Sie keine Klartextantworten wie z.B. „zu lange“.

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Seite **1** von **2**

Page 1 of the examiners questionnaire

Hochschule Aalen

Fragebogen_Untersucher_Vs.2016-01-28 (2)
Studien-ID: **2RodMon____**
Patienten-ID:____________
Untersuchungsdatum: |_|_|_|_|-|_|_|-|_|_|

Wie empfanden Sie die heutigen Messungen insgesamt?

Angenehm |————————————————| Unangenehm

Anmerkungen:

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Seite **2** von **2**

Page 2 of the examiners questionnaire