Medical Engineering & Physics 36 (2014) 490–495

Contents lists available at ScienceDirect

Medical Engineering & Physics

journal homepage: www.elsevier.com/locate/medengphy

Technical note

Development and evaluation of a new instrument to measure visual exploration behavior

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ARTICLE INFO

Article history:
Received 7 June 2012
Received in revised form
19 September 2013
Accepted 22 September 2013

Keywords:
Visual exploration
Functional field of view
Optical instruments

ABSTRACT

Effective visual exploration is required for many activities of daily living and instruments to assess visual exploration are important for the evaluation of the visual and the oculomotor system. In this article, the development of a new instrument to measure central and peripheral target recognition is described. The measurement setup consists of a hemispherical projection which allows presenting images over a large area of ±90° horizontal and vertical angle. In a feasibility study with 14 younger (21–49 years) and 12 older (50–78 years) test persons, 132 targets and 24 distractors were presented within naturalistic color photographs of everyday scenes at 10°, 30°, and 50° eccentricity. After the experiment, both younger and older participants reported in a questionnaire that the task is easy to understand, fun and that it measures a competence that is relevant for activities of daily living. A main result of the pilot study was that younger participants recognized more targets with smaller reaction times than older participants. The group differences were most pronounced for peripheral target detection. This test is feasible and appropriate to assess the functional field of view in younger and older adults.

1. Introduction

1.1. Visual exploration with the human eye

Visual exploration allows us to explore and analyze the visual world. It requires an intact visual and oculomotor system as well as visual attention. It is essential for most activities of daily living, and patients with impaired visual exploration performance complain about difficulties in many activities of daily living (i.e. driving, walking) [1,2].

Visual perception begins in the retina which is a specialized sensory organ that converts light into electrical signals. These signals are then sent through the optic nerve to higher centers in the brain for further processing. Only the fovea has sufficient fidelity for high-resolution vision and when humans examine an object in the world, they have to move the fovea to it. The gaze system performs this function through two components: the oculomotor system, which moves the eyes in the orbit, and the head movement system, which moves the orbits in space. We therefore make frequent fast eye movements (saccades) to capture detailed snapshots (fixations) with the fovea and integrate those into a coherent understanding of the visual environment [3]. Thus, visual exploration of a scene consists of a sequence of fast saccades with suppressed visual sensitivity [4], and fixations with visual data collection.

1.2. Visual field and functional visual field

In the context of this manuscript, the term visual field corresponds to the angular field of view that is seen by the eyes, when they are fixating a point straight-ahead without movement of the head [5,6]. It is commonly assessed using perimetry. The visual field is to be strictly differentiated from the functional visual field, in which the eyes are permitted to have freedom of rotational movement while the head and the body are kept in a constant position [6]. When testing the functional visual field, test objects are presented on non-uniform backgrounds of everyday life pictures. This is in contrast to the visual field testing, where test objects are presented on a uniform background. Since everyday visual experience includes the freedom of movement of the eyes, the functional visual field is a more accurate expression of total visual performance [7]. However, with these greater degrees of freedom, the specific diagnostic value of the classical perimetry is limited, because the

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http://dx.doi.org/10.1016/j.medengphy.2013.09.011

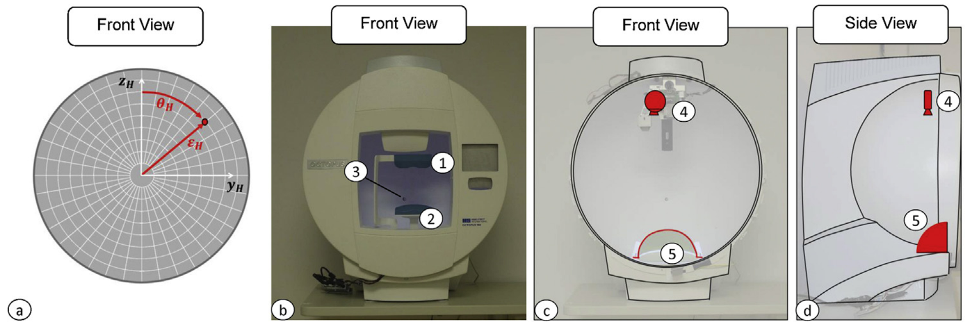

Fig. 1. Mechanical setup for testing the functional visual field. Image (a) shows the Cartesian coordinate frame $H=(x_H, y_H, z_H)$ that is attached to the hemisphere and has its origin in the center of the hemisphere. Image (b) shows the motorized head-rest (1), the chin-rest (2) and a small camera-opening (3) in the back of the hemisphere. Image (c) and (d) show front- and side views from the hemisphere with the miniature-projector (4) and the spherical mirror (5).

performance of the oculomotor system is being combined with the performance of the afferent sensory pathways. With eye movement permitted, the presence of a defect in the visual field can often be masked by compensatory eye movements and may thus escape detection [8].

In earlier work, we have described a setup for testing the functional visual field by presenting images on a computer monitor [6,7]. The planar representation on a 19 inch computer monitor resulted in a limited field of view of ±29° in horizontal and ±22° in vertical direction. This is an important limitation, since in daily life, the perception of peripheral objects is of key importance and should be tested as well [1,2,9,10]. Thus, in this paper, the development and the evaluation of a new instrument to test the functional visual field for a large field of view of ±90° in horizontal and vertical direction are presented. The technical implementation of the functional visual field test requires a hemispherical projection method which is presented in this paper. Feasibility of the test is assessed in 14 younger (21–49 years) and 12 older (50–78 years) test persons.

2. Methods

2.1. Mechanical setup

A hemispheric projection screen (d = 60 cm) has been selected to implement a field of view of ±90° in horizontal and vertical direction. The hemisphere is positioned on a height-adaptable table (73–93 cm) with the test person seated in front of it. The height is adjusted so that the head comfortably lies on a chin- and a forehead-rest (Fig. 1). The chin-rest is motorized and can be moved ±2 cm in horizontal and ±2.3 cm in vertical direction, while the forehead-rest moves in a horizontal direction only (±2 cm). The head is positioned so that the midpoint of the left and right eye coincides with the center of the hemisphere. This is achieved with the help of a camera that is installed in the back of the hemisphere. It points to the desired position of the right eye, which is located about half of the interpupillary distance $0.5d_p$ to the right of the center of the hemisphere. The head is aligned so that the right eye coincides with the desired location. A mean value from literature d_p = 6.35 cm has been selected for the interpupillary distance [11]. The camera is equipped with an infrared-pass filter and there are two infrared LEDs to illuminate the eye.

For convenience, the setup has been implemented by modifying a commercially available perimeter (Octopus 900, Haag Streit AG, Köniz, Switzerland). This was advantageous because the perimeter already is equipped with a motorized chin- and head-rest, a hemisphere of the desired diameter, and an integrated camera with infrared-pass filter and two infrared LEDs (Fig. 1a and b). Nevertheless, the here-described test setup is independent from the hard- and software of the perimeter and could also be implemented elsewise.

Three different solutions for projecting images into a hemisphere have been considered: front-projection, back-projection, and projection via a spherical mirror. Front-projection was not feasible because the test person's head blocks the projection beam (cf. Fig. 1a). Back-projection would be an option if a transparent hemisphere is used. However, the space requirements would be significant and, therefore, a compact projection solution via spherical mirror has been selected. Spherical mirror projection systems have a long history for projecting images into spherical domes, and A. Baltes described the idea of using a spherical mirror to project images into a planetarium in 1958 [12,13]. Today, similar techniques are used for virtual reality applications [14–16] and for gaming [17,18]. The general idea is to project an image onto a spherical mirror that is positioned somewhere in the projection hemisphere. The image is reflected in all directions and the entire hemisphere can be illuminated. For the implementation of the functional visual field test, a spherical mirror of diameter d_m = 23 cm is positioned in the lower region of the hemisphere (cf. Fig. 1c and d). A miniature LED-projector (T25 LED, Apitec Inc.) with 800 × 600 pixel resolution is installed in the upper region of the hemisphere and projects an image onto the spherical mirror. A part (52.3%) of the emitted light hits the spherical mirror and is reflected to all points of the hemisphere. The focus of the projector is adjusted so that the image appears sharp in the middle part of the hemisphere. The technique for presenting images is discussed in Section 2.2.

The Cartesian hemisphere coordinate frame $H=(x_H, y_H, z_H)$is attached to the hemisphere and has its origin in the center of the hemisphere (z_H axis is vertical and pointing upwards, see Fig. 1a). This coordinate frame is fix and the position of a test object T on the surface of the hemisphere is unambiguously determined by the eccentricity angle relative to the hemisphere ε_H and the azimuth angle relative to the hemisphere θ_H.

2.2. Presentation of images

The hemispheric projection screen and the spherical mirror distort the projected image. Therefore, the original image must be wrapped, so that the projected image appears correctly [14]. For that, the direct and inverse transformation equations are calculated with respect to the center of the spherical mirror.

When a beam of light $\vec{L}$ is sent out from the projector $\vec{P}$, it is reflected at the point $\vec{N}$, located on the surface of the spherical mirror toward the hemispheric projection screen. It hits the hemispheric projection screen at the location $\vec{S}$. According to [19], the reflection point $\vec{N}$ is calculated using the following recipe: Frist, calculate the three dot products,

$$\begin{aligned} a &= \vec{S} \cdot \vec{S} \\ b &= \vec{S} \cdot \vec{L} \\ c &= \vec{L} \cdot \vec{L} \end{aligned} \tag{2.1}$$