Full length article

Dynamic Visual Acuity test while walking or running on treadmill: Reliability and normative data

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ABSTRACT

Background: This study aimed to report normative reference data for a Dynamic Visual Acuity test while walking on treadmill. The protocol's suitability was assessed by investigating its test-retest reliability and its validity through the drop-out rate and verification of the frequency of head movements. Furthermore, the influence of age on visual acuity loss (VAL) was determined to reveal the need for age-specific reference data.

Methods: Visual acuity was measured in 171 healthy adult participants (age range: 20.0–77.3 years; mean age: 40.1 years) with the head stationary (SVA) and in a dynamic condition (DVA) while walking on treadmill at 3, 4, 6 and 9 km/h. Relative test-retest reliability on SVA and DVA was investigated with intraclass correlation coefficients (ICC). The measurement errors of SVA, DVA and VAL were calculated for absolute reliability. Influence of age on VAL was investigated with regression analysis, followed by an ANOVA to investigate decade-related differences. The drop-out rate during DVA was mapped using a frequency table. Head frequencies were monitored using 3D motion tracking software.

Results: Strong consistency (ICC ≥ 0.89) was found for SVA and DVA values. Measurement errors for VAL were less than 0.1 logMAR. Younger participants (decade 3–4) showed less VAL at 3 and 4 km/h. The drop-out rate increased with increasing walking speed (0–18.8%), especially in older adults. Although head frequency increased with increasing speed, the dominant frequency ranged around 2 Hz for all walking speeds.

Conclusion: This DVA protocol is reliable and normative data have been established. To facilitate its use in clinical practice, further validation of the protocol in patients with bilateral vestibulopathy is needed.

1. Introduction

Rapid head movements are part of everyday life during which gaze needs to be stabilized to ensure visual acuity (VA) [1–3]. The vestibulo-ocular reflex (VOR) serves as the primary control system for gaze stabilization during head movements at or above 2 Hz by managing contractions of the extra-ocular muscles to keep the eyes fixed on the visual target [2,3]. These compensatory eye movements are essential for correcting retinal slip, which is the degree of motion of the image across the retina causing decreased visual acuity [1–3]. If retinal slip is higher than 2°/s, gaze instability occurs and thereby VA loss (VAL) [4]. Patients with bilateral VOR impairment therefore often complain of gaze instability during daily activities, e.g. reading the signs for the correct

aisle in the supermarket or a bouncing world while jogging [1,3,5,6]. They experience an illusion of visual motion during head movement, which is also referred to as oscillopsia [1,3,6].

To assess VOR function indirectly through gaze (in)stability, the Dynamic Visual Acuity test (DVA test) has been developed [1,5–11]. The DVA test serves as an appropriate outcome measure to assess the effectiveness of vestibular rehabilitation on functional compensation and has also been recommended for screening vestibular deficits [2,3,6–8,12]. However, several DVA test modalities exist [2]. In brief, traditional DVA test protocols focus on the assessment of horizontal and/or vertical semicircular canals in which the head movements can be induced actively or passively. Because of preprogramming during active head movements, passive head movements are preferred [12],

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during which the investigator executes a passive head shaking maneuver. This requires considerable experience and is likely to induce higher inter- and intrasubject variability [12]. Through walking, indirectly, all the vestibular sensors are stimulated, especially the vertical canals (nodding movement of the head) and the otoliths (bouncing up and down of the head), thereby providing a natural kind of stimulation of the vestibular system [2,5]. Hillman et al. [5] reported that test-retest values did not differ significantly, but no further reports on reliability of the DVA on treadmill are available.

Walking speed significantly affects DVA [3]. Nevertheless, the applied walking speeds for DVA on treadmill differ considerably: 2.0 [6], 2.7 [3], 4.0 [6], 5.0 [13], 5.4 [3], 6.0 [6], 6.4 [5], 7.5 [13] and 10.0 [13] km/h. High walking speeds are a concern because the mean self-selected walking speed for patients with vestibular dysfunction approximates 3 km/h [14,15]. To identify bilateral vestibulopathy, Guinand et al. [6] reported 2.0 km/h to be less sensitive compared to 4.0 km/h. This indicates that 2 km/h does not reflect these patients' real-life walking pattern and emphasizes the necessity to redefine the walking speeds for DVA on treadmill. To identify vestibular dysfunction, speed-specific normative reference data are necessary, but still lacking at present.

With increasing age, at the histological level, not only the number of otoconia in saccule and utricle as well as the hair cells in both otoliths and semi-circular canals tend to decrease, distinct changes in their shape and deformation of the cilia in sensory and supporting cells occur as well [16,17]. These gradual morphological changes in the vestibular sensors tend to influence the vestibular output during several vestibular function tests, but not all [18]. For example, where the VOR gain measured with the video Head Impulse Test is not affected by age [18], both horizontal DVA and DVA on treadmill are [3,6,8]. Because of the age-related changes in DVA while walking, not only speed-specific but also age-specific reference data seem needed.

Visual acuity is measured with optotypes, presented on a computer screen (computerized DVA) or with VA charts (clinical DVA) [1,5–11]. Although the computerized DVA test is reliable, it requires expensive equipment and is therefore mainly used in specialized centers.

The present study aims to report normative data of a clinical DVA protocol on treadmill. For this purpose, the protocol's reliability will be assessed and preliminary insights into the protocol's validity will be provided by mapping the drop-out rate and the actual head frequency during DVA on treadmill. Finally, the effect of age and sex on VAL will be investigated to determine how normative data should be presented.

2. Methods

2.1. Study design and participants

In this cross-sectional study, 235 healthy adults between age 20 and 90 were recruited among family members and friends from the researchers as well as sports and recreation clubs for elderly from the vicinity of Antwerp, Belgium. Data were collected between March 2013 and December 2014. Test-retest reliability was determined in a subsample (n = 60). Mean number of days (SD) between test and retest was 24 (25), with a minimum of 1 day and a maximum of 117 days. The test protocol was approved by the local ethical committee (B300201316328). All tests were conducted in the Multidisciplinary Motor Centre Antwerp (M²OCEAN) at the Antwerp University Hospital. Participants gave their written consent after being properly informed.

To ensure subjects did not have any deficits or diseases that could impede normal balance or VA, they filled in a checklist and performed a balance assessment with age-specific criteria before DVA test administration. The checklist comprised questions to map: (1) current complaints or a history of vertigo or dizziness in the last six months, (2) any neurological, otological, musculoskeletal, or other medical conditions impeding balance or mobility of the cervical spine, (3) nursing home residents, (4) dependence on the assistance of another person/device,

e.g. a cane, crutch or walker, (5) an inexplicable fall within the last six months, (6) eye disorders affecting VA such as cataract, (7) VA > 0.5 logMAR that was not corrected for with (non-multifocal) glasses or contact lenses, (8) use of alcohol or other stimulants in the last 24 h. If the subjects presented with any of these features, they were excluded from the sample. Subsequently, age-specific static balance was assessed according to the protocol described by Vereeck et al. [19]. Participants were excluded from the sample if they were unable to perform these tests.

Furthermore, after preliminary inclusion, subjects were removed from the dataset if data were incomplete.

2.2. DVA on treadmill: test procedure and protocol

2.2.1. Set-up

Before DVA test administration, features of both test material and test conditions were controlled. The luminance of the illuminated charts was 182.2 cd/m² for the white color and 3.39 cd/m² for the black color with a Weber contrast of 98%. Illumination in the M²OCEAN laboratory (just about 0.5 m in front of the chart) is 540 lx. Revised 2000 Series ETDRS charts with sloan letters (CDHKNORSVZ) were used. The chart consisted of rows of five randomly chosen letters. LogMAR scale and -notation were used. The chart-subject distance was 4 m for all measurements and the chart was positioned at eye level. Visual acuity was tested binocularly. Measurements were performed with eye corrections for subjects who wore glasses or contact lenses, except for multifocal glasses.

2.2.2. Protocol

Each participant read the optotypes aloud to determine VA and started reading the 0.4 LogMAR line. If they were unable to read all optotypes correctly, they were asked to read the line above, increasing the optotype size with one level. This was repeated until all optotypes on one line were read correctly. Subsequently, the subject had to read the lines with decreasing optotypes size until more than 2 optotypes were missed. To avoid recall, charts with different letter order were used. First, static VA (SVA) was determined while standing on the treadmill, during which participants read the optotypes while keeping their head still. Next, DVA was assessed while walking on treadmill at four non-randomized walking speeds: 3, 4, 6 and 9 km/h. 3 km/h was preferred over 2 km/h because patients with vestibular deficits, though with varying etiology (e.g. vestibular neuritis [15], bilateral vestibulopathy [14], central vestibular dysfunction [14]) walk at approximately 3 km/h and the DVA on treadmill has low sensitivity (76%) in patients with bilateral vestibulopathy when walking at 2 km/h [6]. Walking 6 km/h was implemented because results of an unpublished pilot study, matching literature [20], revealed that all subjects reached a step frequency > 2 Hz. Because younger patients sometimes experience oscillopsia while jogging, 9 km/h was added to induce running. The subjects were allowed ten seconds to familiarize with each walking speed. The test procedure was ended prematurely if the participants felt they could not walk at higher speed.

2.2.3. Movement analysis

Head movements were measured using a headband with four markers (two ventral and two dorsal), fixed horizontally on the subject's head, to determine head frequencies during DVA on treadmill. The movements were registered by an 8-camera infrared system with Vicon T10 camera's (100 fps, 1 Megapixel resolution). Marker trajectories were tracked by Nexus 1.8.5 software and filtered using a low-pass Butterworth filter (4th order, zero-phase) with a cut-off frequency of 6 Hz.

2.3. Variables of interest

Demographic data (age and sex) were used to describe the sample.