

Assessment of optimal ambient lighting: Comparison of two methods

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Abstract

Optimal lighting is an essential part of visual rehabilitation. Generally, lighting levels are assessed depending on the amount of light that is required to fulfil a task. However, it is equally important to assess tasks that rely on ambient lighting. This study compares two different methods to assess optimal ambient lighting levels for people with visual impairment. **Method:** Two different methods were used. During the first method, the 3D Lightlab, subjects were seated on the side of a room and asked to describe which objects they detected and which objects they recognised in the room during increasing illumination levels. In the second method, subjects were asked the same question, but the room and the objects were projected on a screen with a beamer. Illumination levels were controlled using ND-filters. **Results:** Illumination levels for optimal lighting are comparable for both Lightlabs. However, patients have a higher confidence level in the outcome of a 3D Lightlab. **Significance:** Although the 3D Lightlab is generally preferred by people with visual impairment, the 2D Lightlab is suitable for implementation in visual rehabilitation for clients who need to know their illumination levels for optimal lighting.

Keywords

Visual impairment, ambient lighting, lighting assessment

Introduction

Lighting is a crucial factor affecting vision for most clinically assessed visual functions such as visual acuity, contrast sensitivity and visual field (Enoch et al., 2020, Wood et al., 2021, Bühren et al., 2006). People with vision impairment (people with VI) often struggle to find the correct illumination levels for daily use, resulting in illumination levels that are too low for daily functioning (Enoch et al., 2020, Kooijman et al., 1994). Required illumination levels for individual people with VI are usually assessed using tasks (e.g. task lighting for reading). But this does not assess general illumination levels appropriate for activities that rely on ambient lighting such as cleaning, tidying up, or communication. The Lightlab (Bijveld et al., 2013; Cornelissen et al., 1994) attempts to bridge this gap by using ambient light levels to assess the detection and recognition of objects in a given room as a function of illumination level. Cornelissen used a

typical living-room in which illumination is increased from 1 lux (0 log) to 2000 lux (3.3 log) during the course of the experiment (referred to as the 3D Lightlab). Bijveld used the projection of a room on a large screen controlling lumination levels of the beamer by placing neutral density filters (*i.e.* filters that reduce the intensity of all wavelengths equally) in front of the output (referred to as the 2D Lightlab). It is unclear to what extent the 2D Lightlab and the 3D Lightlab led to similar results.

Ambient lighting, also referred to as global lighting, is used to create sufficient light to enable communication and to walk safely around the room without tripping over or bumping into objects. Ambient lighting without daylight is typically around 20-30 lux (1.3-1.5 log) (Brunnström et al., 2004; Cullinan et al., 1979; Eilertsen et al., 2016). Activities relying on the recognition of fine details such as reading are often possible under these conditions for people without VI (Cornelissen et al., 1991; Davis & Garza, 2002). People with VI

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however, require much higher illumination levels for both ambient (Cornelissen 1994) and task lighting (Cornelissen et al., 1991; Henry et al., 2020; Wittich et al., 2018). However, a general approach for rehabilitation is impossible given large individual differences (Cornelissen et al., 1994; Perlmutter et al., 2013). Even people with the same diagnosis may show large differences in optimal lighting levels. Optimal lighting levels may require dedicated lamps and expertise on how to make a room accessible (Eilertsen et al., 2016).

Often, people with VI are unaware of what proper lighting can offer them (Fleissig et al., 2021) and to what extent it can create a safe environment at home (Kivimäki et al., 2020). This makes it a therapeutic method that can easily be overlooked during visual rehabilitation (Perlmutter et al., 2013). It should become an integral part of visual rehabilitation.

Given the prevalence of glare among people with VI, visual rehabilitation is not just about adding more light to the scene. The impact of glare should be assessed and integrated into the lighting plan. Disability glare due to straylight for instance, can be assessed by the C-Quant (Franssen et al., 2006) or by the reduction in contrast sensitivity due to the brightness acuity tester (Holladay et al., 1987). Reduced contrast sensitivity is likely to affect object detection and recognition of objects. Reducing straylight is generally achieved by avoiding highly luminant objects within eyesight and avoiding large differences in luminance. In addition to disability glare, it is necessary to assess discomfort glare and dazzling glare (Vos, 2003). Dazzling glare is experienced when one is overwhelmed by the overall illumination level such as on a sunny beach or snowy field. Usually, this type of glare can be solved by using sunglasses and wearing a cap or hat. However, people with VI often experience this type of glare at much lower illumination levels than people without VI and it is thereby an integral part of a lighting assessment. To do so, a useful method is subjective evaluations of visual comfort (Barstow et al., 2011; Bowers et al., 2001; Dua, 2020; Valberg & Fosse, 2002). Since most people with VI suffer from both elevated detection thresholds as well as dazzling glare (Hooper et al., 2008), they find themselves with a reduced dynamic range for viewing (Enoch et al., 2020).

Cornelissen (Cornelissen et al., 1994) described a method that determines the effect of lighting on the detection and recognition of objects in a room as a function of the illumination level. By increasing

illumination levels from 1 lux to 2000 lux in 7 steps, illumination levels can be assessed to ascertain at which level increasing light does not further benefit detection or recognition. The method is extended by asking clients to mark the individual illumination levels in order to assess illumination levels causing a feeling of dazzling glare. The method to determine the level of optimal illumination for people with VI is successfully implemented at specific locations within the rehabilitation setting and is illustrative for clients and people in their direct environment since it closely matches their daily experience. However, it has its shortcomings. First, it requires a dedicated room and expensive equipment to control illumination levels, which limits accessibility to clients throughout the country and reduces its applicability as a diagnostic tool. Second, since clients may remember the objects presented in the room, it can only be used once every so many years. That is insufficient for those clients with a progressive disorder or those who move to new housing and therefore need a re-assessment. Third, since the locations of objects are fixed during the course of the assessment, it is not possible to assess the effect of disability glare. Once a patient has seen an object they will remember the object during the course of the assessment. Recently, Bijveld (Bijveld et al., 2013) developed a promising alternative technique relying on the same method. Instead of using an actual room, they used a projection on a screen. Luminance levels were controlled by using neutral density filters. They have shown that the set up works in assessing illumination levels for people with Congenital Stationary Night Blindness (CNSB). The assessment does not require a dedicated room with expensive equipment. Although Bijveld (Bijveld et al., 2013) only used one slide showing the image of a room, multiple rooms could be created by using different slides. Marks indicating the maximal exposure levels have not been reported, most likely due to Bijveld's focus on visual performance at low illumination levels for people with congenital stationary night blindness (CSNB).

This project aims to do the following: (1) to investigate whether the 2D Lightlab (projection) shows similar results to the 3D Lightlab (an actual room), (2) to investigate whether the 2D Lightlab can be built up from different scenes (rooms) and reliably assess optimal illumination levels, (3) to investigate if the impact of disability glare can be assessed in a 2D Lightlab set-up by showing a reduced number of detected or recognized objects for increasing illumination levels, and (4) to investigate how patients experience the reliability of

the Lightlab outcomes for their actual needs. To accomplish the above, two experiments were conducted. The first focusses on the calibration of the different scenes for the 2D Lightlab for people without VI. The second looks at the outcome of the 2D and 3D Lightlab for people with VI and people without VI.

Experiment 1: Calibrating scenes 2D Lightlab

Material & Methods

Subjects

Ten healthy adults, from 19 to 40 years old (mean 24), participated as control subjects for the 2D Lightlab. All had typical vision without glasses (mean -0.1 [-0.3; 0.1] logMAR). We obtained written informed consent from each of the participants and approval from the ethical committee of the University of Groningen for this procedure and this study. The research followed the tenets of the Declaration of Helsinki.

Experimental set-up

Fifteen digitally manipulated scenes of a living room containing 20 objects of various sizes and various contrasts were created (see Fig. 1 for an example). Each scene consisted of two small (e.g. cup, toy), 13 middle sized (e.g. painting, side table) and five large objects (e.g. cupboard, couch). As for contrast, there were 12 low contrast objects (< 0.5 logCS; e.g. black uplighter in front of a black curtain, white lamp in front of a white wall), six middle contrast objects (0.3-0.5 logCS; e.g. reed basket against white wall, green plant on cupboard), and two high contrast objects (>0.3 logCS; e.g. red cup on white table, painting of flower).

Objects were selected out of 283 unique objects. Scenes were generated by dedicated software (Paint Shop Pro). Subjects were seated at a distance of 4 metres from the screen, at a small angle (10 degrees) to avoid blocking of the projection of the scene on a Projecta ProScreen CSR (4:3; 183x240). The scene was projected using an NEC PA903x 9000 lumen beamer using an NP13ZLI lens providing a luminance of 500 cd/m² (2,7 log cd/m²), comparable to 2000 lux on white paper (vertical illuminance). Illumination levels were controlled using a combination of a pair of neutral density glasses and neutral density filters placed in front of the beamer (glasses 3 log + ND4

ND1000 filters; glasses 2 log + ND4 ND1000 filters; glasses 1 log + ND4 ND1000 filters; no glasses ND4 ND1000 filters). Apart from the light of the beamer, the room was completely dark. Each scene was tested in random sequence at four illumination levels (3.6, 4.6, 5.6 and 6.6 log). The testing duration was approximately 2 hours. Subjects were allowed to have a short break without leaving the darkened room of the experimental setting.

Procedure

Subjects were instructed to describe their observations. The study distinguished between the detection of an object (seeing something without being able to tell what it is) and the recognition of the object (naming the object). Before starting the experiment, participants were dark adapted for approximately 15 minutes, substantially longer than the dark adaptation times leading to significant changes in visual functioning (Wood et al., 2021) and enough time to complete a thorough anamnesis. Each scene was tested at each of the four filter settings. Detection and recognition were expressed as a number between 0 and 1 for each subject by dividing the number of objects detected or recognized by the total number of objects detected. These data were fitted using a psychometric function, with two degrees of freedom (slope and offset; see eq. 1).

$$P(i, slope, i_{50}) = \frac{1}{1 + e^{-slope(i - i_{50})}} \quad (1)$$

Here, the offset (i_{50}) stands for the luminance level at which 50% of the objects are recognised or detected and the slope stands for the slope of the psychometric curve at which 50% of the objects are detected or recognized (separate fits). A fit was obtained either for each subject or for each scene independently.

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Figure 1. One of the selected scenes used for the 2D Lightlab containing 20 objects. In total 15 different scenes were created.

Statistical analysis

Data were analysed using python 3 package of scipy (Virtanen et al., 2020) using the Levene test of equal variance, the independent t-test and the fit of the psychometric curves. Offsets and slopes that did not converge were considered as missing values.

Results

Figure 2 shows the psychometric fits of the detection of objects (solid line) and recognition of objects (dashed lines) for different subjects (Fig. 2A) and for different scenes (Fig. 2B). The average offset over subjects ($i50$, eq.1) for detection equalled $-5.7 \log$ (st.dev.= $0.23 \log$) and for recognition the offset equalled $-4.7 \log$ (st.dev. = 0.26). A slope (Eq. 1) of $1.23 \log^{-1}$ (st.dev. 0.15) was found for detection and $1.54 \log^{-1}$ (st.dev. 0.18) for the recognition of objects.

An average offset over the different scenes ($i50$, Eq. 1) was found of $-5.7 \log$ (st.dev. 0.12) for detection of objects and $-4.7 \log$ (st.dev. 0.13) for recognition of objects. The slope of the psychometric function of different scenes for the detection of objects equalled $1.1 \log^{-1}$ (st.dev. 0.16) and for the recognition of objects $1.5 \log^{-1}$ (st.dev. 0.24). The scenes used in Experiment 2 were chosen based on similarity and indicated by black lines (Fig. 2B). The lower panels illustrate a scatter plot of the slope of the psychometric curve versus the offset. Paired t-tests and Levene's test for equal variance did not indicate any differences between fits based on subjects or scenes (p -value > 0.05 ;

Levene test) regarding the slope as determined by the psychometric curve.

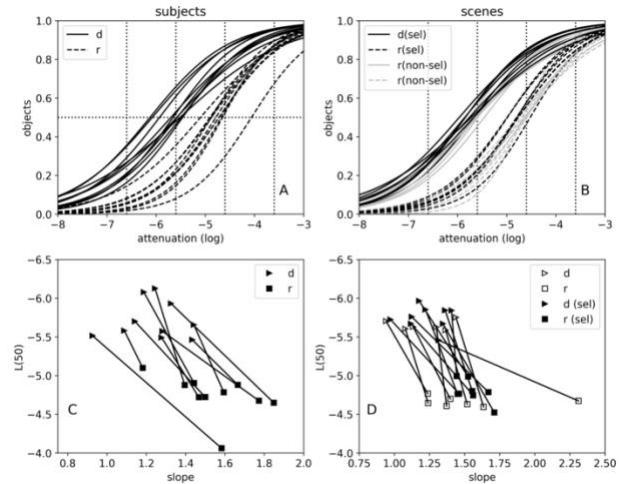


Figure 2. Psychometric curves for different subjects (panel A) and different scenes (panel B) using solid lines for the detection of objects (d), dashed lines for the recognition of objects (r). The black lines in panel B represent scenes used for further study in Experiment 2. The abscissa shows the resulting illumination level of the beamer. Panel C and D show scatter plots of the slope (abscissa) against the offset (ordinate) for detection (triangles) and recognition (squares). Lines were drawn for visibility.

Discussion

There was an increase of 1 log (factor 10) required in illumination levels for recognising objects instead of detecting them. This was similar to Bijveld's results (Bijveld et al., 2013). The same was true for the findings for the offset and the slope (Figure 2C and 2D). Given the absence of statistical differences according to Levene's test, the introduced errors due to using different scenes were small and the different scenes appeared to be well balanced and representative for the use in a 2D Lightlab. Based on the results of this study, eight different scenes were selected out of the original set for Experiment 2 (grey lines in Figure 2).

Experiment 2: 2D versus 3D Lightlab

Material & Methods

Ethics statement

The research followed the tenets of the Declaration of Helsinki. All participants were at least 18 years old, and written informed consent from each of the participants was obtained. Approval was obtained from the ethical committee of the University of Groningen for this procedure and this study.

Subjects

Experiment 2 had 51 participants. Eleven people without VI, aged from 51-76 years of age (mean 60 years), forty people with VI, aged 20-80 years of age (mean 54 years) participated (see Table 1). Visual acuity, contrast sensitivity and ocular disease are given in Table 1. The 2D and 3D lightlab were assessed on the same day for people without VI, for people with VI the 2D and 3D lightlab were assessed on different days.

Table 1: Group characteristics of the participants in the study.

	VIP (n=40)	Non-VIP (n=11)
Age (years) [min.-max.]	54 [20-80]	60 [51-76]
Female	23	8
Ocular disease ¹	16 Retinitis Pigmentosa or Usher syndrome 7 Glaucoma 5 macula degeneration 3 macular oedema 3 myopic degeneration 2 retinal detachment 2 Macular Pucker 2 Optic neuropathy 2 uveitis 1 Non-Arteritic Anterior Ischemic Optic Neuropathy 1 Retinopathy of Prematurity 1 albinism 1 keratitis 1 meningitis encephalitis 1 microphthalmos 1 Idiopathic intracranial hypertension 1 unknown	x
Visual acuity		
< 0,3 LogMAR (>0.5)	15	11
0.3-0.5 logMAR(0.3-0.5)	7	
0.3-1 logMAR (0.1-0.3)	13	
>1 logMAR (<0.1)	5	
Contrast sensitivity		
>1.6 logCS (normal)	3	11
>1.2 logCS (near normal)	12	
>0.8 logCS (moderate)	9	
>0.8 logCS (severely reduced)		
unknown		

¹ Some participants had a combination of ocular diseases. For reasons of clarity they were mentioned separately in this overview

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	1.	6	
	10		
Reason for rehabilitation			
Need for light	17		0
glare	8		0
both	15		0

3D Lightlab

The 3D Lightlab is a calibrated visual environment with real objects to measure detection and recognition capacities of low vision subjects (Cornelissen et al., 1994). It is used in visual rehabilitation to assess the minimal required illumination levels for optimal detection and recognition of objects at one end, and the illumination level at which participants experience dazzling glare at the other. The difference between the two is referred to as the dynamic range of illumination. In total, four different 3D Lightlabs were used in this study (see table 2). Illumination levels could be accurately adjusted in fixed steps. Illumination was provided by fluorescent tubes. Illuminance was measured in the horizontal plane at

a height of 0.20 m with a lux-meter. Objects were carefully selected so that they became detectable over an extensive range of illuminations. In total 4 different 3D Lightlabs were used (of which the location 1 has been described by Cornelissen (Cornelissen et al., 1994) (see Table 2). Illumination levels were regulated by a pair of glasses attenuating illumination levels by 2 log for people without a VI. In order to assess illumination levels at which participants experienced dazzling glare, participants were asked to mark their experience between 1 (much too dark or much too bright) and 10 (perfect). Participants were dark adapted for at least 15 minutes seated in the condition resembling the lowest illumination. On average, it took approximately three minutes to describe the objects in a room for each step in illumination.

Table 2: The conditions provided in the Lightlabs used during the study. For the 2D Lightlab attenuation levels are given instead of the illumination level.

	3D loc - 1	3D loc -2	3D loc 3	3D loc 4	2D
Nr participants	5 (11 non VIP)	30	5	1	51 (11 non-VIP)
Nr objects	24	45	34	45	20
Illumination levels (linear)	1.5, 5, 15, 50, 100, 200, 500, 1000, 2000 lux	1, 3, 5, 15, 50, 150, 500, 1000, 2000 lux	1.5, 5, 15, 50, 100, 200, 500, 1000, 2000 lux	5, 15, 50, 100, 200, 500, 1000, 2000 lux	0.00025, 0.0001, 0.0078, 0.031, 0.063, 0.125, 0.25 E (attenuation)
Illumination levels (logarithmic)	0.2, 0.7, 1.2, 1.7, 2.0, 2.3, 2.7, 3.0, 3.3 log(lux)	0.0, 0.5, 0.7, 1.2, 1.7, 2.2, 2.7, 3.0, 3.3 log(lux)	0.2, 0.7, 1.2, 1.7, 2.0, 2.3, 2.7, 3.0, 3.3 log(lux)	0.7, 1.2, 1.7, 2.0, 2.3, 2.7, 3.0, 3.3 log(lux)	-3.6, -3.0, -2.1, -1.5, -1.2, -0.9, -0.6 logE
Colour temperature (K)	3000 K	2700 K	3000 K	2700 K	n.a.

2D Lightlab

Eight scenes were selected from Experiment 1 on basis of the similarity between the psychometric fits (black lines Fig. 2). At each illumination level two scenes were presented. One scene presented the same scene, referred to as 2D (1), similar to the 3D

Lightlab in which the scene is also fixed. The other scenes changed randomly and will be referred to as 2D (7). Transmission was regulated by using neutral density filters (ND1000+ND4, ND1000, ND16+ND8, ND16+ND2, ND16, ND8, ND4; see table 2 for transmission values). For participants without a visual impairment, illumination levels were

reduced by wearing a pair of glasses containing ND filters of 2 log. Similar to the 3D Lightlab, participants were asked to provide a mark between 1 and 10 on how the illumination level was experienced. Participants were dark adapted for at least 15 minutes seated in the condition resembling the lowest illumination. Describing a scene took on average three minutes including changing the filter settings.

Questionnaire

At the end of the 2D Lightlab a short questionnaire was used containing seven items. The first four items were used to express the participants' experience regarding the trustworthiness of the outcome of the 2D Lightlab. Items focussed on whether the 2D Lightlab was able to determine the amount of illumination required for optimal visual functioning, the illumination level for dazzling glare to occur, the willingness to adapt their home based on the results of the 2D Lightlab and how well they felt the advised illumination levels would enable them to conduct activities they were currently unable to do in their own environment (such as mobility to avoid bumping into doorsteps, running a household, and communicating). Items were rated on a 10-point scale. Two additional items compared the experience of the 2D relative to the 3D Lightlab of the participant regarding required illumination level and dazzling glare on a seven-point scale. Since reducing travel time was one of the reasons to develop a 2D Lightlab, a final item was added asking the participant to imagine a situation in which they had to advise a friend who is hesitant to undergo the assessment due to the required travel time to the 3D Lightlab. How much traveling time (or kilometres) would the friend be willing to travel in order to visit the Lightlab? The questionnaire was filled in directly after completing the 2D Lightlab.

Statistical analysis

Data were analysed using python 3 package of scipy (Virtanen et al., 2020) for the independent t-test and the fit of the psychometric curves, and the Seaborn package (Waskom, 2021) for the linear regression. Offsets and slopes that did not converge were considered as missing values.

Results

Lightlab

Figure 3 shows a scatter plot of the luminance at which 50% of the objects were detected (panel A and B) and recognized (panel C and D), comparing the results obtained by the 2D (ordinate) and 3D (abscissa) Lightlab for subjects without (grey asterisks), and with a VI (black triangles). Results indicated a linear relation between the results of the 2D and the 3D Lightlab ($F\text{-value} > 70$; $p < 0.001$) with a -3.3 dB difference in offset between the 2D and the 3D Lightlab. The average slope of the fit equaled 0.85 (see table 3).

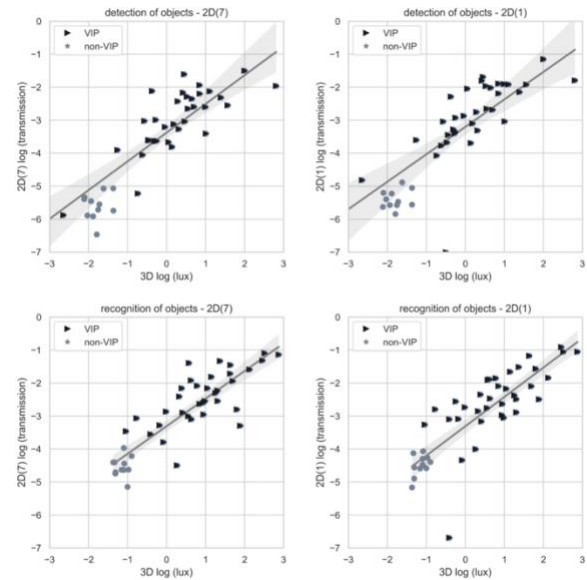


Figure 3. Linear regression plots of the illumination at which 50% is detected (panel A and B) or recognized (panel C and D) as determined by the psychometric fit for people with VI (black triangles) and people without VI (grey stars) for the 2D Lightlab based on 1 scene (panel B and D) and different scenes (2D(7)).

Table 3: Linear regression models for the four fits of figure 3. Column R2 gives the explained variance of the linear regression models. The goodness of the fit is provided by the last column providing the F-value and the accompanying p-value.

	slope	offset	R2	F-value (p-value)
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	mean [2.5%-97.5%]	mean [2.5%-97.5%]		
Detection 3D-2D(1)	0.87 [0.71-1.04]	-3.4 [-3.6; -3.2]	0.72	111 (> 0.001)
Detection 3D-2D(7)	0.83 [0.63-1.03]	-3.2 [-3.5; -2.9]	0.61	70 (> 0.001)
Recognition 3D-2D(1)	0.84 [0.69-0.99]	-3.3 [-3.5; -3.1]	0.74	127 (> 0.001)
Recognition 3D-2D(7)	0.89 [0.71-1.07]	-3.3 [-3.5; -3.1]	0.69	97 (>0.001)

Comparing the results of people with VI to the results of people without VI, no significant difference was found regarding the slopes of the 2D Lightlabs and the 3D Lightlab, neither for the detection of objects (independent t-test; $t < 1.25$; $p > 0.05$) nor for the recognition of objects (independent t-test; $t < 1.27$; $p > 0.05$). However, a significant difference was found comparing the offset for the different Lightlabs regarding the detection of objects (independent t-test; $t > 4.8$; $p < 0.001$) and the recognition of objects (independent t-test; $t > 6.4$; $p < 0.001$). The difference in offset in luminance for detecting and recognizing objects equalled on average 0.6 log and was not significantly different for people with and without VI for the 3D Lightlab and the 2D(1) Lightlab (independent t-test; $t > 1.9$; $p > 0.05$). There was a small significant difference of an extra -0.3 log for the 2D(7) Lightlab (independent t-test; $t = 2.9$; $p = 0.006$) between people with VI and without VI.

Comparing the results for the different Lightlabs, there was no-significant difference found for the offset and the slope of the psychometric curve between 2D(1) and 2D(7) (independent t-test; $t < 1.8$; $p > 0.05$). There was a significant difference between the offset 2D(1) and 2D(7) and the 3D Lightlab for detection of objects as well as for recognition of objects (independent t-test; $t > 3.7$; $p < 0.001$). The slopes of the psychometric curves were not significantly different for the 2D Lightlab and the 3D Lightlab for detection and recognition of objects (independent t-test; $t < 1.8$; $p > 0.05$).

Marks on a 10-points scale were used to assess dazzling glare. The correlation coefficient between the maximal score given by the participants (average 3D Lightlab: 8.1, 2D Lightlab: 7.0) indicated a similar subjective experience (Spearman > 0.4 ; $p\text{-value} < 0.01$) for the 2D Lightlab and the 3D Lightlab. Dazzling glare, as indicated by the reduction in subjective response between the most comfortable illumination level and the maximal illuminance, was similar for the 2D(7) Lightlab and the 3D Lightlab as indicated by Chi2 test ($p\text{-value} < 0.05$), but not for the 2D(1) Lightlab ($p = 0.23$). However, more severe dazzling glare (> 0.8 degradation in subjective experience) could be

established using both the 2D(1) and the 2D(7) Lightlab (Chi2 >42 ; $p\text{-value} < 0.0001$).

Questionnaire

The visually impaired participants indicated a high confidence in the ability to assess the correct illumination levels for visual functioning using the 2D Lightlab (Fig. 4 panel A) and to assess illumination levels at which dazzling glare occurs (Fig. 4 panel B). Over 86% of the people with VI expressed their confidence (>6) in assessing the appropriate lighting levels for their needs using the 2D Lightlab. Over 74% of the participants expected that adjusting their ambient lighting would facilitate them in conducting specific tasks that relied more on ambient lighting (e.g. communication, bumping into doorposts, tripping; see Fig. 4 panel C). Over 87% expected to adjust their own environment (e.g. working space, living room, study room) based on the outcome of the 2D Lightlab (Fig. 4, panel D).

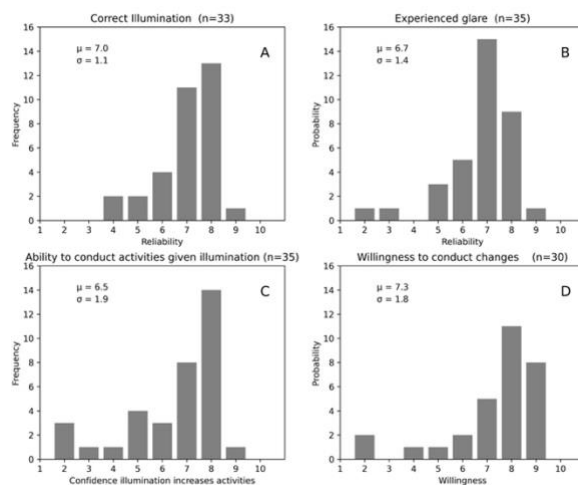


Figure 4. Upper panels regard the confidence in assessing optimal illumination levels (panel A) and assessing dazzling glare levels (panel B). Panel C indicates the confidence participants have that advised illumination levels will increase their ability conducting activities. Panel D shows the willingness to adapt one's home according to the illumination levels obtained from the experiment.

Figure 5 illustrates a preference of 71% of the participants for the 3D Lightlab assessment relative to the 2D Lightlab assessment for determining the

illumination level or the level at which dazzling glare occurred, with a total of 39% of the participants greatly preferring the 3D Lightlab. If asked, participants would advise their friends to go to the 3D Lightlab instead of the 2D Lightlab even if they had to travel for longer than two and a half hours (on average; median 1 hour).

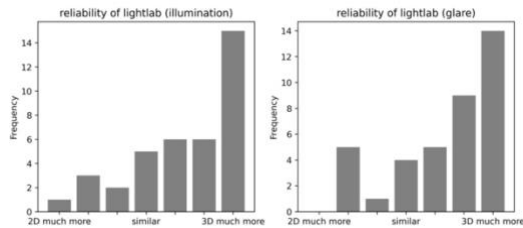


Figure 5. Histogram of the responses asking people with VI to compare the 2D Lightlab and 3D Lightlab on the reliability of the assessment providing optimal lighting levels and dazzling glare.

Discussion

In this study, we validated eight scenes for the 2D Lightlab (Experiment 1) and compared the outcomes of the 2D Lightlab and the 3D Lightlab to each other for 11 people without VI and 40 people with VI (Experiment 2). We distinguished two different 2D Lightlabs, one in which the scene presented on the screen was kept fixed while illumination was increased, referred to as 2D(1), and one in which the scene was changed while the illumination increased, referred to as 2D(7). People without VI detected all objects (ceiling psychometric curve) at approximately 0 log (1 lux) and recognized all objects at approximately 0.7 log (5 lux), similar to the results of Cornelissen et al. (1994). For people with VI, there was a large difference between participants with regard to the offset of the psychometric curve or to the maximal number of recognised or detected objects. The offsets and the slopes for the 2D Lightlab were similar to those reported for people without VI by Bijveld (Bijveld et al., 2013), both for recognition and detection of objects. We found no significant difference between the slopes of people with and without a VI, whereas Bijveld (Bijveld et al., 2013) reported a significant difference for the detection of objects, but not for the recognition of objects. This difference may be explained by the difference amongst people with a VI instead of the focus on people with CNSB. The absence of a significant difference in incremental slopes for the detection and recognition of objects between people with VI and without VI for the psychometric curves (2D) or linear fits (3D;

Table 4) suggests that differences between both groups were mainly attributable to a difference in illumination level at which detection or recognition became possible (i.e. offset, Eq. 1). These offset values are shown in the scatterplots of Figure 2, illustrating an offset of -3.3 log for both the 2D(1) and the 2D(7) Lightlab with the 3D Lightlab for detecting and recognising objects, enabling us to translate the results of the 2D into illumination values as would they have been obtained by the 3D Lightlab. However, the slope of the linear regression fit between 2D and 3D Lightlab offset values (Figure 3) was lower than 1 (0.8). This may be due to a crucial difference between the 2D and 3D Lightlab. In the 2D Lightlab, lighting levels are defined in terms of the maximal luminance of the beamer and the attenuation induced by neutral density values. Given the vertical position of the projection screen, luminance could at most be transferred in vertical illuminance values. In the 3D Lightlab, lighting levels were defined as the horizontal illumination at 20 cm from the floor. The maximal luminance of the beamer (in eco-mode) was equal to 500 cd/m² (i.e. 2.7 log cd/m²), which is roughly comparable to 2000 lux (3.3 log) falling on a white piece of paper, which is the maximum in the 3D Lightlab. However, depending on a number of factors, the horizontal illumination could be estimated roughly based on the vertical illuminance by dividing it by a factor of three (0.5 log) (Bommel, 2019). In order to obtain comparable maximal illumination levels, scenes were filtered by 25% (0.5 log) (ND4) resulting in a maximal illumination that was comparable to the maximal illumination level of the 3D Lightlab (3.2 log 2D Lightlab vs. 3D Lightlab). However, since this study used direct lighting in the 3D Lightlab causing the illuminance to change over the height of measuring, the actual luminance differed not only due to the colour of the object, but also due to its size or height.

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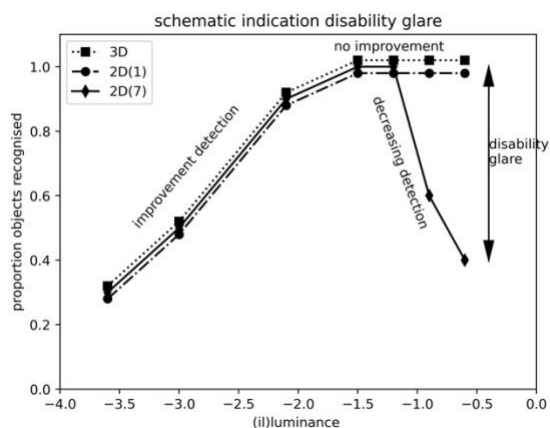


Figure 6. Schematic drawing on slope-determination based on linear fits as described by Cornelissen for the 3D (squares), 2D(1) (circles), and the 2D(7) (diamonds) Lightlab. The curve illustrates three fases, (1) positive slope, higher illumination levels resulting in an increased number of detected or recognized objects, (2) horizontal phase higher illustration levels result in no further improvement, (3) negative slope, higher illumination levels resulting in a decreased performance. The

latter is only shown for the 2D(7) Lightlab given the different scenes.

Since the scene in the 2D(7) Lightlab changed with every step in illumination, a potential benefit could be that it enabled the assessment of a decline in detected or recognised objects due to disability glare. Figure 6 provides a schematic drawing of the three lines, one line indicating the improvement of detection and recognition by increasing illuminance, one line indicating no improvement, and, in the case of disability glare, one line decreasing detection or recognition when disability glare occurs. Table 4 provides the calculated slopes. Comparing the 2D(1) and 2D(7) Lightlab results showed no significant differences for the incremental slope (paired T-test, $p>0.05$), but showed a difference for the decreasing slope for recognizing objects for people with VI (paired T-test, $p<0.01$), but not for detecting objects (paired T-test, $p>0.05$). This suggests that disability glare can be assessed using different scenes in the 2D Lightlab for recognising objects.

Table 4: Data represent the number of objects that are detected or recognized more (second and third column) or less (fourth and fifth column) by a tenfold increase in illumination.

	Increasing slope		Decreasing slope	
	VIP	Non-VIP	VIP	Non-VIP
3D – detection	0.25 $\log^{-1}$ (0.12)	0.32 $\log^{-1}$ (0.06)	-0.03 (0.12)	0 (0)
3D – recogn	0.29 $\log^{-1}$ (0.13)	0.32 $\log^{-1}$ (0.06)	-0.02 (0.09)	0 (0)
2D(1) – detection	0.28 $\log^{-1}$ (0.12)	0.22 $\log^{-1}$ (0.05)	-0.08 (0.12)	-0.03 (0.06)
2D(1) – recogn	0.28 $\log^{-1}$ (0.12)	0.28 $\log^{-1}$ (0.04)	-0.04 (0.14)	-0.03 (0.06)
2D(7) – detection	0.26 $\log^{-1}$ (0.14)	0.22 $\log^{-1}$ (0.05)	-0.09 (0.14)	-0.06 (0.14)
2D(7) - recogn	0.25 $\log^{-1}$ (0.11)	0.30 $\log^{-1}$ (0.08)	-0.11 (0.15)	-0.03 (0.10)

The possibility of transforming the findings of the 2D Lightlab into results that were obtained by the 3D Lightlab made it a potentially valuable tool for visual rehabilitation. Participants indicated the method of the 2D Lightlab to be reliable in estimating their preferred illumination levels. However, when compared to the 3D Lightlab, people prefer the 3D Lightlab, since it enabled participants to experience what optimal illumination would offer them. Subjects experienced a difference between both assessment methods due to the lack of shadows in the 2D Lightlab, which may reduce additional cues for recognising and detecting objects. One subject indicated difficulties judging the size of the room, due to the lack of acoustics and perspective, which in turn led to difficulty determining the size and shapes of objects.

On average, participants would advise their friends to go to the 3D Lightlab instead of the 2D Lightlab even if they had to travel for longer than two and a half hours (on average). However, these data were highly skewed (median of 1 hour), and given that participation was on voluntary basis, these patients were probably more likely to experience fewer difficulties in their transfer to the clinic. For some patients (e.g. children, or when people require psychoeducation for themselves or their loved ones), the 2D Lightlab is too abstract for proper assessment and will need to continue to rely on the 3D Lightlab assessment. However, in general, the 2D Lightlab is a valuable asset in the assessment of optimal ambient lighting. So long as they are informed of the differences, patients should be

given a choice whether to undergo the likely more accessible 2D Lightlab assessment, or the less accessible 3D Lightlab. The 2D lightlab assessment offers a valid method for people with limited traveling time making it accessible for a larger audience. Importantly, this knowledge may differ between the more frequently assessed tasklighting and ambient lighting from the 2D lightlab. In addition, this knowledge may provide specialists clues as to what illumination levels will enable clients to reach independence.

Institutes willing to adopt the 2D-lightlab into their regular care, may obtain reliable results using the scenes. Scenes can be demonstrated using standard MS-PowerPoint software, with the slides obtained by e-mailing the authors (JK).

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