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MISCELLANEOUS

# Repeatability of mesopic visual acuity measurements using high- and low-contrast ETDRS letter charts

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**Abstract**
*Purpose* To determine the repeatability of mesopic high-contrast (HC) and low-contrast (LC) visual acuity (VA) measurements made at distance and near in healthy young individuals. While the repeatability of photopic VA is well-known, there is a lack of information with regard to the repeatability of VA measured under low luminance conditions.
*Methods* In two different sessions 1 week apart, best-corrected monocular VA was determined using HC (96 %) and LC (10 %) ETDRS charts under mesopic luminance conditions (0.75 cd/m$^2$) at distance (HCD, LCD) and near (HCN, LCN) in 47 healthy subjects aged 22.9±6.8 years. Repeatability was estimated by the Bland and Altman method, whereby the mean difference (MD) and the 95 % limits of agreement were determined as the coefficient of repeatability (COR).
*Results* Mean logMAR VA values were HCD = 0.09, LCD = 0.44, HCN = 0.21, and LCN = 0.57. Mean differences in measurements between sessions 1 and 2 were not significant, and low in clinical terms (≤1 letter). Repeatability was better for the distance measurements at both high and lowcontrast (COR $_{HCD}$ ±0.11 and COR $_{LCD}$ ±0.11 logMAR vs COR $_{HCN}$ ±0.15 and COR $_{LCN}$ ±0.16 logMAR), and MDs were also slightly closer to zero for the distance measurements. Similar repeatability was observed between HC and LC VA, both at distance and near.
*Conclusions* In mesopic conditions, ETDRS charts offer repeatable best-corrected monocular VA measurements. The criterion for a significant change in logMAR VA was 1 line at distance and 1.5 lines at near.

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## Introduction

Visual acuity (VA) is probably the most widely used vision test. Besides reflecting the integrity of the central visual pathway, the VA test is used for screening, refractive error determination and monitoring treatment or disease progression. Although photopic high-contrast VA is often considered to be the single most important indicator of the quality of vision [1], recent evidence suggests that mesopic VA may be an earlier indicator of vision change in ocular diseases. Several inherited and acquired disorders involving both rods and cones can affect mesopic vision [2]. Accordingly, impaired night-time vision is among the earliest signs of a range of retinal diseases including diabetic retinopathy [3], retinosis pigmentosa [4], retinitis punctata albescens [5, 6], central serous chorioretinopathy [7], and melanoma-associated retinopathy [8]. Mesopic VA is also a sensitive indicator of impaired macular function in eyes with early age-related macular degeneration (AMD), which may be modified before any photopic HC VA alterations occur [9]. Moreover, mesopic VA is able to predict the risk of future VA loss in subjects with geographic atrophy resulting from AMD [10].

High-contrast VA measurements are not necessarily sensitive to vision loss related to light scatter (e.g., cataract) [11], wavefront aberrations (e.g., keratoconus) [12], or refractive surgery [13]. Vision tests using reduced contrast targets or conducted at mesopic light levels may be more sensitive [14, 15] to vision loss, given that the impact of a small change in retinal image quality in healthy eyes is best reflected by a corresponding change in low-contrast (LC) mesopic VA rather than a change in high-contrast (HC) photopic VA [16]. The exclusive use of HC VA in clinical settings may cause

discrepancy between a clinician's findings and patients' self-reported visual function. Most daily tasks involve visual conditions far from those of the well-illuminated white test chart with black letters [17], and mesopic vision is important, particularly when driving at night [18].

To correctly interpret changes in VA measures, the clinician needs to know the repeatability of a given VA test. This repeatability can be improved through the use of charts based on the logMAR design [19, 20] such as the Bailey–Lovie and the Early Treatment Diabetic Retinopathy Study (ETDRS) test, by incorporating standard measurement procedures [21, 22], and by letter-by-letter scoring. In prior work [23, 24, 20, 25, 26], good test–retest reliability was observed of photopic VA measurements made both at high and low contrast using the ETDRS and Bailey–Lovie tests. However, as far as we know, no study has addressed the repeatability of mesopic distance and near VA measurements made using high- and low-contrast ETDRS charts in healthy subjects. This was the objective of the present study.

## Materials and methods

### Subjects

The study was conducted at the Faculty of Optics and Optometry, Universidad Complutense de Madrid, Madrid, Spain. Measurements were obtained in 47 healthy subjects, 15 men and 32 women, of mean age 22.9±6.8 years (18–43 years).

Inclusion criteria were a best-corrected distance visual acuity (CDVA) of at least 0.1 logMAR (20/25) and no ocular abnormality, including media opacity. Subjects were excluded if they had any systemic disease or eye disease, or had undergone refractive surgery.

The guidelines of the Declaration of Helsinki were adhered to, and full approval for the study was obtained from our institution's review board. Each subject gave their informed consent to participate.

### Visual acuity

Best-corrected visual acuity was measured monocularly in two separate sessions 1 week apart. When both eyes met the inclusion criteria, the eye to be measured was randomly selected. In both sessions, an experienced optometrist determined the four variables: high- and low-contrast VA at both distance and near (HCD, LCD, HCN, LCN). For all mesopic VA measurements, the correction used by participants was that obtained in photopic conditions. The subject was allowed at least 10 min to dark-adapt before the tests. The order of the four VA measurements was randomly assigned to balance out variables such as fatigue and practice. Each test was conducted in exactly the same manner in each subject. In session 2, the examiner was masked to the results of the first session.

The ETDRS logMAR chart used has been described in detail by Ferris et al. [27]. The chart has five letters per row ranging in size from +1.0 to −0.30 logMAR. Each letter read correctly on each line was given a score of 0.02 log units. Thus, scoring was letter by letter [27]. A loss of 1 line of letters corresponds to a logMAR increase of 0.1. LogMAR. Subjects were required to identify each letter on the chart until they identified a full row of letters incorrectly, at which point the test was terminated and acuity calculated. Subjects were encouraged to guess letters if they were unsure.

For distance VA measurements (HCD, LCD), the room light was turned off and the charts (Precision Vision CAT. NO. 2110 (HCD 96 %) and CAT. NO. 2153 (LCD 10 %)) were placed in the original light boxes designed for the ETDRS at a distance of 4 m from the patient. The charts are front-illuminated by two Phillips 40-watt F40T12 fluorescent tubes. For the mesopic luminance level required (0.75 cd/m$^2$), illumination was reduced by covering the fluorescent tubes with an opaque material with pinholes [16].

For near VA measurements (HCN, LCN), the subject held the printed test (Precision Vision charts CAT. NO. 2106 (HCN 96 %) and CAT. NO. 2117 (LCN10%)) at 40 cm. The room was lit using only a halogen lamp connected to a potentiometer, so that the voltage could be adjusted to obtain a mesopic luminance level of 0.75 cd/m$^2$ with the room lighting turned off. This set-up provides uniform luminance over the charts. In each test, the luminance level was checked using a MAVO-SPOT 2 USB luminance meter (Gossen Lighting Control).

### Statistical analysis

Data analysis was performed using Analyse-it for Microsoft Excel (Leeds, UK) and SPSS version 19 for Windows (SPSS Inc., IBM, Somers, New York).

The normal distribution of data was confirmed using the Shapiro–Wilks test. Repeatability was determined by the Bland–Altman method [28], whereby the upper limit of expected measured change when a clinically stable individual undergoes two visual acuity measurements is established. The variables determined were the mean difference (MD), the standard deviation of differences (SD), the coefficient of repeatability (COR = ±1.96 × SD), and the limits of agreement at the 95 % level (MD ± COR). The COR is used to identify the change criterion against which measured differences are judged. Measured changes that lie outside this range are considered to reflect true clinical changes. The paired *t*-test was used to identify

any significant systematic bias between measurements, that is, a MD significantly different from zero. The level of significance was set at $p<0.05$.

## Results

The mean VA values obtained for the four tests in the two sessions are provided in Table 1. No evidence ($p>0.05$) of departure from a normal distribution was detected for any of the VA measurements (HCD, LCD, HCN, LCN).

The coefficients of repeatability observed for the different tests are provided in Table 2. Mean differences between the first and second session measurements were always non-significant, and low in clinical terms (≤1 letter). Repeatability was better for the distance than near tests both at high and low contrast. This was reflected by lower COR recorded for the distance AVs ($COR_{HCD} = \pm 0.11$ logMAR, $COR_{LCD} = \pm 0.11$ logMAR) than near AVs ($COR_{HCN} = \pm 0.15$, $COR_{LCN} = \pm 0.16$ logMAR) and by MDs that were slightly closer to zero for the distance measurements. In contrast, similar COR were observed for HC VA versus LC VA measured both at distance and near.

The graphs in Fig. 1 illustrate agreement between the different VA measurements; the narrower the interval, the better repeatability between sessions will be. The distribution of the differences in Fig. 1 shows the points to be symmetrically distributed about the MD. This pattern indicates that repeated logMAR VA measures in different sessions show random variability.

## Discussion

To determine how precise a test is and thus to distinguish a true clinical change from measurement variability or error, it is essential that the repeatability of its measurements is known. Our study provides estimates of the repeatability of mesopic high-contrast (HC) and low-contrast (LC) visual acuity (VA) ETDRS measurements made at distance and near in healthy young individuals. The repeatability coefficient obtained was ±0.11 logMAR or 1 line for the HCD (96 %) and the LCD (10 %) charts, and this value increased to about ±0.16 logMAR and ±0.15 logMAR for the HCN (96 %) and the LCN (10 %) charts respectively. Thus, CORs were lower for distance vision measurements (±1 line) than near vision (±1.5 lines). In other words, in mesopic lighting conditions a patient's logMAR distance visual acuity needs to change by more than 1 line or 0.1 logMAR (better or worse) for this change to be considered clinically meaningful. In addition, HC and LC VA measurements showed similar repeatability both at distance and near (Table 2).

The literature lacks mesopic near ETDRS VA repeatability data with which to compare our results. In a small population sample ($N=14$), Haegerstrom–Portnoy et al. [29] recorded a COR = ±0.94 lines for dark Smith–Kettlewell Institute Low Luminance (SKILL) chart acuity. This better repeatability is not directly comparable to our value for near LC acuity ($COR_{LCN}$ = ±1.5 lines) due to the different conditions of SKILL dark chart and ETDRS low-contrast chart near AV measurements. The dark SKILL card used under conditions of room lighting, has black letters on a dark gray background and was designed to provide low contrast (14 %) and simulate reduced luminance (10–15 cd/m$^2$). This luminance is, nevertheless, far from the low level used in our study (0.75 cd/m$^2$).

In the only study [30] examining the repeatability of distance mesopic VA values, a better COR (±0.08 logMAR) than observed here was detected for both low- and high-contrast measurements. The authors, Pesudovs et al. [30], however, used a data set for only three subjects (two women, one man; aged 22, 47, and 50 respectively) to calculate repeatability. Apart from the small sample size, no details of the time interval between repeated measurements are provided. If the two measurements were made on the same day, repeatability would probably be better because of the learning effect.

The CORs recorded in our study (±0.11 to ±0.16 logMAR) are in keeping with previously reported data for the use of ETDRS or Bailey–Lovie charts in healthy eyes in photopic conditions (±0.07 to ±0.18 logMAR)

t1.1 **Table 1** Means ± standard deviations recorded for two repeated mesopic VA measurements (logMAR)

| t1.2 Mesopic VA | Session 1 | Session 2 |
|---|---|---|
| t1.3 HCD | 0.09±0.10 | 0.09±0.10 |
| t1.4 LCD | 0.44±0.11 | 0.44±0.12 |
| t1.5 HCN | 0.22±0.09 | 0.19±0.10 |
| t1.6 LCN | 0.57±0.11 | 0.56±0.09 |

*HCD* High-contrast distance, *LCD* Low-contrast distance, *HCN* High-contrast near, *LCN* Low-contrast near

t2.1 **Table 2** Repeatability of mesopic VA measurements (logMAR)

| Mesopic VA | MD | *P* (*t*-test) | COR |
|---|---|---|---|
| HCD | −0.007 | 0.4 | ±0.11 |
| LCD | 0.002 | 0.8 | ±0.11 |
| HCN | −0.020 | 0.1 | ±0.16 |
| LCN | −0.012 | 0.3 | ±0.15 |

*MD* Mean difference, *COR* Coefficient of repeatability, *HCD* High-contrast distance, *LCD* Low-contrast distance, *HCN* High-contrast near, *LCN* Low-contrast near

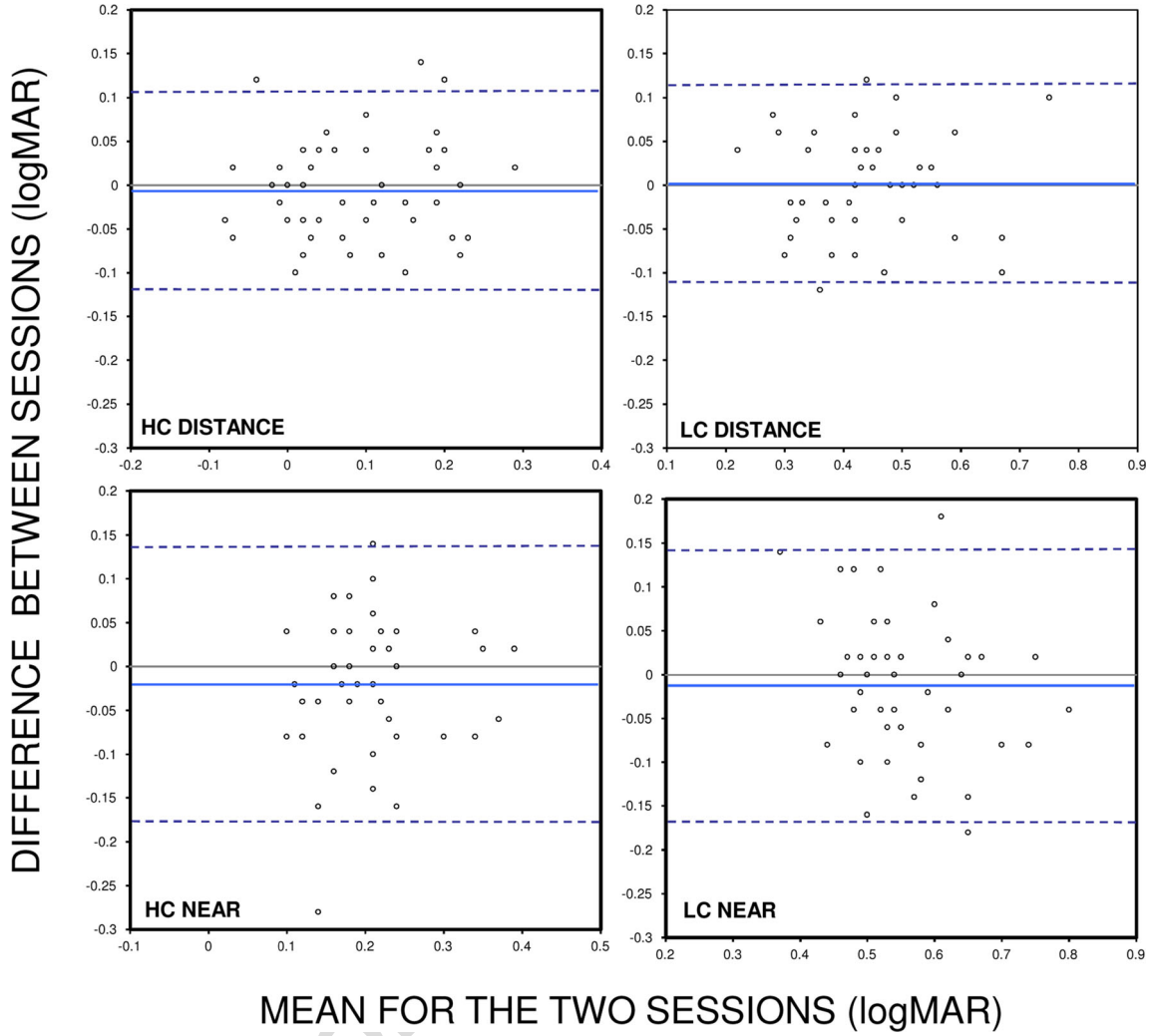


**Fig. 1** Bland–Altman plots obtained in the repeatability study of VA measurements (HCD, LCD, HCN, LCN). The *central line* indicates the mean difference (MD) between measurements. *Dashed lines* indicate the upper and lower limits of the 95 % agreement interval (COR) Q1



[24, 31, 25, 32]. Only a few studies have addressed the repeatability of photopic low-contrast VA measurements. In two such studies [33, 34], better test–retest repeatability was observed at HC than at LC, both at distance and near. Other authors have reported similar repeatability results for photopic HC VA and LC VA at distance [25] (±0.11 and ±0.13 logMAR) and near [31] (±0.12 and ±0.11 logMAR) to those observed for our mesopic measurements. These first authors [25] determined distance visual acuities using Bailey–Lovie high (86.8 %) and low (9.4 %) contrast letter charts in 78 healthy subjects (aged 21 to 68 years), while the latter, Lam et al. [31], measured near visual acuities in 55 healthy young adults (19 to 24 years) using PolyU and Precision Vision near charts in conditions of both high (93 %) and low (16 %) contrast.

In our study, mean mesopic VAs obtained at distance were HCD = 0.09±0.10 logMAR and LCD = 0.44±0.11 logMAR (Table 1). Pesudovs et al. [30] reported mean mesopic VAs of HCD = 0.31±0.14 logMAR and LCD = 0.69±0.12 logMAR at 4 m. Visual acuity was measured using standard logMAR high-contrast (96 % Weber) and low-contrast (18 % Weber) charts at a mesopic illumination level of 0.75 cd/m$^2$. These authors used the same testing protocol as for the present study (i.e., a forced-choice paradigm and strict end-point criterion of five incorrect responses) and the same letter-by-letter LogMAR scoring system. Our mean VA values (Table 1) were, however, better probably because of the younger age and narrower age range of our subjects (mean 22.9, range 18–43 years). The subjects in the study by Pesudovs et al. [30] were older (mean 50.58 years) and the age range (21.6–83.8 years) was much wider. Further VA data for different luminance and contrast levels are needed to confirm our results and establish normality mesopic VA data.

Our findings indicate that used under mesopic luminance conditions, standard ETDRS charts provide repeatable best-corrected monocular VA measurements. Using this method, the smallest meaningful logMAR VA change detected was 1 line at distance and 1.5 lines at near. These criteria are similar to those reported in the literature for photopic VA measurements.

**Conflict of interest** All authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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