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Evaluation of Postural Control in Patients with Glaucoma Using a Virtual Reality Environment

Alberto Diniz-Filho, MD, PhD,[1,2] Erwin R. Boer, PhD,[1,3] Carolina P. B. Gracitelli, MD,[1,4] Ricardo Y. Abe, MD,[1,5] Nienke van Driel, BSc,[3] Zhiyong Yang, MD, PhD,[1] Felipe A. Medeiros, MD, PhD[1]

Purpose: To evaluate postural control using a dynamic virtual reality environment and the relationship between postural metrics and history of falls in patients with glaucoma.

Design: Cross-sectional study.

Participants: The study involved 42 patients with glaucoma with repeatable visual field defects on standard automated perimetry (SAP) and 38 control healthy subjects.

Methods: Patients underwent evaluation of postural stability by a force platform during presentation of static and dynamic visual stimuli on stereoscopic head-mounted goggles. The dynamic visual stimuli presented rotational and translational ecologically valid peripheral background perturbations. Postural stability was also tested in a completely dark field to assess somatosensory and vestibular contributions to postural control. History of falls was evaluated by a standard questionnaire.

Main Outcome Measures: Torque moments around the center of foot pressure on the force platform were measured, and the standard deviations of the torque moments (STD) were calculated as a measurement of postural stability and reported in Newton meters (Nm). The association with history of falls was investigated using Poisson regression models. Age, gender, body mass index, severity of visual field defect, best-corrected visual acuity, and STD on dark field condition were included as confounding factors.

Results: Patients with glaucoma had larger overall STD than controls during both translational (5.12±2.39 Nm vs. 3.85±1.82 Nm, respectively; $P = 0.005$) and rotational stimuli (5.60±3.82 Nm vs. 3.93±2.07 Nm, respectively; $P = 0.022$). Postural metrics obtained during dynamic visual stimuli performed better in explaining history of falls compared with those obtained in static and dark field condition. In the multivariable model, STD values in the mediolateral direction during translational stimulus were significantly associated with a history of falls in patients with glaucoma (incidence rate ratio, 1.85; 95% confidence interval, 1.30–2.63; $P = 0.001$).

Conclusions: The study presented and validated a novel paradigm for evaluation of balance control in patients with glaucoma on the basis of the assessment of postural reactivity to dynamic visual stimuli using a virtual reality environment. The newly developed metrics were associated with a history of falls and may help to provide a better understanding of balance control in patients with glaucoma. *Ophthalmology 2015;■:1–8 © 2015 by the American Academy of Ophthalmology.*

Falls are the leading cause of injury-related death and morbidity in older adults.[1] It is estimated that 1 of 3 adults aged 65 years or older falls at least once per year, and a substantial proportion of those who fall sustain moderate to severe injuries, such as laceration, hip fracture, and head trauma.[2,3] Age-related changes in neural, sensory, and musculoskeletal systems can lead to an impaired ability to maintain postural control and to react to a sudden loss of balance, leading to an increased risk of falling.[4]

Maintaining postural stability requires the complex interaction between musculoskeletal and sensory systems. Several prospective studies have shown that the measurement of individual postural sway is a useful predictor of risk of falling.[5,6] The sensory components involved in postural control include vision, vestibular function, and somatosensation,[7] which act to inform the brain of the position and movement of the body in 3-dimensional space.[8,9] Vision plays a crucial role in detecting hazards, facilitating the adaptation of posture, and maintaining the orientation of the body upright relative to the environment.[10] It has been suggested that elderly people may rely to a greater extent on the spatial framework provided by vision to compensate for reduced vestibular and postural sensation that occurs with aging.[7,11]

Because of the important role of vision in balance control and environment navigation, it is not surprising that conditions that can lead to visual impairment, such as glaucoma, have been implicated as a risk factor for falls[12–14] and are associated with a greater fear of falling.[15] Patients with glaucoma have >3 times higher risk of falling compared with age-matched healthy individuals.[12] The loss of retinal ganglion cells in glaucoma leads to loss of the peripheral

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field of vision, which has a major role in facilitating postural control because of its sensitivity to motion. However, despite this association, previous studies have shown only a weak correlation between measurements of visual field loss by standard automated perimetry (SAP) and risk of falls.[16–18] This may be related to an inadequate ability of the static white-on-white stimuli of SAP to evaluate the complex demands put on vision for adequate postural control during daily activities and challenging situations.

A few previous studies have evaluated postural stability in patients with glaucoma.[19–21] Although these studies have shown a significant reduction of the visual contribution to posture stabilization in glaucoma, they have not attempted to assess postural metrics that could explain a history of falls in these subjects. In addition, these studies have been limited by evaluating balance control in relatively simple conditions, such as with eyes closed or with eyes open and fixating on a static target. Evidence has suggested that differences in postural control may be detectable only when the inducing environment is dynamic rather than static.[22–24] Therefore, stimuli consisting of dynamic information (i.e., optic flow) may be more appropriate when assessing the role of vision in postural control.[24,25]

In this study, a novel paradigm for evaluation of postural control in glaucoma is presented. Postural control was evaluated using a force platform, and the postural reactivity to dynamic visual information was assessed using an immersive virtual environment with head-mounted goggles. Differences in postural reactivity between glaucomatous patients and control subjects were evaluated, and the ability of the newly developed metrics in explaining history of falls was assessed in this population.

Methods

Participants from this study were included in a prospective longitudinal study designed to evaluate functional impairment in glaucoma, the Diagnostic Innovations in Glaucoma Study: Functional Impairment, conducted at the Visual Performance Laboratory of the University of California San Diego. Written informed consent was obtained from all participants, and the institutional review board and human subjects committee approved all methods. All methods adhered to the tenets of the Declaration of Helsinki for research involving human subjects, and the study was conducted in accordance with the regulations of the Health Insurance Portability and Accountability Act.

All participants underwent a comprehensive ophthalmologic examination, including review of medical history, visual acuity, slit-lamp biomicroscopy, intraocular pressure measurement, gonioscopy, ophthalmoscopic examination, stereoscopic optic disc photography, and SAP using the Swedish Interactive Threshold Algorithm with 24-2 strategy of the Humphrey Field Analyzer II, model 750 (Carl Zeiss Meditec, Inc, Dublin, CA). Visual acuity was measured using the Early Treatment Diabetic Retinopathy Study chart, and letter acuity was expressed as the logarithm of the minimum angle of resolution. Only subjects with open angles on gonioscopy were included. Subjects were excluded if they presented any other ocular or systemic disease that could affect the optic nerve or the visual field. Optic nerve damage was assessed by masked grading of stereophotographs. Subjects were excluded if they presented with a history of systemic conditions affecting the lower limbs, such as arthritis, gout, history of knee or hip replacement, or any other pathology affecting the vestibular system.

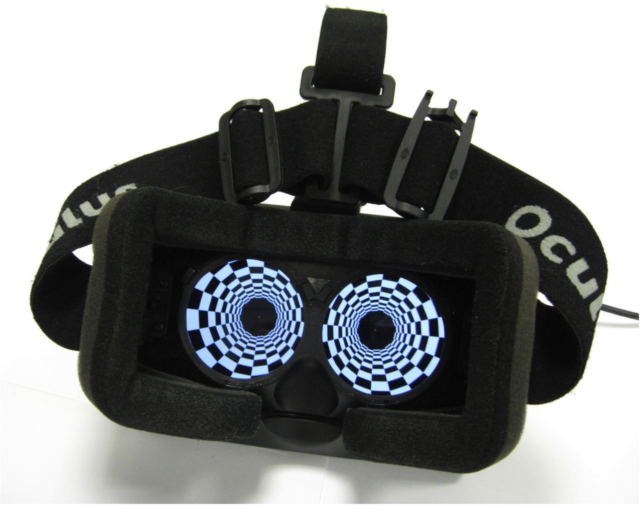

Figure 1. The head-mounted stereoscopic goggles used for stimulus presentation (Oculus Rift, Oculus VR, LLC, Irvine, CA).

Glaucoma was defined by the presence of repeatable abnormal SAP test results (pattern standard deviation with $P < 0.05$ or a Glaucoma Hemifield Test outside normal limits) and corresponding optic nerve damage in at least 1 eye. Control subjects had no evidence of optic nerve damage and had normal SAP visual field test results in both eyes. Only reliable visual field tests were included (<33% fixation losses or false-negative errors, and <15% false-positive errors). Control subjects were recruited from the general population through advertisements and from the staff and employees of the University of California San Diego.

All subjects had measurements of weight and height obtained at the time of testing. These were used to calculate the body mass index (BMI) for each subject, as the quotient of mass (in kilograms) divided by the square of height (in meters). History of falls was obtained using a standard questionnaire, the Falls Screening and Referral Algorithm.[26,27] The questionnaire asked about the number of falls the patient had over the past year. A fall was considered when the individual found him/herself suddenly on the ground, without intending to get there, from a sitting or standing position.

Experimental Paradigm

Postural reactivity to visual information was assessed using an immersive virtual environment with head-mounted stereoscopic goggles (Oculus Rift, Oculus VR, LLC, Irvine, CA) (Fig 1). The Oculus Rift presents a different projection of the virtual world onto each eye. These projections mimic the view that each individual eye would receive if the world were real. A lens is mounted in front of each eye so that the image is perceived at a wide field of view. The resulting stereoscopic 3-dimensional view presents the same information to each eye, but the left eye sees an area to the left that the right eye does not see and vice versa. The binocular field of view is approximately 100 degrees diagonal. The 7-inch (18 cm) screen has a resolution of 1280×800 (16:10 aspect ratio) broken up into 2 panels of 640 pixels wide per eye. The image for each eye is presented in the panel as an inverse barrel distorted image that is then distorted by a pincushion effect created by lenses in the headset, generating a correct spherical-mapped image for each eye. Postural stability was evaluated using a force platform (AMTI Optima Human Performance System,

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