MASTER

The Effect of Lighting on the Visual Performance of Participants Aged 35 to 55 when Reading Medicine Labels

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The Effect of Lighting on the Visual Performance of Participants Aged 35 to 55 when Reading Medicine Labels

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Abstract

Hospitals reportedly suffer from inadequate lighting, which can lead to unnecessary medication errors, as lighting can affect task performance. In addition, natural aging reduces the vision of most humans, mostly starting somewhere between the age of 32 to 40 (presbyopia), increasing the demand for more light. Nurses are unaware of the role lighting can play in the visual performance. The goal of this study was to find the optimal lighting conditions supporting the visual performance of nurses aged 35 to 55. To reach this goal, the main research question was formulated as follows: *Which lighting conditions results in the best visual performance of reading medicine labels of females in the age at 35 to 55?*

Measurements were conducted in a repeated measures set-up under controlled conditions. The search for the optimal lighting condition for reading medication labels was conducted under nine lighting conditions (combinations of 100 lx, 500 lx, 1000 lx with 3000 K, 4000K, and 6500 K), with three material labels (Blister, Baxter, Orange), and three font sizes (Arial 3.0 pt., 3.5 pt., 4.5 pt.). Visual Acuity (VA) was analyzed as a between-condition. Participants (N=30) were instructed to read and recite from booklets containing 18 randomized 10-letter text sequence medicine labels per session. Visual performance was assessed by the two outcome measures reading errors and reading speed. Results showed that participants with a moderate VA (<1.0 in equivalent decimal notation) made significantly reading more errors (M_{errors}=237) and had much lower reading speeds (M_{speed}= 1463 s) than Participants with a normal VA (VA≥1.0), M_{errors}=31; M_{speed}=993 s for the total experiment.

Significant differences in reading errors were found for participants with VA<1.0 reading under lower illuminance (100 lx) compared to higher illuminances (500 lx, and 1000 lx). This also holds up for differences between all label materials, and all font sizes. In summary, with moderate vision; reading from blister labels and largest font size resulted in the least amount of reading errors and highest reading speed. While participants VA>1.0 were generally insensitive to changes in material and font size, showing no significant differences in reading errors and reading speed. Significant effects on reading speed were found by the largest font size and a task illuminance of 500 lx. The correlated color temperature had no effect on visual performance in both participants with moderate vision and normal vision.

In conclusion, the results from this study showed that lighting conditions in hospitals should provide an illuminance of 1000 lx on the reading task in order to support the visual performance of participants with mild vision loss by significantly reducing reading errors and increasing reading speed.

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1 Introduction

Hospital lighting is designed to create a visually comfortable environment for patients and medical staff alike. In addition, lighting can also increase visual performance and productivity, because lighting influences environmental perception and responses of hospital occupants (Bernhofer et al., 2014; Dalke et al., 2006). Nurses aged 45 and older have reported the increasing need for more lighting to conduct their tasks than at a younger age (Graves et al., 2015). Research since long has stated that adequate lighting can improve task performance and can reduce visual fatigue (Megaw, 1979). However, there does not seem to be wide agreement which lighting conditions are optimal. More recent studies mention a variety of ranges to be adequate e.g. seemingly low illuminance in an office between 250 lx and 500 lx (Taniguchi et al., 2011) or higher at least 800 lx (Inoue & Akitsuki, 1998) and 1500 lx for hospital pharmacies (Ulrich, R. & Barach, 2006). Especially for the medical staff, it is important to work in a well-designed lighting environment to cope with the physiological and physical intensity of the job (Mahmood et al., 2011). Shift work, heavy work load, and (emotional) work environments are known sources of stress for the medical staff. This stress can have adverse effects on work performance of medical staff, for example causing errors during the medicine dispensing process which can affect patient safety (Hersch et al., 2016). In addition to these stress factors, inadequate lighting is one of the main causes of dispensing errors, due to decreased readability (James et al., 2009). The reading ability of humans depends on visual function. A common measure for visual functioning is visual acuity (VA). Visual acuity defines the size of an object that can be resolved with an eye (Kaiser, 2009); for a target with a fixed luminance contrast (Boyce, 2003).

The visual acuity of most humans starts to decrease somewhere between the age of 32 to 40; this condition resulting from natural aging is called presbyopia (Glasser & Campbell, 1998). Presbyopia is caused by age-related elasticity changes of the eye lens. However, the exact of manifestation of presbyopia resulting in reduced vision is unknown and depends on individual factors such as accommodative ability, distance refraction, sex, and ethnicity (Holden et al., 2008). After the manifestation of presbyopia, generally 34% to 55% of those affected do not correct their vision (Wolffsohn & Davies, 2019), which evidently impacts productivity and task performance (Smith et al., 2009). With 55% of Dutch nurse workforce being aged 35 to 55

(Centraal Bureau voor Statistiek, 2017) and in the light of reducing dispensing errors, it is important to understand which lighting condition(s) results in the best visual performance when reading medicine labels. Furthermore, it is also important to assess whether the best lighting condition for reading medicine labels is different for different labels and font sizes. The assumption is that if the lighting is adjusted to improve visual performance of medical staff with moderate visual acuity, then the medical staff with better visual acuity will also benefit also.

There have been studies on dispensing errors (Cina et al., 2006; Gonzales, 2010; Hamilothoris, 2008; Picone et al., 2008) and studies investigating the relationship between dispensing errors and lighting conditions (Buchanan et al., 1991; James et al., 2009; Mahmood et al., 2009; Ulrich, R. & Barach, 2006). However, to the knowledge of the author, only one study has investigated the influence of label material and lighting conditions on the ability to read medicine labels correctly. Aarts et. al. (2019) have investigated the relationship between lighting conditions, dispensing errors, and medication labels (N=37). The majority of the participants had normal or better visual acuity (VA higher than 1.0 in equivalent decimal notation or 6/6 in Snellen notation) and reading performance seemed unaffected by the lighting conditions (min. value 100 lx, 3000 K). However, seven participants with moderate visual acuity (lower than 1.0 but higher than 0.5 or 6/12 in Snellen notation) had a substantially higher error rate than participants with normal visual acuity (Aarts et al., 2019). This may indicate that the impact of the lighting conditions differs between people with a higher (VA >1) and a lower VA (<1).

This follow-up study focused on participants with moderate visual acuity to assess the visual performance of reading tasks of medication labels under different lighting conditions, as the results of the previous study imply that the impact of lighting is high for this group. Visual performance is assessed by reading errors and reading speed.

1.1 Research Objectives and Research questions

This study investigates the effect of lighting conditions on the visual performance of participants with a moderate visual acuity when reading medicine labels. The aim is to determine under which lighting conditions the visual performance of nurses aged 35 to 55 will be increased, resulting in fewer reading- and medicine dispensing errors. The visual performance is assessed on number of reading errors and reading speed (time in seconds spent reading).

Following this, the main research question is: "Which lighting condition(s) results in the best visual performance for reading medicine labels of females in the age at 35 to 55?".

Main Question:

"Which lighting conditions results in the best visual performance of reading medicine labels of females in the age at 35 to 55?"

Sub Questions:

1. "What is the influence of the *medicine label material* on the visual performance while reading medicine labels?"
2. "What is the influence of the *font size* on the visual performance while reading medicine labels?"
3. "What is the influence of *visual acuity* on the visual performance while reading medicine labels?"

2 Methodology

The aim of the experiment is to study the effect of lighting on the visual performance while reading medicine labels in hospitals. To answer the research questions during this study, a measurement setup was used based on the experimental setup by Craenmehr (2017).

2.1 Participants

The participants (N=31; M_{age}=46.5, *SD*=5.55) have been contacted through the JFS Participants Database[1], through e-mail among the TU/e-employees[2], and snowball sampling. The target demographic for this study were women between the age of 35 and 55. Males were excluded from the experiment due to the majority of nurses being female. In addition, men have faster reaction times when performing high concentration tasks under blue-enriched light (Chellappa et al., 2017). The participants conducted the test with their habitual visual acuity. Participants were allowed to participate with a binocular visual acuity of at least 0.5 or better ($N_{VA<1}$=15, $N_{VA>1}$=16). Usage of vision correction such as glasses and/or lenses was allowed during the experiment, given that the participant wore vision correction most hours of the day. No vision correction aid was provided to the participants by the experimenters. Participants have given their written informed consent and received financial compensation of €15,- for participation in this study. This study was conducted by the Building Lighting Group within the Unit of Building Physics and Services with approval of the group of Human-Technology Interaction, which adheres to the Code of Ethics of the NIP[3].

Exclusion criteria: Aside from presbyopia, the participants should have no ocular deficiencies; such as amblyopia, cataract, diabetic retinopathy, and glaucoma. These impairments challenge the controllability of the experiment as there will be effects following these impairments that are in play. The participants were tested for age-related macular degeneration (AMD) through the Amsler-test. The Amsler test is used to identify presence of deficiencies in the central visual field, which indicates decreases in macular vision (Faes et al., 2014; Liu et al., 2019). The seven participants failing the Amsler-test were advised to contact their general practitioner for a professional diagnosis. Subjects with AMD were allowed to participate in the experiments, due

[1] The JFS Participants Database is managed by the Human-Technology Interaction group of the Department of industrial engineering & innovation sciences of Eindhoven University of Technology.
[2] TU/e is the abbreviation of Eindhoven University of Technology
[3] NIP is the Nederlands Instititutt van Psychologen – the Dutch Institute of Psychologists

to lack of participants. Comparisons of the results of participants scoring positive and negative on the Amsler test for reading errors (Z= -.25, r= .05, p=1.00) and reading speed (Z= .417, r= .08, p=.701) showed no significant differences for the two groups. As a result, participants with AMD were included in the analysis.

2.2 Study Design

During the experiments, participants were asked to recite short text sequences printed on three types of labels (Blister, Baxter, Orange), mimicking typically used medicine labels. These text sequences consist of 10 randomized letters printed in three different font sizes in the font of Arial (3.0 pt., 3.5 pt., and 4.5 pt.), with no changes to the width between letters. The participants were exposed to nine different lighting conditions, which were combinations of three illuminances (100 lx, 500 lx, 1000 lx) and three correlated color temperatures (3000 K, 4000 K, 6500 K). For every lighting condition, each participant went through one booklet of 18 medicine labels.

2.2.1 Study Design: Setting

The study was conducted in the laboratory of the Unit Building Physics and Services at the Eindhoven University of Technology. The windows of the test room (19.3 m^2) were blinded for this study in order to completely darken the room. An overview of the room is given in Figure 1. The only (illuminated) light sources in the room were the luminaire in the setup and a desk lamp for the experimenter which was completely invisible and obstructed for the participant. In addition, the experiment room was closed off to avoid the disturbance of participants during the reading sessions. The surrounding area was considered quiet. A humidifier and electrical heater were placed in the room to control the room temperature and relative humidity between 21°C to 24°C and 40% to 60%, respectively.

The experiments took place between the 2^{nd} of March 2019 and 16^{th} of May 2019. The participants were able to choose from four timeslots throughout the whole day: 09:15, 11:15, 13:30, 15:30. Upon arrival, the participant was offered water, coffee, tea, and cookies.

The experiment was conducted using the experimental setup of Craenmehr (2017). For a complete overview of the measurement setup and design choices are given in Craenmehr, (2017).

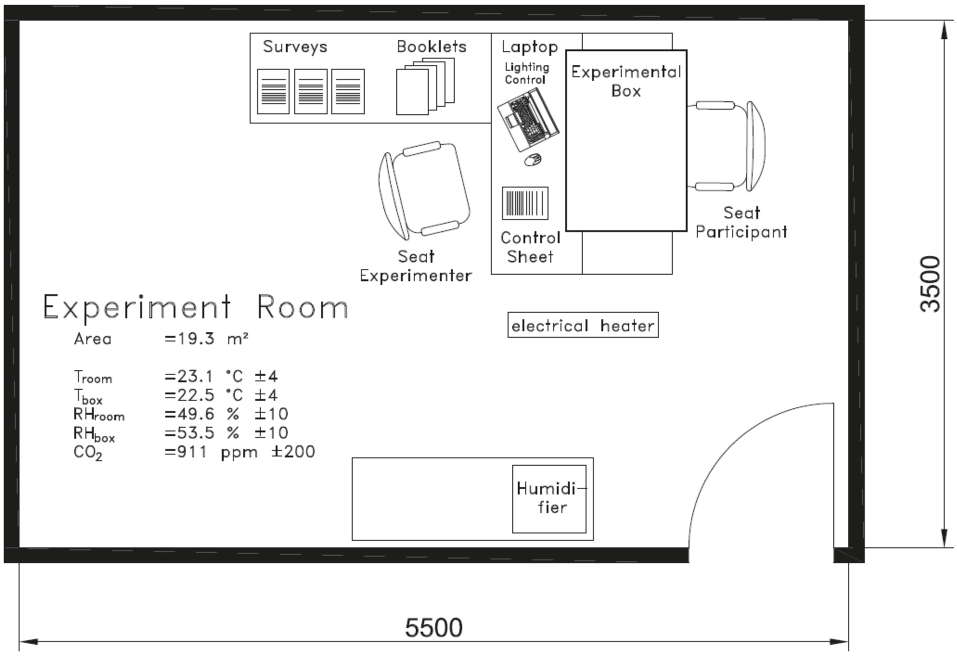

Figure 1: Lay-out of experiment room in the laboratory of Unit Building Physics and Services

This report only presents the relevant information regarding the setup, coupled with the slight adjustments to the setup and process: Amsler test, removal of the smallest text size (2.5 pt) and different devices measuring indoor climate conditions were used and the repeating survey was conducted after the participant went through a lighting condition. An overview of the setup of the experimental box is provided in Figure 2. The experimental box (1.2m x 0.8m x 0.8m) was equipped with a Philips Smart Balance RC484B LED78S luminaire that connected to a DALI-control system (Helvar Digidim) which allowed the experimenter to adjust the condition to one out of nine desired lighting conditions using a laptop. A booklet stand placed inside the experimental box allowed the booklet to be placed on a fixed angle and position. Combined with the head+chinrest, this ensured a fixed distance of 40 cm under a fixed angle of 60° to the eyes of the participant for the duration of the experiments. In addition, there was a microphone that recorded the voice of the participant allowing post-assessment of reading errors and reading speed. A non-recording camera was placed in the box which allowed the researcher to observe the participant and to assess if the measurements were conducted under the correct conditions. A Konica Minolta CL-500A spectrophotometer was used to measure illuminance, correlated color temperature (CCT), color rendering index (Ra), and spectral power distribution (SPD). The spectrophotometer was mounted on the bookstand, allowing to measure the lighting conditions at the same position of the text sequence. The mean values of measured photometric quantities can be found in Appendix F.

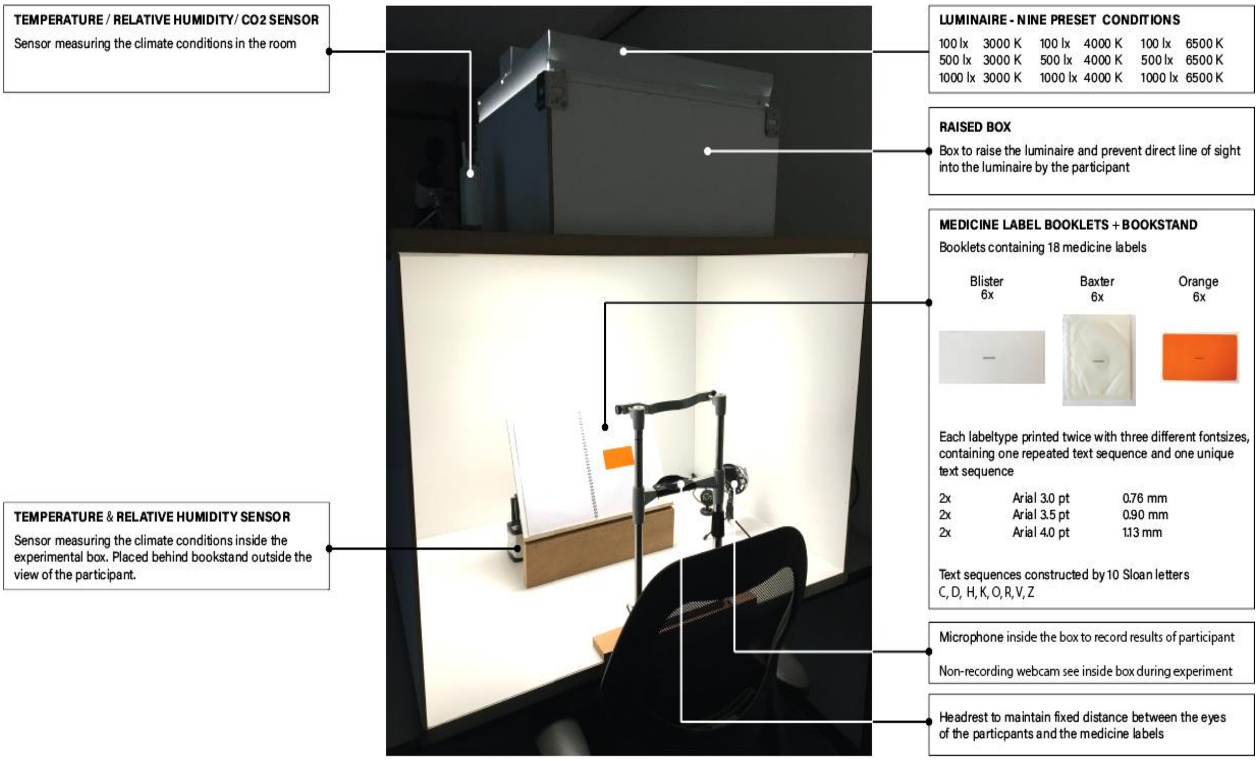

Figure 2: Overview of experimental box. Slightly modified from Craenmehr, 2017

2.2.2 Study Design: Experiment process

The experiment began with an explanation of the procedure (visualized in Figure 3). After the explanation, the participants signed the Form of Consent and filled in the General Survey. The form of consent and all surveys can be found in Appendix G. After the General Survey, the Amsler-test was taken and the ETDRS visual acuity test was conducted to determine the VA of the participants. In cases where the participants wore glasses, the visual acuity test was measured once with glasses and once without glasses.

Then, a dummy test was conducted to take the learning effect of the participants into account, as performance might increase over time. The dummy test was taken under conditions of 500 lx and 3000 K, which is the recommended value for illuminance according to the NEN-EN 12464-1(NEN-EN, 2011) and values found for average CCT typically found in hospital medication rooms (Aarts & Kort, 2017). After filling in the first Repeating Survey, the actual sessions started. The Repeating Survey was taken after every session. After the 10th session, the participant filled in the End Survey. The experiment was designed to finish in 90 minutes.

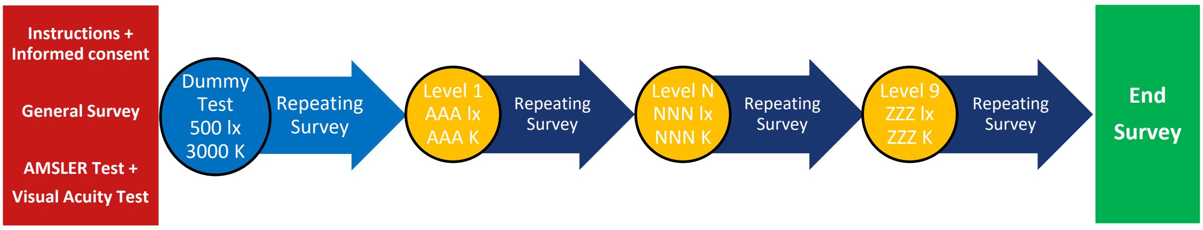

Figure 3: Measurement Process. Dummy test always starts with 500 lx and 3000 K, the lighting conditions in all following levels are randomly designated for each participant.

General survey: This survey was taken before the experiment starts. The General Survey asked for general information such as: Name, Age, Education level, Vision correction. Finally, the participant was also asked to express the level of thermal comfort and how they experience background noise in the room.

Repeating survey: The repeating survey was taken nine times, each time after a session was completed. This survey served to determine how the participant experiences the illuminance, correlated color temperature, eye hindrance, and state of alertness.

End survey: The final survey was similar to the repeating survey. To conclude the experiment, the participant was asked several additional questions; preference of label material, noticeable difference in readability, also the questions regarding thermal comfort and background noise nuisance were repeated.

2.2.3 Study Design: Test procedure

Participants were instructed to read text sequences in strings of 10 randomized letters out loud. The subjects were told that there is no time limit, but that they should read as well as they can; adding they should not rush through the test, but also not take all the time to read.

The lighting conditions were changed by the researcher. The illuminance and correlated color temperature were changed after every booklet, but only after the participant had filled in the repeating survey. This ensured that the participant rated the lighting condition while under that condition. After the survey, the participant had to wait two minutes before starting the next session to allow her eyes to adapt to the new lighting condition. The order of lighting conditions and booklets were both randomized to control for combination and order effects. Every participant went through all nine lighting conditions and reading the same text sequences as the other participants.

2.3 Medicine label material

There are three types of labels used in this experiment that mimic the medicine labels used in the medical field. The labels are displayed in Figure 4; the upper labels are used in the field and the lower labels are used in the experiment. The blister label is a label with a matte-white background and printed on with black ink. The baxter label is a plastic label with a translucent, reflective background. The orange label is a label with a matte orange background printed on black ink.

Figure 4: The three medicine labels from left to right: Orange, Blister, Baxter. (Image: Craenmehr (2017)).

2.4 Text Sequences

The text sequences in this study have remained mostly the same as in the previous study of Craenmehr (2017). The text sequences consisted of the same Sloan letters used in the EDTRS[4] chart; C, D, H, K, N, O, R, S, V, Z. The text sequences were printed on three different types of medicine labels typically found in the Dutch medical field (Craenmehr, 2017). The letters in the text sequences will be randomly distributed in such a way that words and well-known acronyms are avoided. For every label type, there was a recurring text sequence and a unique text sequence, which allowed direct comparison of reading errors and reading speed under different lighting conditions. The unique text sequences were also added to increase difficulty and prevent memorization of text sequences. The assumption was made that participants with moderate visual acuity would have difficulties reading the labels with this font size; placing the emphasis of the test would be placed on the impact of the font size of the label, rather than the effect of lighting conditions.

[4] Early Treatment of Diabetic Retinopathy Study-Chart. This is a visual acuity test chart used for most clinical research studies with Visual Acuity as an outcome variable (Bailey & Lovie-Kitchin, 2013).

To avoid this, the six labels (three unique and three recurring) with a font size of 2.5 points were removed from the original booklets and replaced with three labels in the font size of 4.5 points. The text sequences of these new labels were previously used on the three unique 2.5 points labels. The text sequences on these labels remained unchanged, only the size was increased of the unique text sequences.

Table 1: Overview of font sizes used in this experiment, presented in Equivalent notation, LogMAR, millimeters, and points

Equivalent notation (Snellen)	LogMAR [-]	Letter size [mm]	Arial font size [pts]	Example
0.50 (20/40)	+ 0.3	1.13	4.5	NCVDZOSRHK
0.63 (20/32)	+ 0.2	0.9	3.5	NCVDZOSRHK
0.80 (20/25)	+ 0.1	0.6	3.0	NCVDZOSRHK

2.5 Data analysis

2.5.1 Data processing

The influence of the lighting conditions (and label material) on the visual performance will be assessed through the number of reading errors made under the occurring condition and on the reading speed. To determine the number of reading errors made, the observer will use a control sheet. This control sheet (found in Appendix H) contains an overview of each text sequence that the participant will go through. Each participant went through all nine lighting conditions. A maximum of 1620 errors[5] could be made per participant, this means 180 errors per session. Participants were instructed to read to the best of their abilities. The participants were informed this meant to read as fast as they comfortably can while making as few errors as possible.

Errors are marked as follows:
A. A letter has been skipped by the participant.
B. A letter has been recited incorrectly by the participant.
C. The participant changes the position of two adjacent letters.
D. A letter has been skipped by the participant as she is not able to read this letter.
E. The experimenter was unable to distinguish which type of error is made.
F. The participant adds an extra letter within the recited text sequence.

[5] In theory, a participant could achieve an error rate higher than 180 and 1620, because in some cases they read an extra letter (marked as a "type F" error).

After the experiment, the recorded audio files were used to check for reading errors again. A double check is to ensure that all false positives and false negatives are taken out of the dataset. The outcome measures will be (1) the number of errors made, (2) type of errors. Reading speed will be measured as the time spent reading a single text sequence.

The precise time was deducted manually using the waveform of the recorded audio files in post-processing in Audacity 2.3.0. In Figure 5, an example is presented of the deduction of the reading speed for a medicine label. The reading speed is measured as the time between the moment the participant turns the page and the moment the phoneme of the last letter in the text sequence is perceived in the audio waveform.

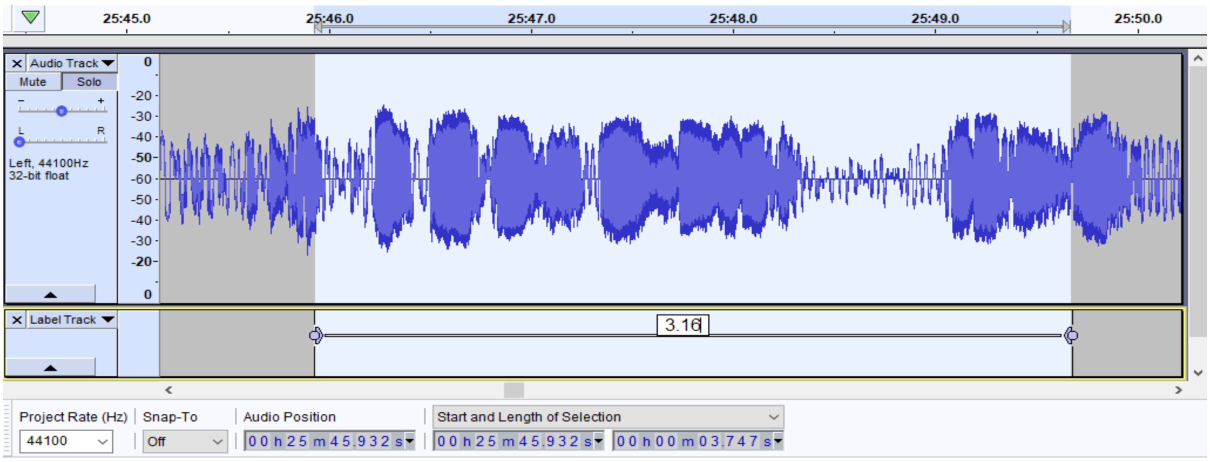

Figure 5: Measuring reading speed in Audacity. Labels were created for every text sequence, allowing the deducting of the reading time. The example here is from Participant 1, Session 3, label 16; Here, Reading Speed was 3.7 s.

2.6 Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics Version 25 for Windows. The study had a within-subjects design. The experiment was based on repeated measures of assessing visual performance through *reading errors* and *reading speed* (two dependent variables) under nine different *lighting conditions* on three types of *materials* in three different *font sizes* (81 independent variables). The sample population can also be divided into two between-subject groups, Visual Acuity (lower visual acuity ($VA<1.0$) and higher visual acuity ($VA\geq1.0$)) and Age (35-45, and 46-55). To test the impact of lighting on the number of errors and reading speed for the two different groups, the aim was to conduct MANOVA to analyze the data. However, the data is non-normal and violates homogeneity. As such, assumptions to perform a multivariate ANOVA is violated. Thus Friedman`s ANOVA is used with Wilcoxon Signed-Rank as a post-hoc test to explain differences between categories. The Mann-Whitney U test is used to explain differences between the related visual acuity groups. To correct for the familywise errors between comparisons in the post-hoc tests, the Bonferroni correction was applied. The cut-off level for statistical significance was set at a 2-tailed *p*-value less than 0.05.

3 Results

In this experiment 31 subjects participated. However, this chapter shall report on the data based on 30 participants. Participant P30 was excluded from the analysis.

Inspection of Q-Q plots showed that data for both reading errors and reading speed were not normally distributed. Furthermore, Levene`s Test for Equality of Variances gave significant results, thus declining the assumption of homogeneity of variance. As a result, the data from the experiments violates assumptions for normality and homogeneity, increasing the chances of incorrectly rejecting the null-hypothesis when conducting parametric tests. Instead of using parametric tests such as independent t-tests and ANOVA, the statistical analysis was conducted using non-parametric tests.

The participants were divided among two visual acuity groups. The group with mild vision loss with VA lower than 1.0 was categorized under lower VA, while the group in the range of normal vision with a VA 1.0 and higher were placed in the group with higher VA.

3.1 Exclusion P30

Participant P30 is excluded from the analysis. P30 had a binocular VA of 1.25, but failed the Amsler test. Upon asking, P30 stated that her ophthalmologist excluded age-related macular degeneration, but was unable to diagnose which ocular impairment she does have. P30 made substantially more reading errors than other participants in the higher visual acuity range. In addition, P30 was not able to read most labels with the smallest font sizes, and upon turning to these pages, skipped very quickly. Resulting in an incorrectly deducted reading speed, because it took much longer to read the labels with the largest font size. As such, it is not possible to give a correct overview for reading speed for participant P30. Furthermore, due to the state of her visual impairment combined with her high visual acuity, it is unclear how appropriate her results are. P30 did not wear multi-focal spectacles.

3.2 Non-Parametric Analysis of Independent Groups (moderate vs. normal visual acuity)

To determine whether there is a statistically significant difference between the lower and the higher visual acuity groups, Mann-Whitney U tests were conducted. This has been done once for reading errors and once for reading speed, by summing the mean reading errors made and reading speed under all lighting conditions per participant. The results for this test are presented in Table 2. Figure 6 shows the mean reading errors and mean reading speed under every lighting condition divided under the visual acuity groups. Participants with a lower visual acuity made more reading errors and required more reading time, especially under low illuminance (100 lx), while the reading errors and speed of participants with a higher visual acuity remain stable under all lighting conditions. The comparison between lower and higher visual acuity has shown significant differences with large effect sizes for reading errors and reading speed.

Table 2: Results of the comparison between the VA groups on reading errors and reading speed

Visual Acuity		Reading errors [-]	Reading speed [s]
Lower VA to Higher VA	*mdn VA <1*	178.0	1376
	mdn VA >1	29.0	1045
	Mean VA <1	237.0	1463
	Mean VA >1	31.0	993
	U	19.5	33.0
	Z	-3.859	-3.298
	p	≤.0001	.037
	r	-.70	-.60

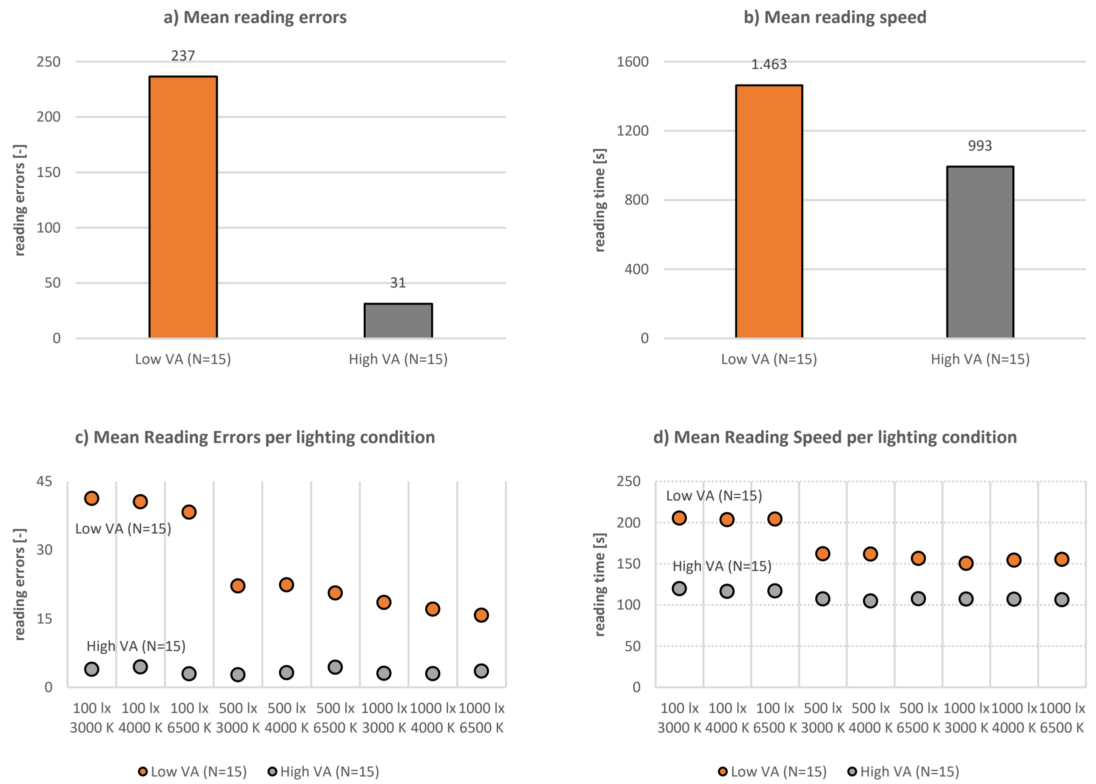

Figure 6: Mean reading error and mean reading speed for every lighting condition per visual acuity group. a/c: lower means less errors, higher means more errors. b/d: lower means faster, higher means slower. Figure 6a and Figure 6b contain summed up totals from the means of all lighting conditions per visual acuity group

3.3 Non-Parametric Analysis of Independent Groups (age)

To study the effect of age on the visual performance, the participants were split into two groups; age 35-45, N=13 and group B (46-55, N=17). Group A read faster and made less reading errors than Group B (Figure 7). To determine whether there is a statistically significant difference between the two age groups, Mann-Whitney U tests were conducted once for reading errors and once for reading speed. This was done by summing the reading errors made and reading speed under all lighting conditions per participant. The results of the tests are presented in Table 3.

Participants aged 35 to 45 (*Mdn*=37) made more significantly reading errors for all lighting conditions on average than participants aged 46 to 55 (*Mdn*=78). Age seems to have moderate effect on making reading errors under different lighting conditions. Speed did not show any significant differences in age. This is probably because the effect of visual acuity on reading speed is stronger than the effect of age on reading speed.

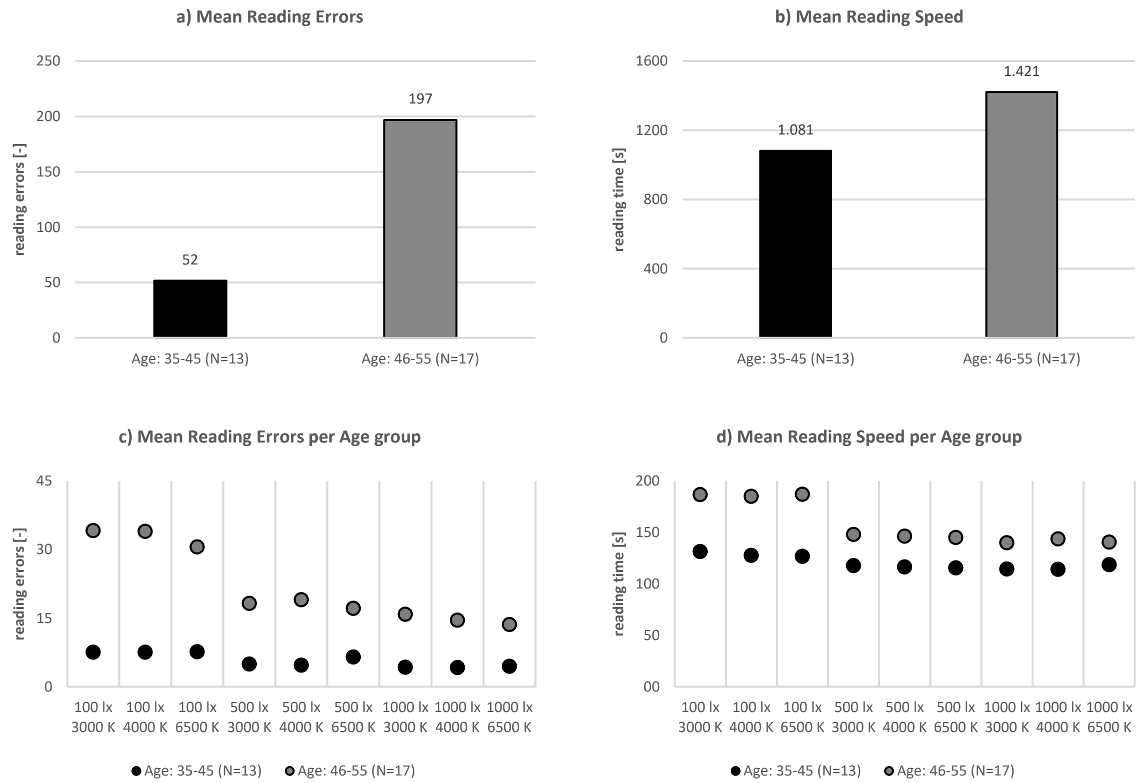

Figure 7: Mean reading errors and mean reading speed for every lighting condition per age group. a/c: lower means less errors, higher means more errors. b/d: lower means faster, higher means slower

Table 3: Results of the comparison between the age groups on reading errors and reading speed

Age		Reading errors [-]	Reading speed [s]
35 – 45 to 46 - 55	*mdn 35 – 45*	37	1072
	mdn 46 - 55	78	1204
	mean 35 – 45	51.6	1081
	mean 46 - 55	196.8	1421
	U	57.5	90.0
	Z	-2.22	-.86
	p	.026	.117
	r	-.40	-.15

3.4 Non-Parametric Analysis of Related Groups (Nine lighting conditions)

To determine the differences and the effect of the nine lighting conditions on the dependent variables, Friedman`s ANOVA was conducted. This was done with both visual acuity groups mixed (N=30), and then separately (2x N=15). First looking at all participants (N=30) to compare the effect of the lighting conditions on the reading errors and reading errors. There was a significant effect of the lighting conditions on the amount of errors made, $\chi^2(8)=30.6$, $p=<.0001$. A significant effect was also found for reading speed comparing the lighting conditions, $\chi^2(8)=76.2$, $p=.00$.

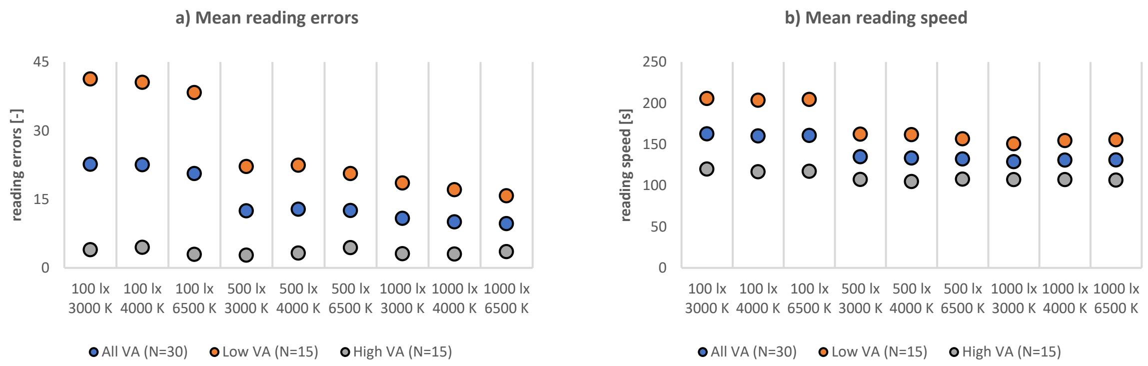

Figure 8: Mean reading error and Mean reading speed for every lighting condition. a: lower means less errors, higher means more errors. b: lower means faster, higher means slower

As a follow-up to the findings of Friedman`s ANOVA, the Wilcoxon Signed-Rank test was conducted to determine which lighting conditions were different. For reading error, significant differences were only found for four out of 36 pairwise comparisons. For reading speed, it was 18 out 36 comparisons. The relevant results of the post hoc analysis are presented in Table 4 & Table 5, which are the pairwise comparison combinations of 100 lx/3000K, 100lx/4000K, 100lx/6500K to all other lighting conditions for both reading speed and reading errors. The complete table providing data for all 36 comparisons can be found in Appendix C.

Table 4: The results from the Wilcoxon Signed-Rank as a post-hoc for Friedman`s ANOVA. Comparing the errors made between lighting conditions. N=30. *p*= adjusted significance, *Z*=Z-score test statistic, *r*= effect size

Reading Errors		100 lx 3000K	100 lx 4000K	100 lx 6500K	500 lx 3000K	500 lx 4000K	500 lx 6500K	1000 lx 3000K	1000 lx 4000K	1000 lx 6500K
100 lx 3000K	*p*	-	1.00	1.00	0.19	0.01	0.27	0.06	0.02	0.08
	Z	-	-0.77	-1.86	-2.79	-3.55	-2.67	-3.13	-3.40	-3.05
	r	-	-0.34	-0.51	-0.65	-0.49	-0.57	-0.62	-0.56	-0.05
100 lx 4000K	*p*	-	-	1.00	0.09	0.02	0.10	0.10	0.04	0.14
	Z	-	-	-0.28	-3.03	-3.46	-3.00	-3.00	-3.28	-2.89
	r	-	-	-0.05	-0.55	-0.63	-0.55	-0.55	-0.60	-0.53
100 lx 6500K	*p*	-	-	-	0.94	0.11	1.37	0.59	0.20	0.54
	Z	-	-	-	-2.23	-2.97	-2.07	-2.40	-2.78	-2.43
	r	-	-	-	-0.41	-0.54	-0.38	-0.44	-0.51	-0.44

Table 5: The results from the Wilcoxon Signed-Rank as a post-hoc for Friedman`s ANOVA. Comparing the reading speed between lighting conditions. N=30. *p* = adjusted significance, Z= Z-score test statistic, r = effect size

Reading Speed		100 lx 3000K	100 lx 4000K	100 lx 6500K	500 lx 3000K	500 lx 4000K	500 lx 6500K	1000 lx 3000K	1000 lx 4000K	1000 lx 6500K
100 lx 3000K	*p*	-	1.00	1.00	0.00	0.00	0.02	0.00	0.00	0.03
	Z	-	-0.15	-0.55	-3.82	-4.47	-3.50	-4.06	-4.08	-3.36
	r	-	-0.18	-0.28	-0.14	-0.02	-0.06	-0.10	-0.06	-0.12
100 lx 4000K	*p*	-	-	1.00	0.01	0.00	0.00	0.00	0.00	0.00
	Z	-	-	-0.05	-3.54	-4.31	-4.06	-4.04	-3.98	-3.88
	r	-	-	-0.01	-0.65	-0.79	-0.74	-0.74	-0.73	-0.71
100 lx 6500K	*p*	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00
	Z	-3.84	-4.41	-4.34	-4.17	-4.12	-3.92	-3.84	-4.41	-4.34
	r	-	-	-	-0.70	-0.81	-0.79	-0.76	-0.75	-0.72

3.5 Non-Parametric Analysis of Related Groups - Illuminance (100lx - 500 lx -1000 lx)

To investigate the effect of illuminance, Friedman`s test has been conducted to determine whether there is a difference between the errors made under lighting conditions with an illuminance of 100 lx, 500 lx, and 1000 lx. An overview of the results is presented in Table 6.

As a follow-up to the findings of Friedman`s ANOVA, the Wilcoxon Signed-Rank test was conducted to determine which conditions were significant different when comparing the reading speed and reading errors made under 100 lx, 500 lx, and 1000 lx. While Table 4 only shows a few significant differences for a few lighting conditions, the results in Table 7 show that for low VA participants, a higher illuminance value (both 500 lx and 1000 lx) results in significantly fewer reading errors, while participants with higher VA do not make significantly more reading errors.

While reading errors show this strict distinction, reading speed seems to improve significantly for both low VA and high VA readers when comparing for 100 lx to 500 lx. Increasing the illuminance to 1000 lx only shows significant differences in reading speed for low VA participants. There is no significant difference in reading speed when comparing 500 lx to 1000 lx for participants with a visual acuity higher than 1.0. The difference between mean reading errors under 100 lx and 500 lx is larger than the difference between 500 lx and 1000 lx.

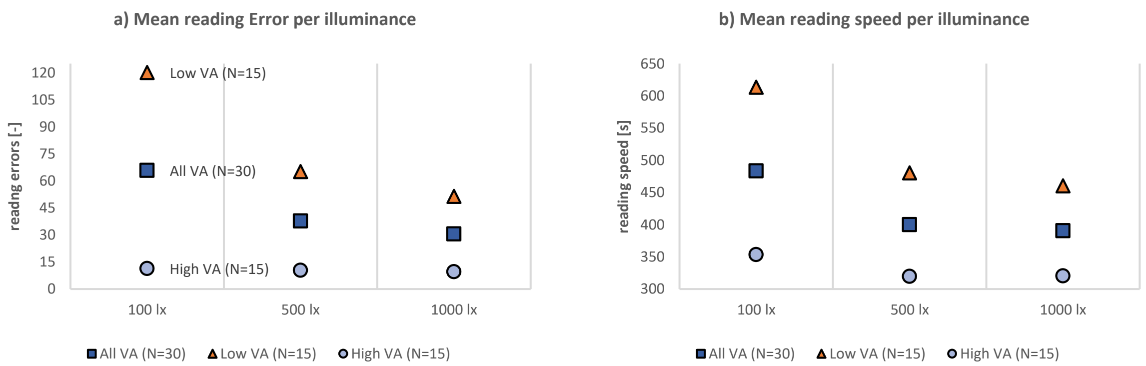

Figure 9: Mean reading errors and mean reading speed under 100 lx, 500 lx, and 1000 lx. a: lower means less errors, higher means more errors. b: lower means faster, higher means slower.

Table 6: Results of the Friedman`s test for the different Visual Acuity groups

Illuminance		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
Comparison *100 lx – 500 lx – 1000 lx*	χ^2	10.74	19.2	.140	36.87	25.20	14.93
	df	2	2	2	2	2	2
	p	.005	≤.001	.932	≤.001	≤.001	.001

Table 7: Results Post-hoc Tests Illuminance

Illuminance		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
100 lx to 500 lx	*Mdn 100 lx*	16.5	97.0	11.0	418	532	369
	Mdn 500 lx	17.0	46.0	8.0	367	418	331
	Mean 100 lx	65.7	120.1	11.3	483	613	353
	Mean 500 lx	37.7	65.1	10.3	400	480	320
	Z	-3.03	-3.12	-.378	-4.68	-3.41	-3.18
	p	.01	.005	1.00	.0001	.002	≤ .001
	r	-.55	-.57	-.07	-.85	-.62	-.58
100 lx to 1000 lx	*Mdn 100 lx*	16.5	97.0	11.0	418	532	369
	Mdn 1000 lx	17.5	29.0	8.0	360	414	343
	Mean 100 lx	65.7	120.1	11.3	483	613	353
	Mean 1000 lx	30.5	51.3	9.6	390	460	320
	Z	-3.09	-3.18	.63	-4.41	-3.41	-2.56
	p	.01	.004	1.00	≤ .001	.002	.03
	r	-.57	-.58	-.12	-.81	-.62	-.47
500 lx to 1000 lx	*Mdn 500 lx*	17.0	46.0	8.0	367	418	331
	Mdn 1000 lx	17.5	29.0	10.0	360	414	343
	Mean 500 lx	37.7	65.1	10.3	400	480	320
	Mean 1000 lx	30.5	53.3	9.6	390	460	320
	Z	-2.49	-2.84	-.06	-1.67	-3.12	-.48
	p	.04	.01	1.00	.29	.04	1.00
	r	-.45	-.52	-.01	-.30	-.45	-.09

3.6 Non-Parametric Analysis of Related Groups – CCT (3000 K - 4000 K - 6500K)

This section discusses the effect and differences between different correlated color temperatures on the visual performance. Friedman`s test has been conducted to determine whether there is a difference between the errors made under lighting conditions with a CCT of 3000 K, 4000 K, and 6500 K. The results in Table 8 and Table 9 show that changing CCT has no significant effect on the reading speed and reading errors for participants with low VA and participants with high VA. Figure 10 shows that under all three Correlated Color Temperature, the reading speed and reading errors made remain stable. The effect size was small under all comparisons.

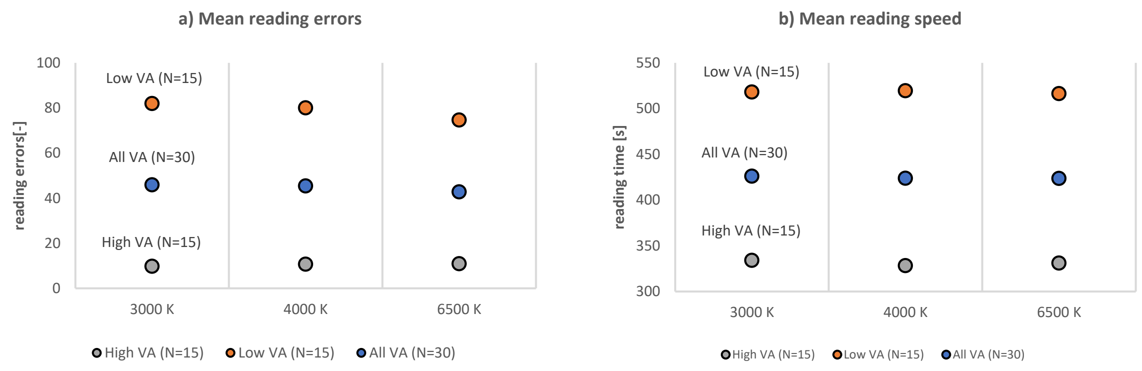

Figure 10: Mean reading errors and reading speed per Correlated Color Temperature. a: lower means less errors, higher means more errors. b: lower means faster, higher means slower

Table 8: Results from Friedman`s test for Correlated Color Temperature

Correlated Color Temperature		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
Comparison *3000 K – 4000 K – 6500 K*	χ^2	.33	1.32	.255	1.40	1.73	4.13
	df	2	2	2	2	2	2
	p	.846	.516	.880	.50	.42	.13

Table 9: Results from comparing CCT

Correlated Color Temperature		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
3000 K to 4000 K	*Mdn 3000 K*	18.0	46.0	11.0	400 s	471 s	337 s
	Mdn 4000 K	15.5	48.0	13.5	380 s	453 s	346 s
	Mean 3000 K	45.8	81.9	9.7	426 s	518 s	334 s
	Mean 4000 K	45.3	80.0	10.7	424 s	519 s	328 s
	Z	-.61	-.91	-.67	-.73	-17	-.85
	p	1.00	1.00	1.00	1.00	1.00	1.00
	r	-.11	-.17	-.12	-.13	-.03	-.16
3000 K to 6500 K	*Mdn 3000 K*	18.0	46.0	11.0	400 s	471 s	337
	Mdn 6500 K	13.5	53.0	9.0	385 s	453 s	348
	Mean 3000 K	45.8	81.9	9.7	426 s	518 s	334 s
	Mean 6500 K	42.7	74.6	10.8	424 s	516 s	331 s
	Z	-.26	-.85	-.97	-.67	-.40	-.23
	p	1.00	1.00	1.00	1.00	1.00	1.00
	r	-.05	-.17	-.18	-.12	-.07	-.04
4000 K to 6500 K	*Mdn 4000 K*	15.5	46.0	13.5	380 s	471 s	346 s
	Mdn 6500 K	13.5	53.0	9.0	385 s	453 s	348 s
	Mean 4000 K	45.3	80.0	10.7	424 s	519 s	328 s
	Mean 6500 K	42.7	74.6	10.8	424 s	516 s	331 s
	Z	-.59	-.68	-.20	-.13	-.63	-1.99
	p	1.00	1.00	1..00	1.00	1.00	.14
	r	-.11	-.12	-.036	-.02	-.11	-.36

3.7 Non-Parametric Analysis of Related Groups – Materials (Blister - Baxter - Orange)

To investigate the effect the effect of label material, the Friedman test was conducted to determine whether there is a significant difference in the errors made during reading. The results are plotted in Table 10; While participants with VA<1 showed significant difference in reading errors and reading speed while reading from the three different labels, participants with VA>1 showed no significant difference in performance. To determine where the differences lie, the Wilcoxon signed rank test was conducted as a post-hoc test. The results of the post-hoc test (Table 11) show that participants with low VA perform significantly different regarding reading errors and reading speed depending on the label material. Figure 11 shows that the most reading errors were made while reading from orange labels, especially under low illuminance (100 lx). For all label types, the differences for both reading speed and reading errors between 500 lx and 1000 lx are much smaller than between the differences between 100 lx and 500 lx. Significance was not investigated due to the high number of comparisons (36).

Table 10: Results from Friedman`s Test comparing Blister, Baxter, and Orange type medicine labels

Medicine Label Material		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
Comparison *Blister - Baxter - Orange*	χ^2	26.0	25.55	5.16	18.8	22.93	2.07
	df	2	2	2	2	2	2
	p	≤ .001	≤ .001	.076	≤ .001	≤ .001	.36

Table 11: Results from Wilcoxon Signed-Rank test as post-hoc to determine differences between medicine labels

Materials		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
Blister to Baxter	*mdn Blister*	14.0	39.0	10.0	376	417	340
	mdn Baxter	14.0	52.0	9.0	388	462	350
	mdn Blister	33.5	57.5	9.6	397	469	326
	mdn Baxter	42.6	78.8	9.3	420	510	331
	Z	-2.48	-2.92	-.39	-2.83	-2.90	-.51
	p	.04	.01	1.00	.01	.01	1.00
	r	-.45	-.53	-.07	-.52	-.53	-.09
Blister To Orange	*mdn Blister*	14.0	39.0	10.0	376	417	340
	mdn Orange	20.0	78.0	12.0	402	504	350
	mean Blister	33.5	57.5	9.3	397	469	325
	mean Orange	57.8	103.8	12.3	456	575	337
	Z	-4.28	-3.41	-1.99	-4.04	-3.29	-1.99
	p	≤ .001	.002	.14	≤ .001	.002	.14
	r	-.77	-.62	-.072	-.74	-.60	-.36
Baxter to Orange	*mdn Baxter*	14.0	52.0	9.0	388	462	350
	mdn Orange	20.0	79.0	12.0	402	504	350
	mean Baxter	42.6	75.8	9.6	420	510	330
	mean Orange	57.8	103.3	12.3	456	575	337
	Z	-4.14	-3.30	-.39	-4.18	-3.41	-2.10
	p	≤ .001	.003	1.00	≤ .001	.003	.11
	r	-.76	-.60	-.072	-.76	-.62	-.38

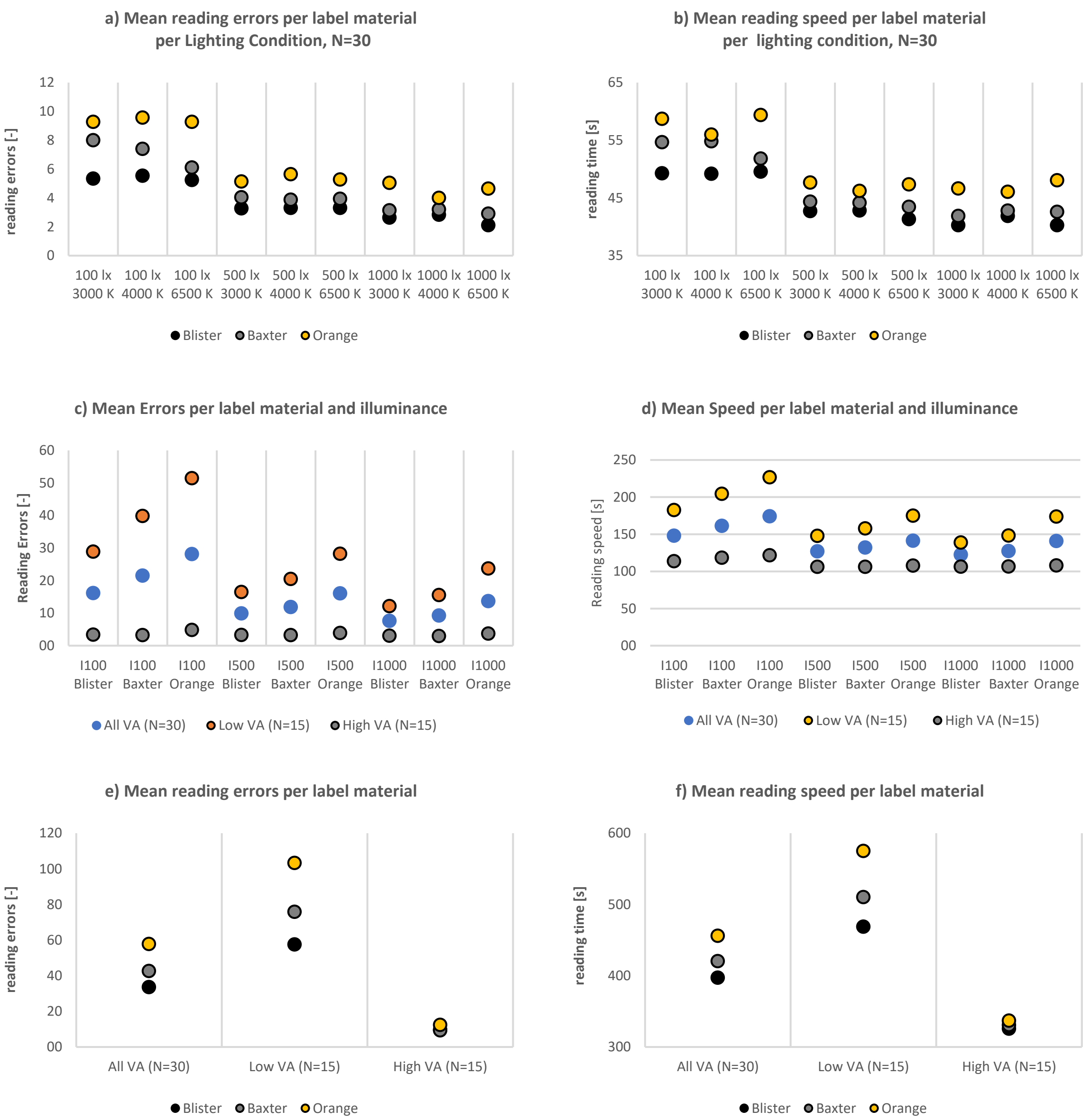

Figure 11: Mean reading errors and reading speed per label material. a/c/e: lower means less errors, higher means more errors. b/d/f: lower means faster, higher means slower. Figures “c” and Figures “d” consists of data summed based on the illuminance. Figure “d” and “e” consist of the mean reading errors and reading speed for every medicine label type under all lighting conditions combined as read by the different visual acuity groups

3.8 Non-Parametric Analysis of Related Groups – Font size (3.0 pt. – 3.5 pt. – 4.0 pt.)

To investigate the effect the effect of font size, the Friedman test was conducted to determine whether there is a significant difference in the errors made during reading and reading speed. The results of this test are plotted in Table 12; It shows that font size has a significant effect on reading errors for participants with a lower VA, but for participants with higher VA no significant effect was found. However, for reading speed under different font sizes, there was a significant difference for both lower VA and higher VA groups. Figure 12d shows that the differences for mean reading speed between different font sizes with higher VA is smaller than the differences for the mean reading speed with lower VA. To determine where the differences lie, the Wilcoxon signed rank test was conducted as a post-hoc test. The results of the post-hoc test (Table 13) show increasing the font size significantly reduces reading speed, regardless of the visual acuity.

Table 12: Results from Friedman`s test for Font Size

Font Size		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
Comparison	χ^2	22.1	24.40	3.89	50.5	24.40	30.0
3.0 pt. –	*df*	2	2	2	2	2	2
3.5 pt.- 4.5 pt.	*p*	< .001	< .001	.143	< .001	< .001	< .001

Table 13: Results from the Wilcoxon Signed Rank test to find differences between font sizes

Font size		Reading errors [-]			Reading speed [s]		
		All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)	All VA (N=30)	Lower VA (N=15)	Higher VA (N=15)
3.0 pt. to 3.5 pt.	*mdn 3.0 pt.*	23.5	92.0	12.0	399	548	364
	mdn 3.5 pt.	14.5	60.0	7.0	372	440	346
	mean 3.0 pt.	67.0	120.9	13.0	476	590	363
	mean 3.5 pt.	43.2	77.5	8.9	409	490	327
	Z	-3.96	-3.35	-1.89	-4.37	-3.24	-3.41
	p	< .001	.002	.18	< .001	.004	.002
	r	-.72	-.61	-.35	-.80	-.59	-.62
3.0 pt. to 4.5 pt.	*mdn 3.0 pt.*	23.5	92.0	10.0	399	548	364
	mdn 4.5 pt.	12.0	19.0	12.0	332	382	332
	mean 3.0 pt.	67.0	120.9	13.0	476	590	363
	mean 4.5 pt.	23.8	38.1	9.3	343	382	304
	Z	3.99	-3.35	-1.86	-4.72	-3.35	-3.41
	p	< .001	.002	.19	< .001	.002	.002
	r	-.73	-.61	-.34	-.86	-.61	-.62
3.5 pt. to 4.5 pt.	*mdn 3.5 pt.*	14.5	60.0	7.0	372	440	346
	mdn 4.5 pt.	12.0	19.0	10.0	332	382	332
	mean 3.5 pt.	43.2	77.5	9.3	409	490	327
	mean 4.5 pt.	23.8	38.1	8.9	343	382	304
	Z	-2.91	-3.41	-.28	-4.66	-3.35	-3.41
	p	.011	.002	1.00	< .001	.002	.002
	r	-.53	-.62	-.05	-.85	-.61	-.62

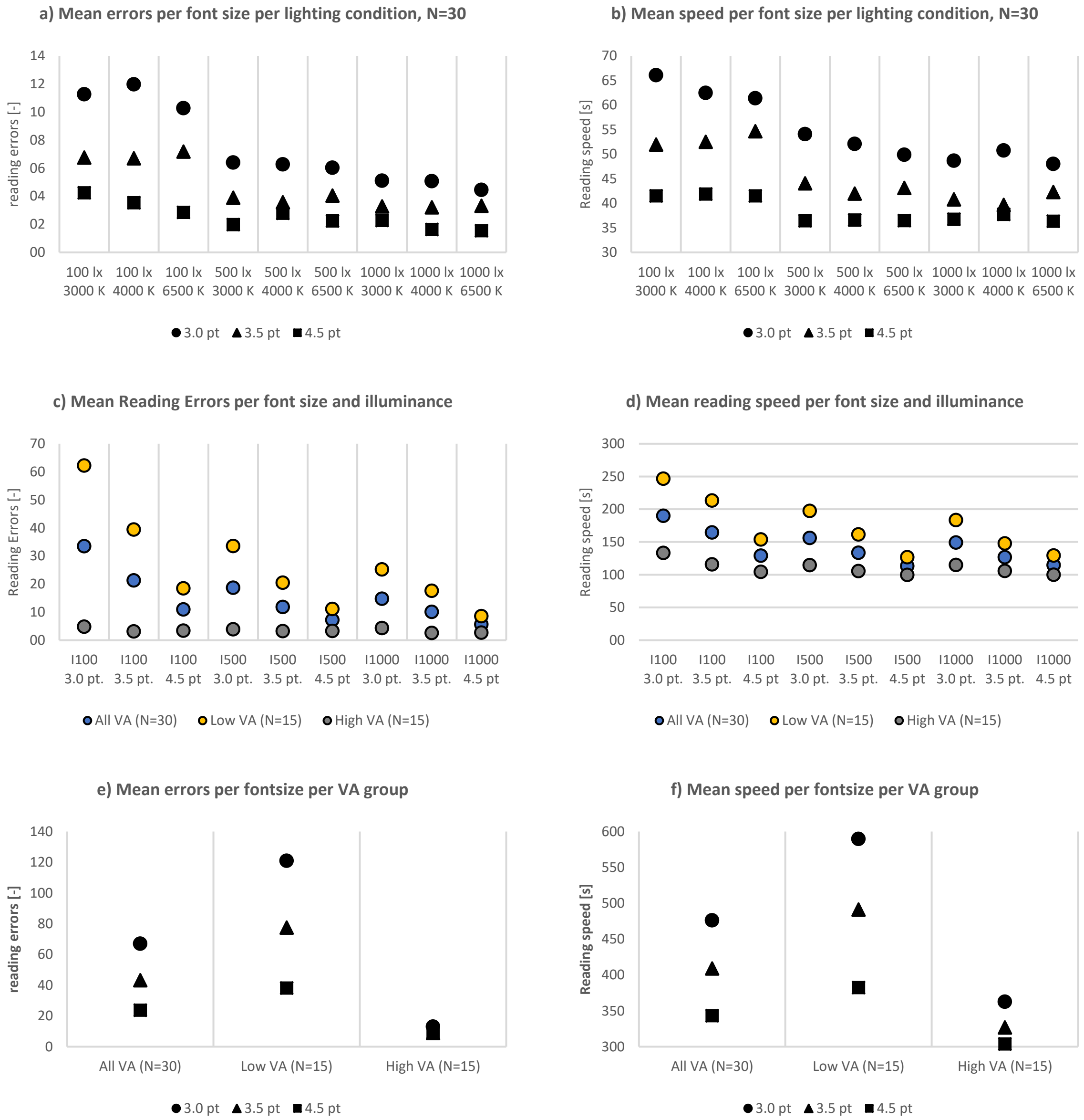

Figure 12: Mean errors and reading speed per font size. a/c/e: lower means less errors, higher means more errors. b/d/f: lower means faster, higher means slower

3.9 Types of Errors made

In total, participants with lower VA (<1) made substantially more reading errors than participants with higher VA (>1). Table 14 visualizes the type of errors made by participants in both visual acuity groups. Participants with lower VA mostly mistook letters for other letters, while participants with higher VA mostly skipped letters. In addition, there were 388 cases in which the letters were unreadable to the low VA participant, this only occurred twice in the higher VA group. Furthermore, participants with low VA made substantially more reading errors which were indistinguishable from other error types (113 vs. 0). The high amount of mistaken errors clearly shows how difficult it can be for participants with lower VA to read the correct letter.

Table 14: Error types most commonly made during the experiments. Type A= skipped letter, Type B= misread letter, Type C= Adjacent letters mixed, Type D= skipped letter due to inability to distinguish letter, Type E= error undistinguishable, Type F= extra letter added to the text sequence.

Error Type	Type A	Type B	Type C	Type D	Type E	Type F	Total
Lower VA (N=15)	701	2140	131	388	113	75	3548
Higher VA (N=15)	254	104	88	2	0	21	469
Total	955	2244	219	390	113	96	4017

3.10 Preference of lighting conditions

Figure 13 shows the preference level rating by the participants for the lighting conditions. The participants were asked how satisfied they felt about the lighting condition on a 1 to 7 Likert scale, with 1 being not satisfied at all and 7 being very satisfied. Low illuminance conditions generally have been rated lower compared to 500 lx and 1000 lx respectively. Coupled with the illuminance, the participants rated generally 6500 K lower than 4000 K and 3000 K.

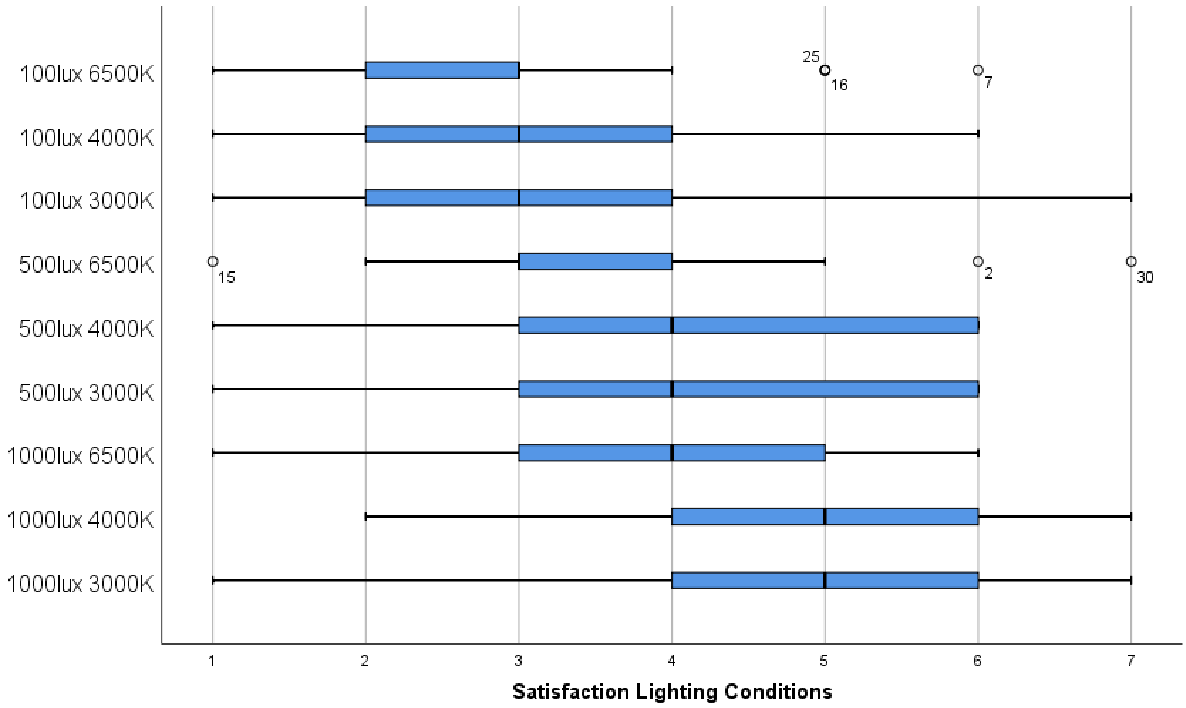

Figure 13: Preferences for lighting conditions expressed in satisfaction rate,(N=30). Rated 1(very unsatisfactory) to 7 (very satisfactory) on a Likert scale.

3.11 Preference of Material

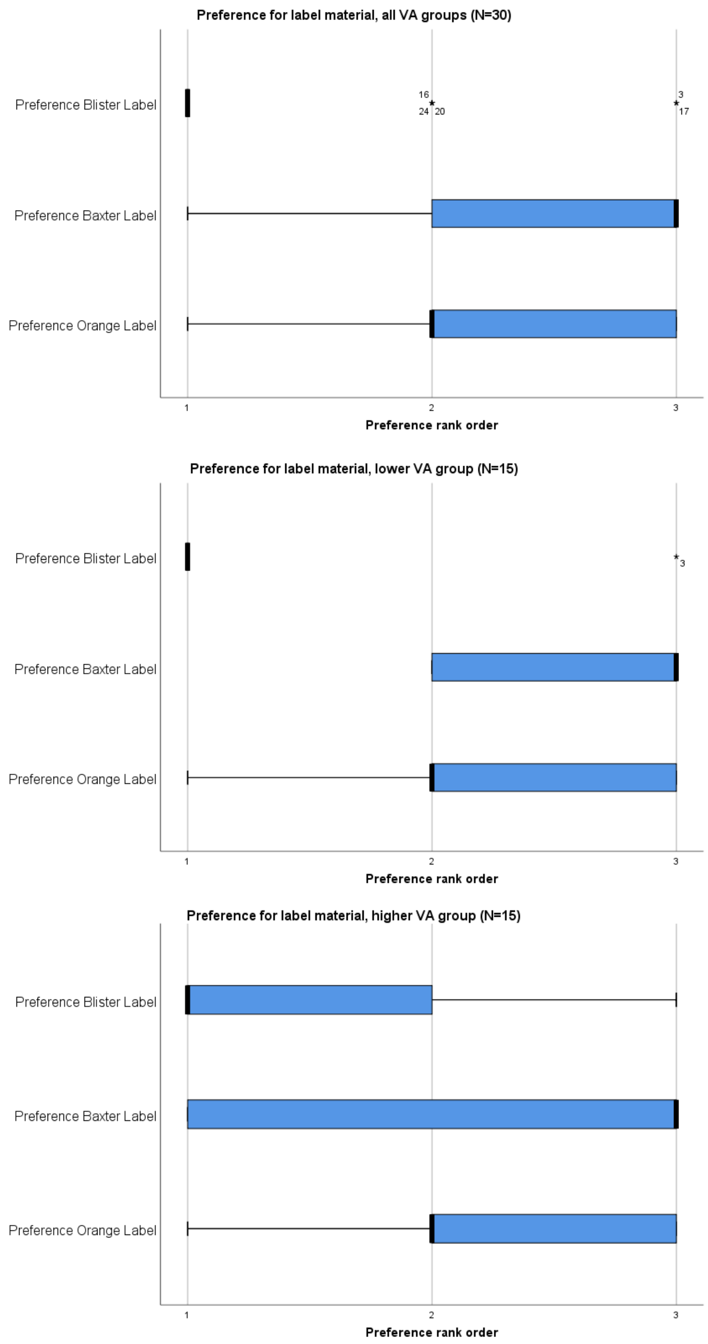

Figure 14: Preferences for label material. Ranked from 1 to 3

At the end of the experiment, participants expressed their preferences for label material by ranking the label types from one to three (one being most preference three least preferred). An overview of the preferences for the label materials is given in Figure 14.

In general, the blister label is the most preferred label type. Baxter and Orange labels were similarly rated with orange being rated slightly better than Baxter.

The mean preferences are equal between all VA groups.

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4 Discussion

4.1 Differences between-groups

4.1.1 Age

This experiment was aimed at women in the age group 35 to 55. This age group is seen as a transition age, as most humans will experience loss of vision to some extent. In this experiment, the age-group was divided in two to see whether there are differences within these newly created groups. The results showed that the younger group made fewer errors and read faster on average than the older group. The statistical comparison between the two different age groups in this study showed that age has a significant effect on reading error and reading speed. It is to be noted that the effect sizes of age (r_{errors}=-.40 , r_{speed}=-.15) is lower than effect sizes VA, this indicates that the effect of VA on reading errors (r_{errors}=-.70) and reading speeds (r_{speed}=-.60) are larger than age. Inspecting the average visual acuity of every age group shows that the younger group has a higher mean visual acuity ($M_{VA,h}$= 1.25) than the older group ($M_{VA,l}$=0.86). These results build on the findings of Aarts et. al. (2019), where age (r=0.32) also had a much smaller effect to reading errors compared to visual acuity (r=0.98). This higher VA seems to be the reason that that the performance in the younger group was better, as it is known that visual acuity declines as a function of age (Daffner et al., 2013).

4.1.2 Visual Acuity

Visual acuity had large effect on the ability to read. The statistical analysis confirms that there is a difference in the performance between the two VA groups. In most cases, no significant difference was found between different lighting conditions in high VA groups. In the study of Aarts et.al. (2019), it was seen that visual acuity has significant impact on the visual performance of participants with lower visual acuity; However, the sample size of N=7 did not allow for conclusions.

4.2 Differences within-groups

4.2.1 Lighting Conditions

Looking at the absolute data, there are large differences in the performance of lighting conditions with an illuminance of 100 lx compared to lighting conditions with an illuminance of 500 lx or 1000 lx. Figure 6 shows a clear increase of reading errors (42.5%) and reading time

(41.9%) averaging the results of all visual acuity groups when reading under at 100 lx compared to 500 lx with any correlated color temperature. Friedman`s test showed that there indeed are differences for both reading errors and reading speed when comparing 100 lx to 500 lx and 100 lx to 1000 lx; However, when conducting follow-up pairwise comparisons to determine where the differences lie, only a few lighting conditions appeared statistically significant for reading errors. This contrasts with the pairwise comparisons for differences in reading speed between lighting conditions. Here, the expected comparisons (100 lx to 500 lx and 100 to 1000 lx) did return significantly different. This is likely due to the deviation from normality and homogeneity of the data for reading errors. In addition, the data is very skewed; Especially for reading errors due to many values being close to zero, introducing a positive skewness. The distribution of reading errors and reading speed under the three illuminance groups is presented in Appendix E.. The Q-Q plots in Figure 15 shows that the deviation from normality is much more extreme for the reading errors made under 100lx/3000K than for the reading speed under 100lx/3000K (This also applies for comparisons of normality between the other eight lighting conditions). The deviation from normality decreases power for the statistical analysis, thus decreasing the probability of rejecting the null-hypothesis.

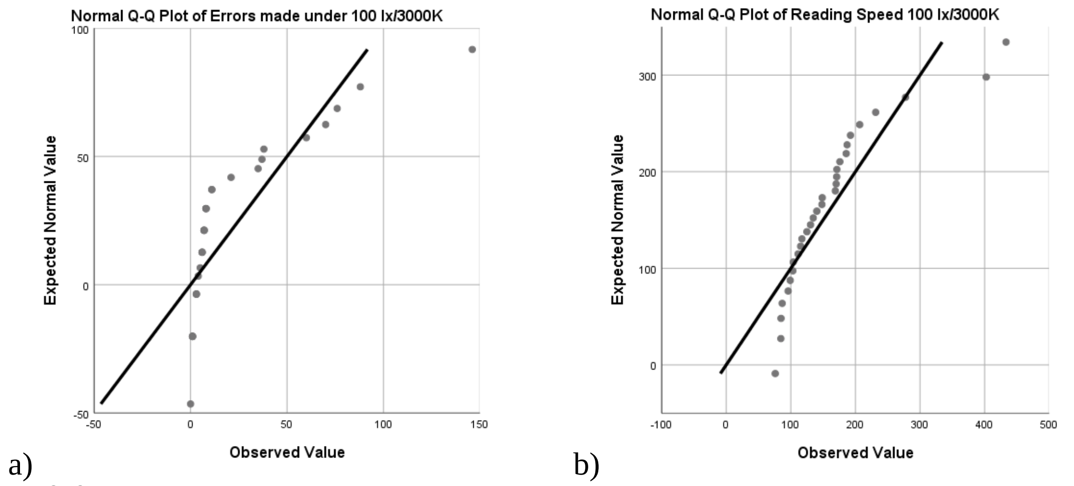

Figure 15: Q-Q plots showing the deviation from normality of the data. The diagonal line is regarded normal, data points not on the line are considered a deviation from normality. Figure 15a plotted reading errors made under 100 lx/3000K, Figure 15b is plotted for reading speed under 100 lx/3000K.

Furthermore, the probability of rejecting the null-hypothesis is additionally decreased due to controlling for the family wise error-rate. In this study, the Bonferroni correction is applied to correct the asymptotic p-values retrieved from the follow-up Wilcoxon Signed Rank Test. This correction is applied by multiplying the amount of pairwise comparisons (m) with the asymptotic *p*-values. In the case of *k*=9 lighting conditions, this requires $m = \frac{k*(k-1)}{2} = 36$ pairwise comparisons; This further inflates the chances of rejecting the null-hypotheses and finding a significant value. Before correction, the asymptotic *p*-values showed significant differences for the expected lighting conditions (100 lx compared to 500 lx and 1000 lx). However, common conventions state that without a correction for multiple pair-wise comparisons, the chances of incorrectly rejecting a null hypothesis increases (Type I error).

This correction makes the statistical analysis of this study design with nine conditions more complex than study designs with three or four conditions. The analysis of the nine lighting conditions did not explain for the effects of lighting clearly. Even though drawing firm conclusions will be more difficult, the nine lighting conditions were split up in three illuminance groups (100 lx, 500 lx, 1000 lx) and three CCT groups (3000 K, 4000 K, 6500 K) to determine the effect of the lighting conditions on the visual performance.

Conducting the Wilcoxon Signed Rank test filtered on the average reading errors and reading speed filtered for the illuminance showed that illuminance proved statistically significant differences between all pairwise comparisons for reading errors (100 lx vs. 500, 100 lx vs. 1000 lx, 500 lx vs. 1000 lx) for participants with lower visual acuity (VA$<$1), but no significant differences were found for participants with a higher visual acuity (VA$\geq$1). For reading speed, participants with higher VA showed significant differences when comparing 100 lx to 500 lx and 1000 lx, while participants with lower VA showed significant differences in reading speed across all illuminance values. This indicates that a higher illuminance supports participants with lower visual acuity better than participants with higher visual acuity.

Analysis of differences for the three CCT (3000 K, 4000 K, 6500 K) tested in this experiment showed no significant differences between all comparisons and in all visual acuity levels. The amount of reading errors and reading speed showed to be insensitive to changes in the CCT in the lighting conditions. When looking at CCT in this experiment, lighting conditions with higher CCT seems to give slightly better performance in most cases, as the medicine labels are generally read with slightly less errors and slightly faster in lighting conditions with 4000 K and even less under 6500 K. Considering this slight performance boost, on average participants rated the conditions with 6500 K consistently less satisfactory than lower CCT conditions.

Perhaps for a follow-up study less CCT-conditions should be tested to decrease the complexity of the study design and allow direct comparison of the set lighting conditions without sorting the resulting. With less comparisons, the Bonferroni correction factor for the significance is smaller, leading to a less inflated adjusted significance and a higher chance of rejecting the null hypothesis to confirm the differences between conditions. In addition, less conditions will reduce the duration of the experiment, which could be quite straining for the participant as the experiment takes longer than an hour. A shorter experiment is less influenced by tiredness or mood of a participant. The Figure in Appendix D shows that over the course of the experiment, the tiredness of the participants increased one unit on average. While this shows that tiredness did not have an effect in most cases. Many participants mentioned the duration of the experiment being very long and somewhat straining. The effect of mood on the performance of the participants on the results has not been tested in this experiment.

This study has been conducted in a controlled environment. The participants in this experiment were instructed to try to read as fast as they comfortably can, while making as few errors possible. The results indicate that there is a correlation between the decrease of illuminance and decrease of visual performance. In the field however, conditions are varied, and participants are not placed under the same pressure. Shadowing employees in the medication dispensing room before and after changing lighting conditions could lead to insight in performance (less reading/dispensing errors) and productivity (more labels read/medicine dispensed). The experiment was conducted in approximately one hour under high concentration. A working day is typically eight to nine hours, the effects of the lighting conditions under this long-term exposion might return different results and show adverse reactions. In addition, there is no fixed distance from eye to the medicine label text in the field. During the experiment, the medicine labels were placed on a fixed bookstand and participants placed their heads in the headstand to maintain a fixed distance. Placing their head in the stand is uncomfortable and might lead to more errors, because a comfortable and habitual working distance is not regarded. For participants with lower visual acuity in the field, they are not restricted and may bring the labels to their habitual working distance to reduce the reading difficulty. Given that near-visual acuity increases as the distance between eye and target text decreases, participants with lower VA might perform the same as participants with higher VA, allowing for lower illuminance levels. In a study into preferred lighting conditions, Tanichugi et. al. (2011) found that office workers preferred a lower illuminance (between 250 lx and 500 lx) for certain tasks.

4.2.2 Medicine label material

The investigation of the impact of the label material (Blister, Baxter, Orange) on reading errors and reading speed showed similar results as for the other independent factors when comparing the low visual acuity group to the normal visual acuity group. The participants with a higher visual acuity were insensitive to differences in label material, with similar reading errors and reading speed for all three label types. For participants with a low visual acuity, the label easiest to read was the Blister label, then Baxter label, and finally Orange label. This is the same for higher VA, but difference is insignificant. The luminance contrasts of the three labels were very similar. (0.96 cd/m^2, 0.95 cd/m^2, and 0.93 cd/m^2 respectively as found by (Aarts et al., 2019)).

Similar results were found in Aarts et al. (2019) in the comparisons of Orange to Blister and Baxter; However, the pairwise comparison between Blister labels and Baxter labels did not return a significant difference. This must be due to the low number of participants with lower visual acuity having less impact on the visual performance of the groups combined. The ratio low VA/high VA participants in that study were 7 to 30, while this follow-up study was 15 to 15. Also, it is to be noted that all the text on the labels was printed (in the same font) in this study. In practice, some of the text on labels is hand-written. In addition, glare was not a factor in this experiment; although the Baxter labels were somewhat reflective. This can introduce difficulties in reading that are not accounted for by the experiment conducted in this study.

4.2.3 Font size

The investigation of font size (3.0 pt., 3.5 pt., 4.5 pt.) on reading errors and reading speed showed that the font size also had impact on reading errors and reading speed. Under low illuminance conditions, more reading errors on average were made and more time was needed to read the labels; 121 to 9 mean errors for the smallest font size (3.0 pt.). This was especially the case for participants with a low VA. The font size had no significant impact on participants with a high VA for differences in reading errors under different lighting conditions; Perhaps with a smaller font size, the effect of the lighting conditions for high VA participants would become apparent. However, such small sizes will not be encountered in the field as mentioned by Craenmehr (2017), it would not justify effects from the lighting conditions on the visual performance of these participants.

In section 4.2.2, the omission of handwritten labels was already mentioned as a limitation. For methodological reasons also only one font style was used in this experiment. Mansfeld et. al (1996) have shown that font style has significant effects on readability and is different for participants with moderate vision and normal vision. Serif fonts have been shown to be easier to read for participants with lower vision than non-serif fonts. But for higher vision, it is exactly the opposite. When font sizes reach reading limit allowed by visual acuity, font choice could significantly affect the visual performance for normal vision and moderate vision (Mansfield et al., 1996).

4.3 Limitations

4.3.1 Missing Data

There were two occasions during the experiments in which an incorrect lighting condition was set; Once during a session of P7 (1000 lx/6500K was applied instead of 100 lx/6500K) and once during a session of P25 (500 lx/3000K was applied instead of 100 lx/6500K). This resulted in missing a test of one lighting condition in the dataset of both participants. This also means that these participants did one lighting condition twice. To maintain the randomization of the lighting order, the data of misplaced sessions is discarded.

4.3.2 Deduction of reading speed

The participants were instructed to read up to their abilities, by reading as fast as they can while trying to keep reading errors to a minimum and not tripping over the words they recited. The first dummy session was used to comfort the participants and remind them that they should not repeat the text sequence when they realize they made a mistake. Nonetheless, some labels were still repeated. The repeating of the text sequences depended on the participants, in some cases they repeated a letter, and in other cases the complete label. This impacted the reading time. It is unclear why this happened. Still, the participant made a mistake, and was regarded as such by being taken into account in all cases, regardless if the participant corrected herself. For reading speed, the labels were timed until the participant completely finished reading the label or decided to skip.

4.3.3 Remarks regarding data

Participants did not make substantially more mistakes and did not read faster when comparing the unique text sequences to recurring text sequences. Differences between repeated sequences and unique sequences was 1.02% for reading errors and 0.61% for reading speed. This indicates that a learning effect did not affect the measurement of the data.

During the experiment with P9 and later with P10, a strange tapping or striking noise was perceivable during some of the sessions. This could have led to P9 and P10 to make more errors or read slower. P12 wore multi-focal lenses, according to her, this gave her difficulties reading in not well-lit environments.

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5 Conclusion

This research aimed to identify which lighting conditions is best for reducing reading errors of medicine labels. The objective was to gain insight in which conditions lead to the best task performance in females in the age group of 35 to 55. N=30 subjects participated in this experiment. The division of participants into two visual acuity categories (VA <1 and VA ≥ 1) showed that higher visual acuity groups perform significantly different from lower visual acuity groups. In general, participants with normal vision (N=15, VA$\geq$1) did not seem to be affected by the lighting conditions as much as participants experiencing mild vision loss (N=15, VA$<$1). Participants with a VA <1 made substantially more reading errors than participants with a higher VA ($\geq$1). Participants with VA $\geq$1 did not seem to be affected by changes in the lighting condition as much.

In fact, in the lowest illuminance settings (100 lx), participants with higher VA made 10 times fewer reading errors (M=3.8) than participants with lower visual acuity (M=40.0). On average, all participants made more reading errors and required more reading time in lower illuminance settings (100 lx) than in higher illuminance settings (500 lx, 1000 lx respectively). Compared to the three 100 lx lighting conditions, participants performed at least 40% better under 500 lx and 1000 lx ($M_{\text{errors,allVA}}$= 21.9 to 12.6/10.2 errors, $M_{\text{speed,allVA}}$ =483 s to 455 s/429 s). Participants with a VA$<$1 made significantly fewer reading errors under 1000 lx compared to 500 lx and 100 lx. Participants with high visual acuity do not show any significant differences in reading errors for changes in illuminance.

For reading speed, participants with vision loss and no vision loss both generally perform significantly different with increased illuminance. Participants with a low VA perform significantly better under 1000 lx than under 100 lx and 500 lx. Participants with a High VA only show an increase in reading performance when comparing 100 lx to 500 and 1000 lx, but show no significant difference in reading speed between 500 lx and 1000 lx. Overall participants seemed to prefer 1000 lx over 500 lx;

The correlated color temperature showed no significant differences for reading errors and reading speed between 3000 K, 4000 K, and 6500 K. Participants rated 3000 K and 4000 K higher and (*although not significant*) performed slightly better under 6500 K.

Both participants with moderate vision and normal vision performed best reading from Blister labels, then Baxter, and finally orange labels. Orange labels had a detrimental effect on the visual performance of participants with moderate vison loss.

Based on these conclusions, it is not recommended to equip medicine dispensation rooms with luminaires providing 100 lx on the task area. For the best visual performance supporting nurses with (emerging) vision loss, it is recommended to increase the illuminance to 1000 lx on the task area. This will reduce reading errors for nurses with moderate vision and improve reading speed of the medical staff with and without vision loss. Hospitals could consider the lighting conditions to provide an illuminance of at least 1000 lx on the task area, with preferably a CCT of 3000K or 4000 K.

References

Aarts, M. P. J., Craenmehr, G., Rosemann, A. L. P., Loenen, E. J. van, & Kort, H. S. M. (2019). International Journal of Industrial Ergonomics Light for patient safety : Impact of light on reading errors of medication labels. *International Journal of Industrial Ergonomics*, *71*(March), 145–154. https://doi.org/10.1016/j.ergon.2019.03.004

Aarts, M. P. J., & Kort, H. S. M. (2017). Lighting conditions in hospital medication rooms and nurses appraisal. *Healthy Buildings 2017 Europe*, (July 2017), 0118. https://doi.org/ISBN: 978-83-7947-232-1

Bailey, I. L., & Lovie-Kitchin, J. E. (2013). Visual acuity testing. From the laboratory to the clinic. *Vision Research*, *90*, 2–9. https://doi.org/10.1016/J.VISRES.2013.05.004

Bernhofer, E. I., Higgins, P. A., Daly, B. J., Burant, C. J., & Hornick, T. R. (2014). Hospital lighting and its association with sleep, mood and pain in medical inpatients. *Journal of Advanced Nursing*, *70*(5), 1164–1173. https://doi.org/10.1111/jan.12282

Boyce, P. R. (2003). *Human factors in lighting - 2nd Edition*. (CRC Press, Ed.) (2nd ed.). Boca Raton: Taylor & Francis Group.

Buchanan, T. L., Barker, K. N., Gibson, J. T., Jiang, B. C., & Pearson, R. E. (1991). Illumination and errors in dispensing. *American Journal of Hospital Pharmacy*, *48*(10), 2137–2145. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1781468

Centraal Bureau voor Statistiek. (2017). Aantal verpleegkundigen toegenomen. Retrieved January 16, 2019, from https://www.cbs.nl/nl-nl/nieuws/2019/19/aantal-verpleegkundigen-toegenomen

Chellappa, S. L., Steiner, R., Oelhafen, P., & Cajochen, C. (2017). Sex differences in light sensitivity impact on brightness perception, vigilant attention and sleep in humans. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/s41598-017-13973-1

Cina, J. L., Gandhi, T. K., Churchill, W., Fanikos, J., McCrea, M., Mitton, P., … Poon, E. G. (2006). How Many Hospital Pharmacy Medication Dispensing Errors Go Undetected? *The Joint Commission Journal on Quality and Patient Safety*, *32*(2), 73–80. https://doi.org/10.1016/S1553-7250(06)32010-7

Craenmehr, G. H. W. (2017). *The impact of light on the visual for selecting medication*. Eindhoven.

Daffner, K. R., Haring, A. E., Alperin, B. R., Zhuravleva, T. Y., Mott, K. K., & Holcomb, P. J. (2013). The impact of visual acuity on age-related differences in neural markers of early visual processing. *NeuroImage*, *67*, 127–136. https://doi.org/10.1016/j.neuroimage.2012.10.089

Dalke, H., Little, J., Niemann, E., Camgoz, N., Steadman, G., Hill, S., & Stott, L. (2006). Colour and lighting in hospital design. *Optics and Laser Technology*, *38*(4–6), 343–365. https://doi.org/10.1016/j.optlastec.2005.06.040

Faes, L., Bodmer, N. S., Bachmann, L. M., Thiel, M. A., & Schmid, M. K. (2014). Diagnostic accuracy of the Amsler grid and the preferential hyperacuity perimetry in the screening of patients with age-related macular degeneration: Systematic review and meta-analysis. *Eye (Basingstoke)*, *28*(7), 788–796. https://doi.org/10.1038/eye.2014.104

Glasser, A., & Campbell, M. C. W. (1998). Presbyopia and the optical changes in the human crystalline lens with age. *Vision Research*, *38*(2), 209–229. https://doi.org/10.1016/S0042-6989(97)00102-8

Gonzales, K. (2010). Medication administration errors and the pediatric population: A systematic search of the literature. *Journal of Pediatric Nursing*, *25*(6), 555–565. https://doi.org/10.1016/j.pedn.2010.04.002

Graves, K., Symes, L., Cesario, S. K., & Malecha, A. (2015). Is There Light? Well It Depends-A Grounded Theory Study of Nurses, Lighting, and Medication Administration. *Nursing Forum*, *50*(4), 241–251. https://doi.org/10.1111/nuf.12107

Hamilothoris, A. J. (2008). *a Comparison of Dispensing Error Detection Methods for the Department of Defense*. Auburn, Alabama. Retrieved from http://etd.auburn.edu/xmlui/bitstream/handle/10415/1234/Hamilothoris_Achilles_23.pdf?sequence=1

Hersch, R. K., Cook, R. F., Deitz, D. K., Kaplan, S., Hughes, D., Friesen, M. A., & Vezina, M. (2016). Reducing nurses' stress: A randomized controlled trial of a web-based stress management program for nurses. *Applied Nursing Research*, *32*, 18–25. https://doi.org/10.1016/j.apnr.2016.04.003

Holden, B. A., Fricke, T. R., Ho, S. M., Wong, R., Schlenther, G., & Cronje, S. (2008). Global Vision Impairment Due to Uncorrected Presbyopia, *126*(12), 1731–1739.

Inoue, Y., & Akitsuki, Y. (1998). The Optimal Illuminance for Reading: Effects of Age and Visual Acuity on Legibility and Brightness. *Journal of Light Visual Environment*. https://doi.org/10.1016/j.geoderma.2014.11.003

James, K. L., Barlow, D., McArtney, R., Hiom, S., Roberts, D., & Whittlesea, C. (2009). Incidence, type and causes of dispensing errors: a review of the literature. *International Journal of Pharmacy Practice*, *17*(1), 9–30. https://doi.org/10.1211/ijpp/17.1.0004

Kaiser, P. (2009). Prospective evaluation of visual acuity assessment: a comparison of snellen versus ETDRS charts in clinical practice (An AOS Thesis). *Transactions of the American Ophthalmological Society*, *107*, 311–324. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2814576&tool=pmcentrez&rendertype=abstract

Liu, G. T., Volpe, N. J., & Galetta, S. L. (2019). The Neuro-Ophthalmic Examination. In *Liu, Volpe, and Galetta's Neuro-Ophthalmology* (Third Edit, p. 16). Elsevier. https://doi.org/10.1016/B978-0-323-34044-1.00002-X

Mahmood, A., Chaudhury, H., & Gaumont, A. (2009). Environmental Issues Related to Medication Errors in Long-Term Care: Lessons from the Literature. *HERD: Health Environments Research & Design Journal*, *2*(2), 42–59. https://doi.org/10.1177/193758670900200204

Mahmood, A., Chaudhury, H., & Valente, M. (2011). Nurses' perceptions of how physical environment affects medication errors in acute care settings. *Applied Nursing Research*, *24*(4), 229–237. https://doi.org/10.1016/j.apnr.2009.08.005

Mansfield, J. S., Legge, G. E., & Bane, M. C. (1996). Psychophysics of reading. XV: Font effects in normal and low vision. *Investigative Ophthalmology and Visual Science*, *37*(8), 1492–1501.

Megaw, E. D. (1979). Factors affecting visual inspection accuracy. *Applied Ergonomics*, *10*(1), 27–32. https://doi.org/10.1016/0003-6870(79)90006-1

NEN-EN. (2011). *Een nieuwe norm voor werkplekverlichting*.

Picone, D. M., Titler, M. G., Dochterman, J., Shever, L., Kim, T., Abramowitz, P., … Rui Qin, R. (2008). Predictors of Medication Errors Among Elderly Hospitalized Patients. *American Journal of Medical Quality*, *23*(2), 115–127. https://doi.org/10.1177/1062860607313143

Smith, T. S. T., Frick, K. D., Holden, B. A., Fricke, T. R., & Naidoo, K. S. (2009). Potential lost productivity resulting from the global burden of uncorrected refractive error. *Bulletin of the World Health Organization*, *87*(6), 431–437. https://doi.org/10.2471/BLT.08.055673

Taniguchi, Y., Miki, M., Hiroyasu, T., & Yoshimi, M. (2011). Preferred illuminance and color temperature in creative works. In *2011 IEEE International Conference on Systems, Man, and Cybernetics* (pp. 3255–3260). IEEE. https://doi.org/10.1109/ICSMC.2011.6084171

Ulrich, R., & Barach, P. (2006). Designing Safe Healthcare Facilities—What are the data and where do we go from here? *Position Paper for the Healthcare Environments Research Summit 2006 Atlanta, GA Feb 8- 2006*, (March), 1–34.

Wolffsohn, J. S., & Davies, L. N. (2019). Presbyopia: Effectiveness of correction strategies. *Progress in Retinal and Eye Research*, *68*(March 2018), 124–143. https://doi.org/10.1016/j.preteyeres.2018.09.004

Appendix

Appendix A: Description of Participants

Appendix B: Climate conditions during experiment

Appendix C: Raw Statistical Data

Appendix D: Raw Absolute Data

Appendix E: Measured Lighting Conditions (illuminance, CCT, Ra, SPD)

Appendix F: Surveys

Appendix G: Experimenter Control Sheet

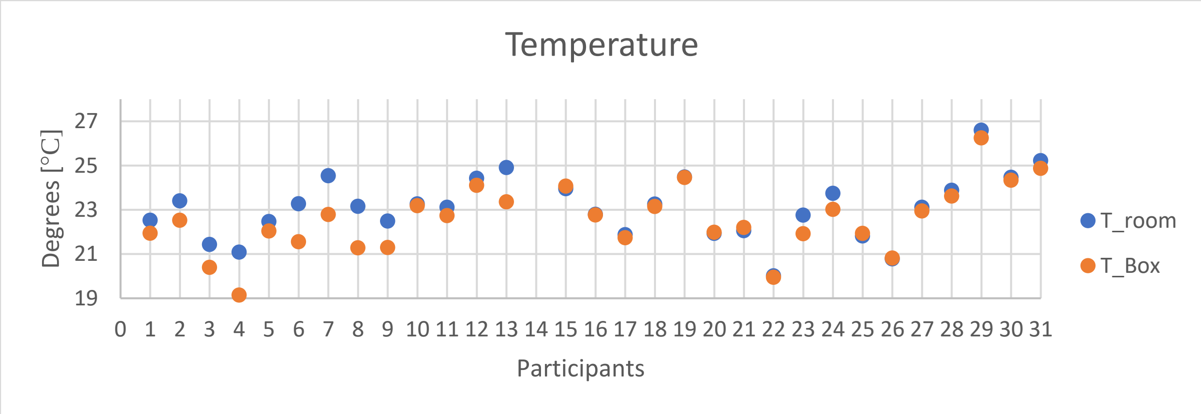
Appendix H: Measurement Equipment

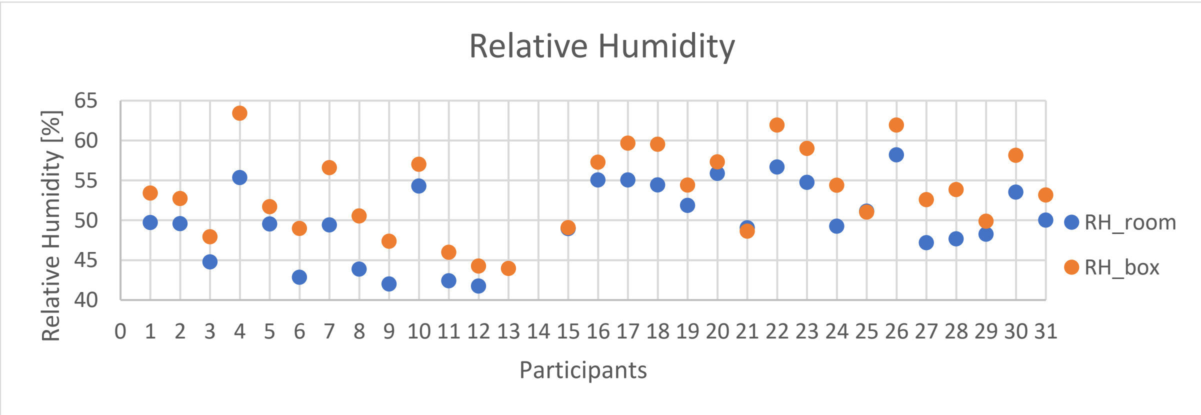
Appendix A. Description Participants

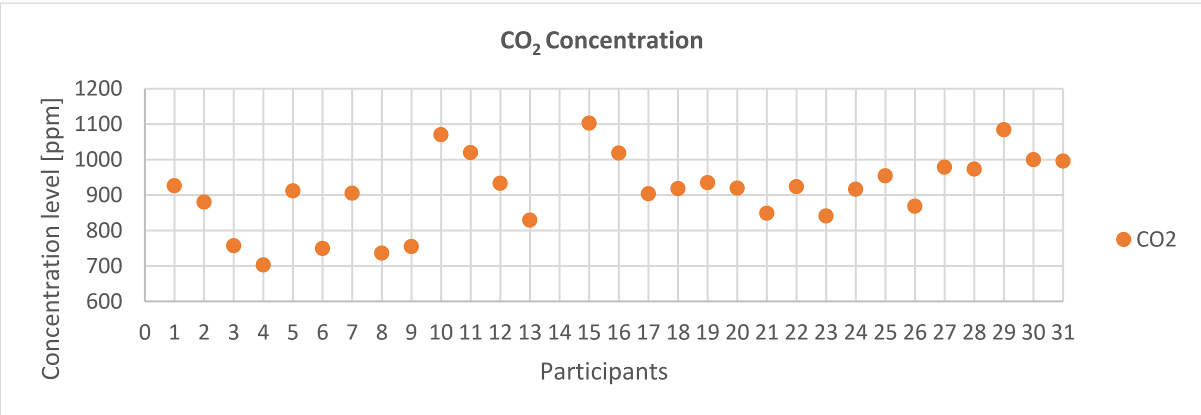
	Age	Visual Acuity	Glasses	Outcome Amsler Test
P01	41	1.25	-1.5	No AMD
P02	54	0.8	Positive Dioptry	Sees wavy lines, indicates AMD according to Amsler test
P03	55	1.25	Multi-focus 2.25+-	No AMD
P04	45	1.25	None	No AMD
P05	49	1.25	-3.25	No AMD
P06	48	1.0	None	left eye, all squares have somewhat brown line
P07	39	1.25	None	No AMD
P08	40	1.25	L- 1, R -0.5	No AMD, sees black "lanes" diagonally
P09	53	0.8	Negative Dioptry	Amsler shows MD in right eye
P10	43	0.63	+1.5	No AMD
P11	44	1.00	None	No AMD
P12	52	0.8	L -3.25, R-2.5, both +2.5	No AMD
P13	38	1.25	-1.75 both eyes	Left eye shows yellow colored squares
P14	35	1.25	None	No AMD
P15	47	0.63	?	Has been diagnosed with AMD
P16	46	0.8	None	Right eye seems to show beginning symptoms, Left ok
P17	51	0.8	MF +/-6.5	No AMD
P18	45	0.8	Multifocus	No AMD
P19	51	0.8	?	No AMD
P20	40	1.25	L -4.5, R -4.25	No AMD
P21	50	1.00	+1	No AMD
P22	42	1.00	None	No AMD
P23	38	1.25	None	No AMD
P24	49	1.0	Multi-Focus	No AMD
P25	51	0.8	L +0.25, R +2, -0.5 LR	Left eye shows yellow squares to the right of the dot, Right eye OK
P26	51	0.8	+2.25	No AMD
P27	52	0.63	None	No AMD
P28	55	0.63	+1	No AMD
P29	48	0.8	Glasses +1	No AMD
P30*	53	1.25	Glasses+1, Lenses: -1.25, -1.75.	No AMD
P31	42	0.8	None	No AMD

*P30 was excluded from the results and analyses.

Appendix B. Climate Conditions during the experiments







Appendix C. Raw Statistical Data

Results from Wilcoxson Signed Rank test, post-hoc for reading errors

Reading Errors		100 lx 3000K	100 lx 4000K	100 lx 6500K	500 lx 3000K	500 lx 4000K	500 lx 6500K	1000 lx 3000K	1000 lx 4000K	1000 lx 6500K
100 lx/3000K	*p*	-	1.00	1.00	0.19	0.01	0.27	0.06	0.02	0.08
	Z	-	-0.77	-1.86	-2.79	-3.55	-2.67	-3.13	-3.40	-3.05
	r	-	-0.34	-0.51	-0.65	-0.49	-0.57	-0.62	-0.56	-0.05
100 lx/4000K	*p*	-	-	1.00	0.09	0.02	0.10	0.10	0.04	0.14
	Z	-	-	-0.28	-3.03	-3.46	-3.00	-3.00	-3.28	-2.89
	r	-	-	-0.05	-0.55	-0.63	-0.55	-0.55	-0.60	-0.53
100 lx/6500K	*p*	-	-	-	0.94	0.11	1.00	0.59	0.20	0.54
	Z	-	-	-	-2.23	-2.97	-2.07	-2.40	-2.78	-2.43
	r	-	-	-	-0.41	-0.54	-0.38	-0.44	-0.51	-0.44
500 lx/3000K	*p*	-	-	-	-	1.00	1.00	1.00	1.00	1.00
	Z	-	-	-	-	-0.02	-0.18	-1.45	-1.56	-1.68
	r	-	-	-	-	0.00	-0.03	-0.26	-0.28	-0.31
500 lx/4000K	*p*	-	-	-	-	-	1.00	1.00	1.00	1.00
	Z	-	-	-	-	-	-0.46	-0.63	-1.91	-1.39
	r	-	-	-	-	-	-0.08	-0.11	-0.35	-0.25
500 lx/6500K	*p*	-	-	-	-	-	-	1.00	1.00	1.00
	Z	-	-	-	-	-	-	-1.55	-1.42	-1.74
	r	-	-	-	-	-	-	-0.28	-0.26	-0.32
1000 lx/3000K	*p*	-	-	-	-	-	-	-	1.00	1.00
	Z	-	-	-	-	-	-	-	-0.86	-0.70
	r	-	-	-	-	-	-	-	-0.16	-0.13
1000 lx/4000K	*p*	-	-	-	-	-	-	-	-	1.00
	Z	-	-	-	-	-	-	-	-	-0.09
	r	-	-	-	-	-	-	-	-	-0.02

Results from Wilcoxson Signed Rank test, post-hoc for reading speed

Reading Speed		100 lx 3000K	100 lx 4000K	100 lx 6500K	500 lx 3000K	500 lx 4000K	500 lx 6500K	1000 lx 3000K	1000 lx 4000K	1000 lx 6500K
100 lx/3000K	p	-	1.00	1.00	<.001	<.001	0.02	<.001	<.001	0.03
	Z	-	-0.15	-0.55	-3.82	-4.47	-3.50	-4.06	-4.08	-3.36
	r	-	-0.18	-0.28	-0.14	-0.02	-0.06	-0.10	-0.06	-0.12
100 lx/4000K	p	-	-	34.52	0.01	<.001	<.001	<.001	<.001	<.001
	Z	-	-	-0.05	-3.54	-4.31	-4.06	-4.04	-3.98	-3.88
	r	-	-	-0.01	-0.65	-0.79	-0.74	-0.74	-0.73	-0.71
100 lx/6500K	p	-	-	-	<.001	<.001	<.001	<.001	<.001	<.001
	Z	-	-	-	-3.84	-4.41	-4.34	-4.17	-4.12	-3.92
	r	-	-	-	-0.70	-0.81	-0.79	-0.76	-0.75	-0.72
500 lx/3000K	p	-	-	-	-	1.00	1.00	1.00	1.00	1.00
	Z	-	-	-	-	-0.94	-0.63	-1.00	-1.51	-0.78
	r	-	-	-	-	-0.17	-0.11	-0.18	-0.28	-0.14
500 lx/4000K	p	-	-	-	-	-	1.00	1.00	1.00	1.00
	Z	-	-	-	-	-	-0.11	-0.33	-0.53	-0.32
	r	-	-	-	-	-	-0.02	-0.06	-0.10	-0.06
500 lx/6500K	p	-	-	-	-	-	-	1.00	1.00	1.00
	Z	-	-	-	-	-	-	-0.64	-0.50	-0.76
	r	-	-	-	-	-	-	-0.12	-0.09	-0.14
1000 lx/3000K	p	-	-	-	-	-	-	-	1.00	1.00
	Z	-	-	-	-	-	-	-	-0.67	-0.30
	r	-	-	-	-	-	-	-	-0.12	-0.05
1000 lx/4000K	p	-	-	-	-	-	-	-	-	1.00
	Z	-	-	-	-	-	-	-	-	-0.36
	r	-	-	-	-	-	-	-	-	-0.07

Appendix D. Raw Absolute Data

Table: Overview of average reading errors and reading speed. A division is also made for the seperate VA groups. The reading errors are given in amount of errors made and percentage (1 error = 0.55%), reading speed is presented in seconds.

Lighting Conditions		Mean reading errors [-]			Mean reading speed [s]		
		All VA (N=30)	Low VA (N=15)	High VA (N=15)	All VA (N=30)	Low VA (N=15)	High VA (N=15)
100 lx	3000 K	22.6 (12.6%)	41.3 (22.9%)	3.9 (2.2%)	162.6	205.4	119.8
100 lx	4000 K	22.5 (12.5%)	40.5 (22.5%)	4.5 (2.5%)	159.9	203.4	116.5
100 lx	6500 K	20.6 (11.4%)	38.3 (21.3%)	2.9 (1.6%)	160.7	204.3	117.1
500 lx	3000 K	12.4 (6.9%)	22.1 (12.3%)	2.7 (1.6%)	134.7	162.1	107.2
500 lx	4000 K	12.8 (7.1%)	22.4 (12.4%)	3.2 (1.5%)	133.2	161.6	104.7
500 lx	6500 K	12.5 (6.9%)	20.6 (11.4%)	4.4 (2.4%)	132.1	156.6	107.6
1000 lx	3000 K	10.8 (6.0%)	18.5 (10.3 %)	3.1 (1.7%)	128.7	150.5	107.0
1000 lx	4000 K	10.0 (5.6%)	17.1 (9.5 %)	3.0 (1.7%)	130.7	154.4	106.9
1000 lx	6500 K	9.6 (5.4%)	15.7 (8.7%)	3.5 (2.0%)	130.9	155.4	106.3
Total Mean		14.9	26.3	3.5	141.5	172.6	110.4

Table: Overview of average reading errors and reading speeds filtered per material per lighting conditions

Lighting Conditions	Mean reading errors [-]			Mean reading speed [s]		
	All VA (N=30)	Low VA (N=15)	High VA (N=15)	All VA (N=30)	Low VA (N=15)	High VA (N=15)
I100 Blister	16.1 (8.9%)	28.9 (16.0%)	3.3 (1.9%	148.0	182.4	113.6
I100 Baxter	21.5 (11.9%)	39.8 (22.1%)	3.2 (1.8%)	161.3	204.3	118.2
I100 Orange	28.1 (15.6%)	51.4 (28.6%)	4.8 (2.7%)	174.0	226.5	121.5
I500 Blister	9.9 (5.5%)	16.5 (9.1%)	3.3 (1.8%)	126.8	147.7	105.9
I500 Baxter	11.8 (6.6%)	20.5 (11.4%)	3.2 (1.8%)	131.9	157.8	106.1
I500 Orange	16.0 (8.9%)	28.2 (15.7%)	3.9 (2.1%)	141.2	174.9	107.5
I1000 Blister	7.6 (4.2%)	12.1 (6.7%)	3.0 (1.7%)	122.4	138.6	106.1
I1000 Baxter	9.2 (5.1%)	15.5 (8.6%)	2.9 (1.6%)	127.2	148.1	106.3
I1000 Orange	13.7 (7.6%)	23.7 (13.1%)	3.7 (2.0%)	140.7	173.6	107.9
Total Mean	14.9	26.3	3.5	141.5	172.6	110.4

Table: Overview of average reading errors and reading speeds filtered on illuminance. A division is also made for the separate VA groups. The reading errors are given in amount of errors made and percentage (1 error = 0.55%), reading speed is presented in seconds.

Lighting Conditions	Mean reading errors [-]			Mean reading speed [s]		
	All VA (N=30)	Low VA (N=15)	High VA (N=15)	All VA (N=30)	Low VA (N=15)	High VA (N=15)
100 lx	21.9	40.0	3.8	161.1	204.4	117.8
500 lx	12.6	21.7	3.4	133.3	160.1	106.5
1000 lx	10.2	17.1	3.2	130.1	153.4	106.8
Total Mean	14.9	26.3	3.5	141.5	172.6	110.4

Table: Overview of average reading errors and reading speeds filtered per material

Materials	Mean reading errors [-]			Mean reading speed [s]		
	All VA (N=30)	Low VA (N=15)	High VA (N=15)	All VA (N=30)	Low VA (N=15)	High VA (N=15)
Blister	33.5 (6.2 %)	57.5 (10.6%)	9.6 (1.8%)	397.2	468.7	325.6
Baxter	42.6 (7.6%)	75.8 (14.0%)	9.3 (1.7%)	420.4	510.1	330.6
Orange	57.8 (10.4)	103.3 (19.1%)	12.3 (2.3%)	455.9	574.9	336.9
Total Mean	44.6	78.8	10.4	424.5	517.9	331.1

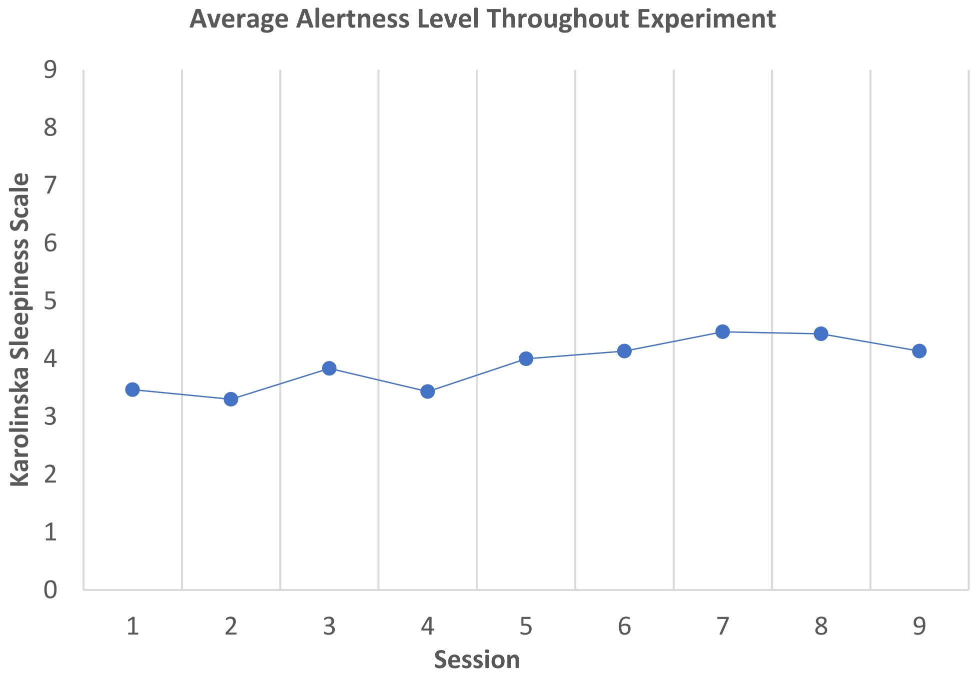


Figure: Alertness level of participants throughout experiment.

Appendix E. Distribution of data

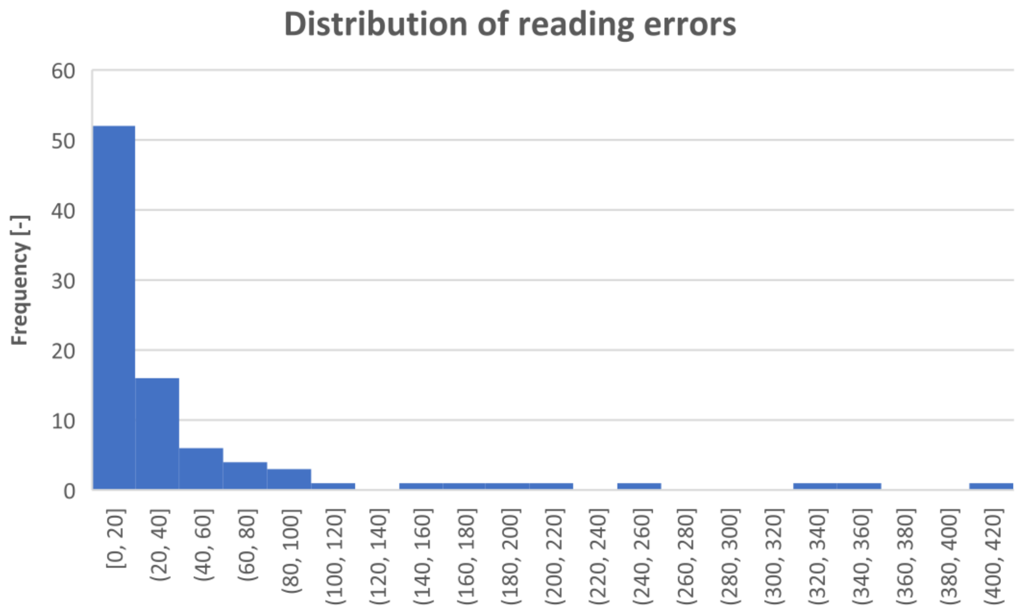


Figure: Distribution of Reading Errors made under illuminances of 100 lx, 500 lx, 1000 lx (N=30)

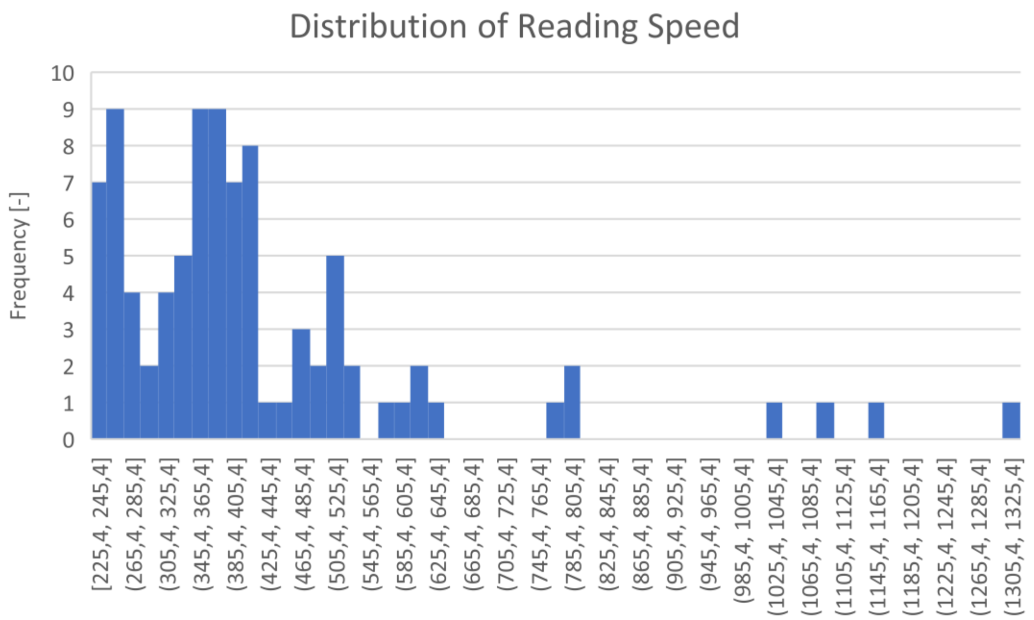


Figure: Distribution of Reading Errors made under illuminances of 100 lx, 500 lx, 1000 lx (N=30)

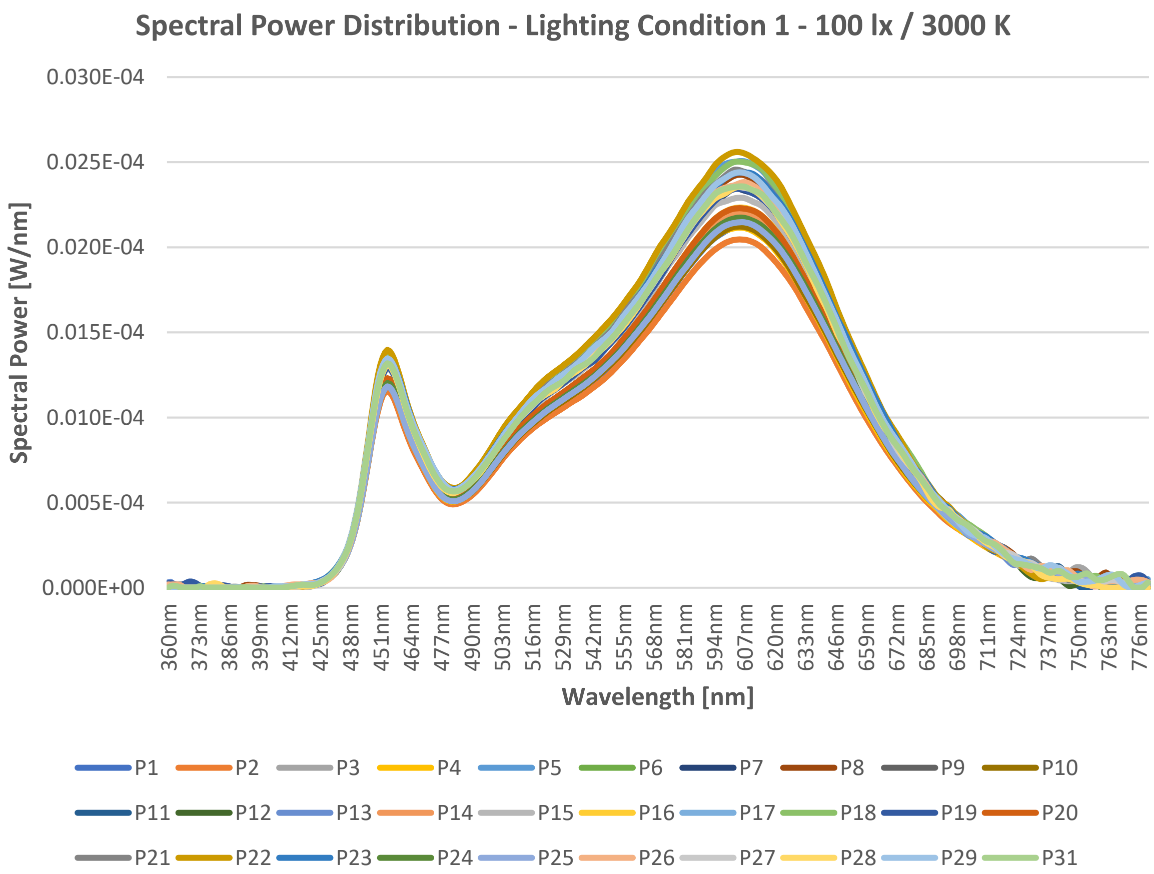
Appendix F. Measured Lighting Conditions

Table: Measured Lighting conditions

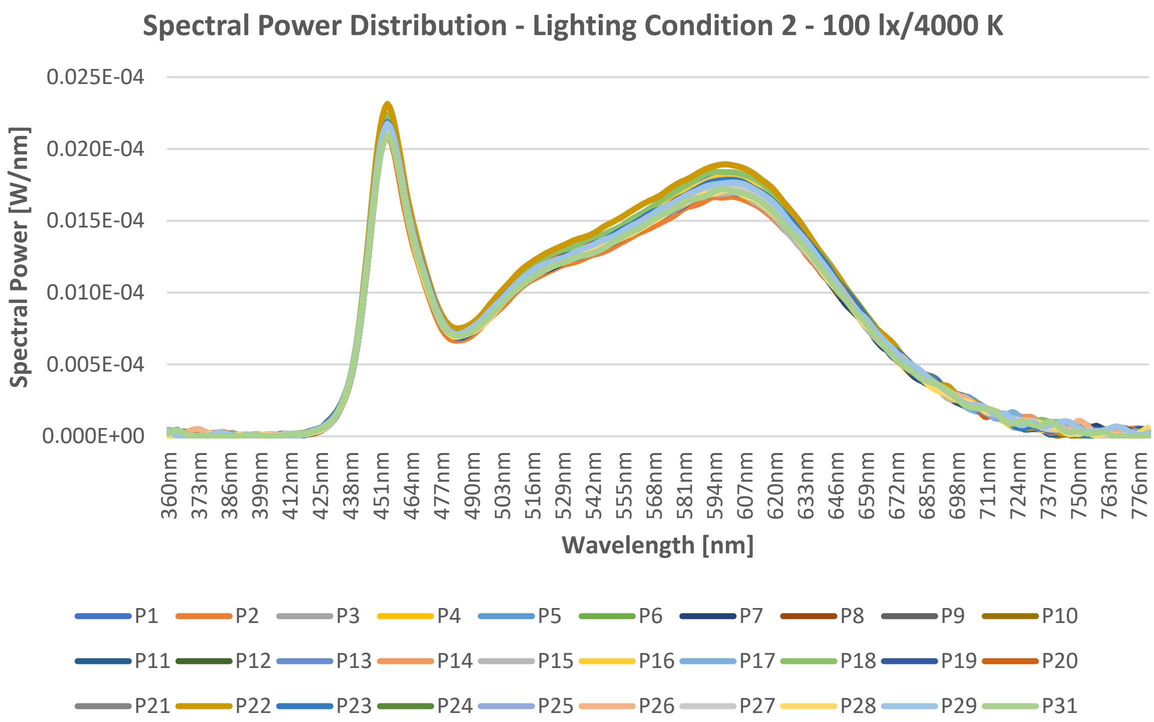
Lighting Condition		Mean Illuminance [Measured in lx]	Mean CCT [Measured in K]	Mean R_a [Measured index]
1	100 lx / 3000 K	114 ± 6.5	3058 ± 15.9	84 ± 0.1
2	100 lx / 4000 K	102 ± 2.5	4117 ± 28.7	88 ± 0.2
3	100 lx / 6500 K	113 ± 5.2	6608 ± 59.2	85 ± 0.3
4	500 lx / 3000 K	522 ± 12.6	3069 ± 17.3	84 ± 0.1
5	500 lx / 4000 K	501 ± 11.6	4014 ± 23.5	87 ± 0.1
6	500 lx / 6500 K	515 ± 11.2	6547 ± 55.5	85 ± 0.3
7	1000 lx / 3000 K	1003 ± 22.8	3079 ± 15.3	84 ± 0.2
8	1000 lx / 4000 K	3079 ± 15.3	4017 ± 22.3	87 ± 0.2
9	1000 lx / 6500 K	1018 ± 25.4	6501 ± 39.0	84 ± 0.2

SPECTRAL POWER DISTRIBUTION

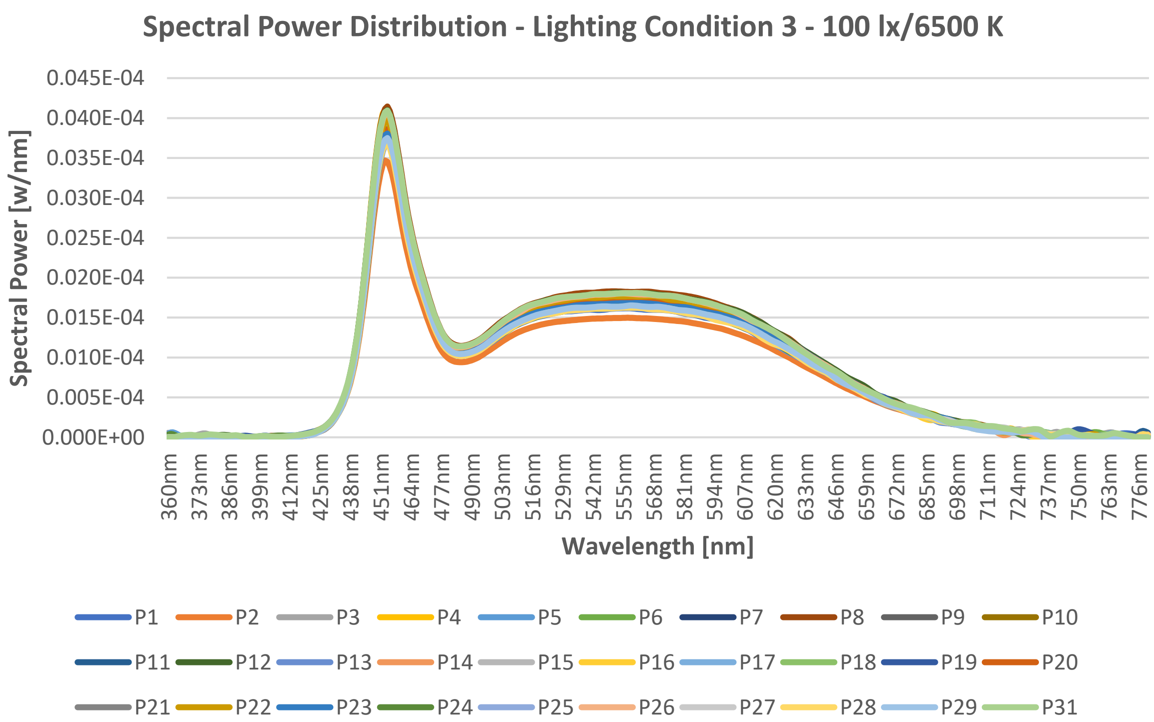
Lighting Condition 1: 100 lx/3000 K



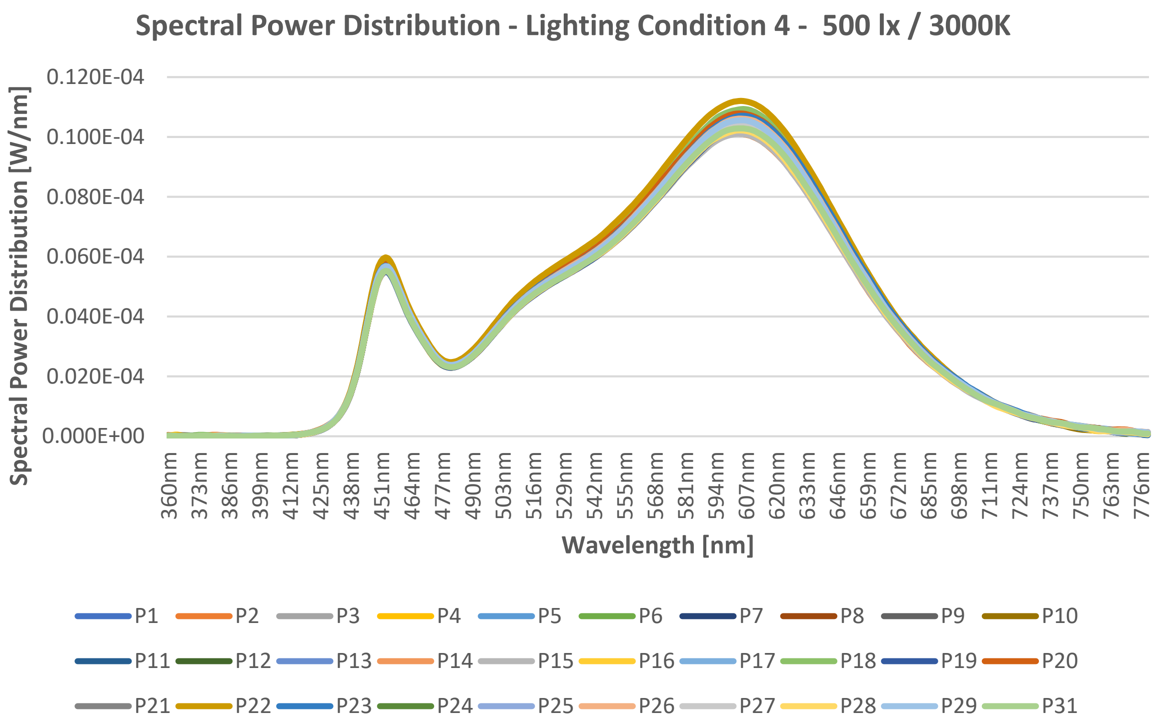
Lighting Condition 2: 100 lx/4000 K



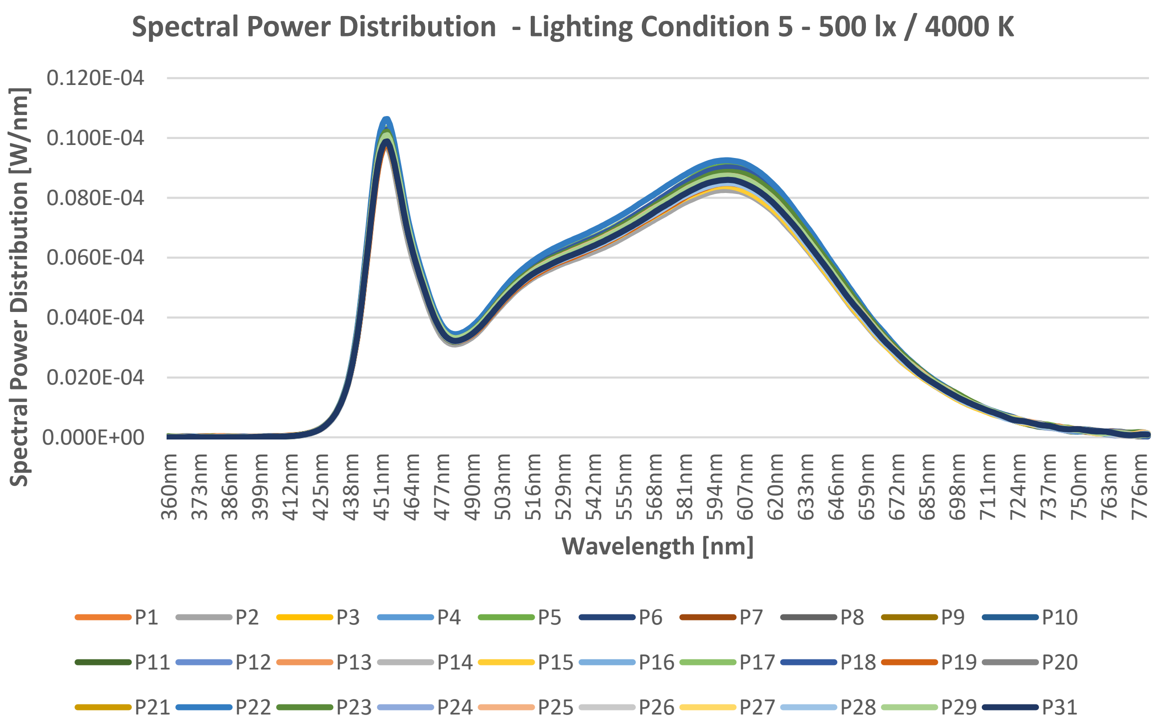
Lighting Condition 3: 100 lx/6500 K



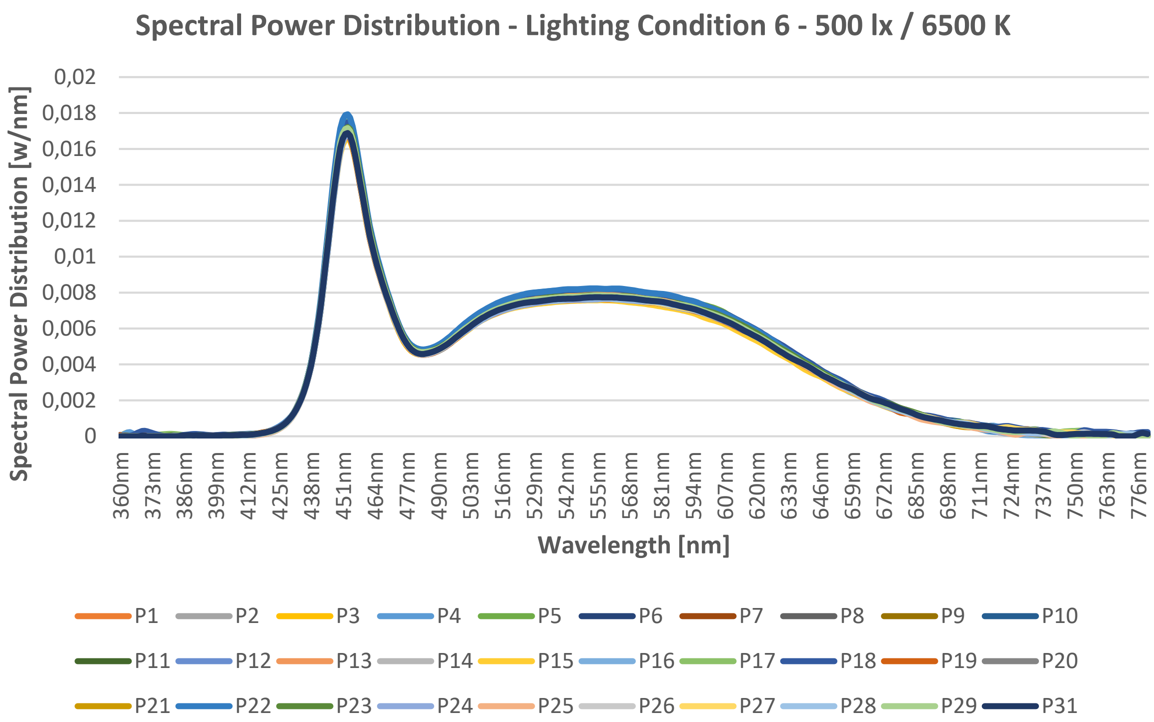
Lighting Condition 4: 500 lx/3000 K



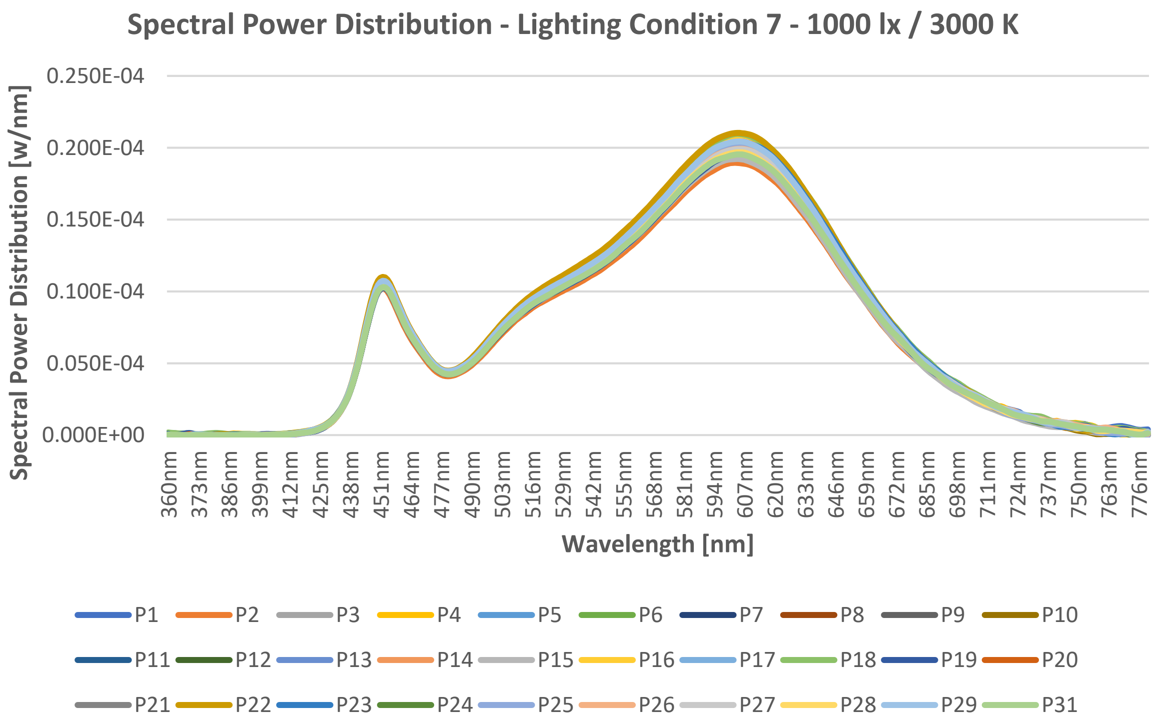
Lighting Condition 5: 500 lx/4000 K



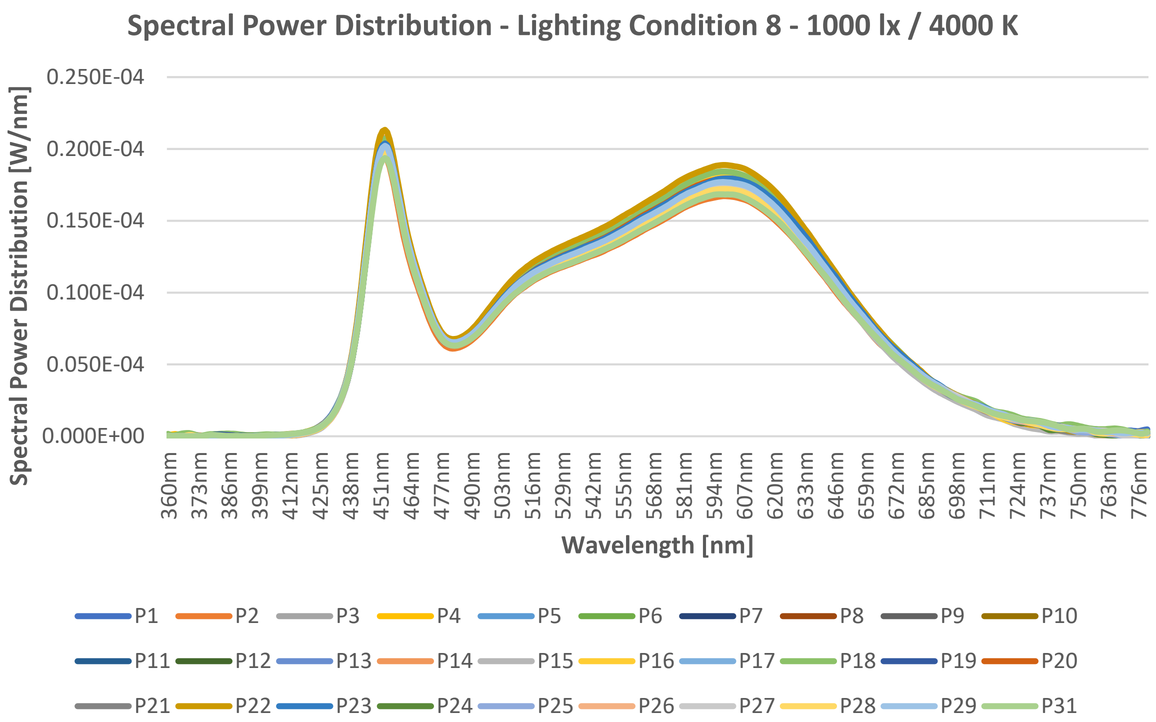
Lighting Condition 6: 500 lx/6500 K



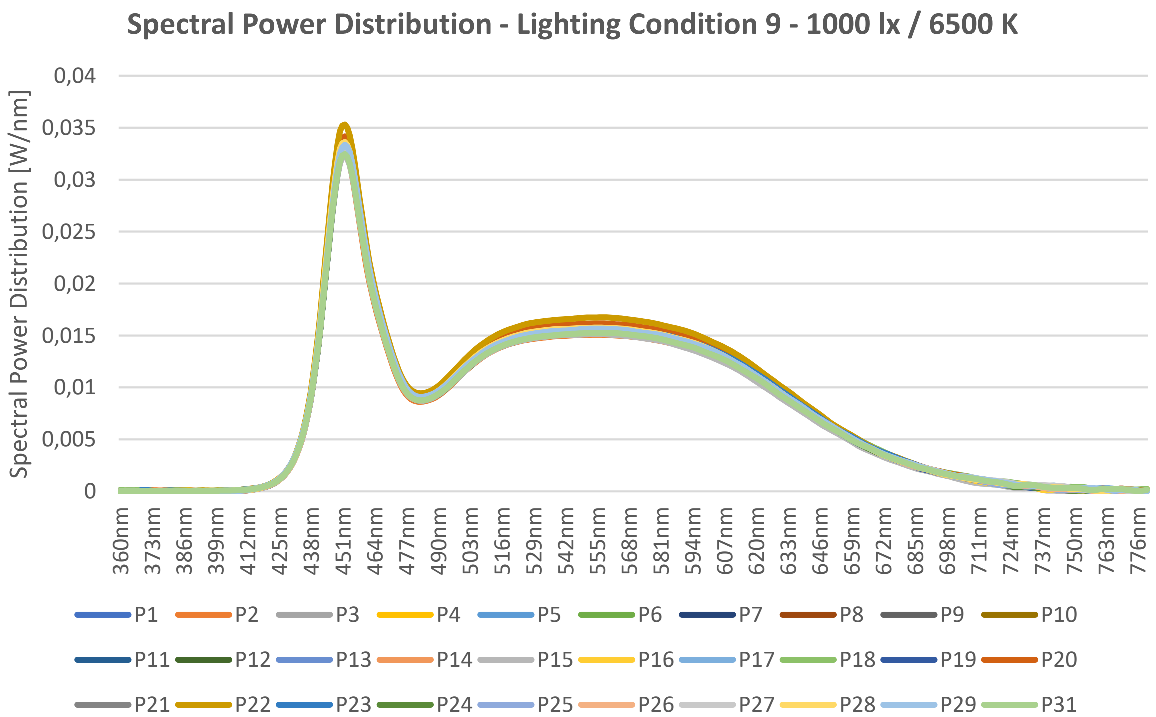
Lighting Condition 7: 1000 lx/3000 K



Lighting Condition 8: 1000 lx/4000 K



Lighting Condition 9: 1000 lx/6500 K



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Appendix G. Surveys

The following surveys are based on the surveys used in (Craenmehr, 2017)**.**

F1 – Informed Consent Form

F2 – General Survey

F3 – Repeated Survey

F4 – End Survey

F1- Informed Consent Form

Instemming deelname onderzoek

Dit document geeft u informatie over het onderzoek “Lighting for medication”. Voordat het onderzoek begint, is het belangrijk dat u kennisneemt van de werkwijze die bij dit onderzoek gevolgd wordt en dat u instemt met vrijwillige deelname. Leest u dit document a.u.b. aandachtig door.

Doel en nut van dit onderzoek

Het doel van dit onderzoek is om te meten wat het effect van lichtcondities zijn op de visuele prestatie. De verkregen informatie wordt gebruikt om te kijken of de lichtcondities in ziekenhuizen kunnen worden verbeterd met betrekking tot het lezen van de medische informatie.

Het onderzoek wordt uitgevoerd in kader van het project ‘Creating Healthy Environments Hospitals’ door Diyako Shadmanfar, afstudeerstudent Architecture Building and Planning, onder supervisie van ir. Mariëlle Aarts, Unit Building Physics & Services, Faculteit Bouwkunde.

Procedure

Tijdens het experiment zullen tekstreeksen in verschillende groottes en op verschillende materialen worden getoond. U zult gevraagd worden om deze tekstreeksen hardop voor te lezen. Elke sessie zal bestaan uit 18 tekstreeksen, waarbij in elke sessie de lichtconditie zal veranderen. In totaal zullen er 10 sessies worden gehouden en tussen elke sessie zal een korte pauze van drie minuten worden ingelast. Voorafgaand aan de leessessies zullen er twee testjes worden uitgevoerd ter bepaling van uw visus. De onderzoekers behouden het recht om u op basis van de uitkomsten van de visustesten, niet te laten deelnemen aan het onderzoek.

Risico`s

Dit onderzoek brengt geen risico`s en nadelige bijwerkingen met zich mee.

Duur onderzoek

Het onderzoek duurt tussen 60 en 80 minuten.

Vrijwilligheid

Uw deelname is geheel vrijwillig. U kunt zonder opgaaf van redenen weigeren mee te doen aan het onderzoek en uw deelname op ieder gewenst moment kunt afbreken. Ook kunt u achteraf (binnen 24 uur) weigeren dat uw gegevens voor het onderzoek gebruikt mogen worden. Dit alles te allen tijde zonder nadelige gevolgen.

Paraaf Participant

______

Vertrouwelijkheid

Dit onderzoek wordt uitgevoerd door de Unit Building Physics & Services met goedkeuring van Human-Technology Interaction waar gewerkt wordt volgens de ethische code van het NIP (Nederlands Instituut voor Psychologen).

Wij delen geen persoonlijke informatie over u met mensen buiten het onderzoeksteam. Er wordt geen video opgenomen en audio-opnames die u zouden kunnen identificeren zullen uitsluitend worden afgespeeld in het bijzijn van de onderzoekers. Het materiaal zal uitsluitend gebruikt worden voor wetenschappelijke analyse. De informatie die we met dit onderzoek verzamelen wordt gebruikt voor het schrijven van wetenschappelijke publicaties en wordt slechts op groepsniveau gerapporteerd. Alles gebeurt geheel anoniem en niets kan naar u herleid worden.

Nadere toelichting

Indien u nog meer informatie wilt met betrekking tot dit onderzoek, kunt u contact opnemen met Diyako Shadmanfar (e-mail d.shadmanfar@student.tue.nl).

Indien u klachten heeft met betrekking tot dit onderzoek, kunt u contact opnemen met de supervisor Mariëlle Aarts (e-mail m.p.j.aarts@tue.nl).

Instemming onderzoeksdeelname

Bij dezen verklaar ik, (NAAM)……
dat ik dit document gelezen en begrepen heb en dat ik de gelegenheid heb gehad om vragen te stellen. Ik stem ermee in om vrijwillig deel te nemen aan dit onderzoek van de unit Building Physics & Services, Technische Universiteit Eindhoven.

____________________ ________________

Handtekening Participant Datum

F2- General Survey

Datum en Tijd _______________ **Participant nummer** _______ (in te vullen door onderzoeker)

Naam ____

Geboortedatum _______________ (DD – MM – YYYY)

Werkfunctie ____

Hoogst afgeronde opleidingsniveau ______________________________

Dyslexie Ja/Nee

Oogcorrectie Lenzen/ Bril

Ver / Dichtbij/ Multifocus Sterkte _____

Laatst getest op _______________________________

Medische condities m.b.t. uw ogen? (Zoals: glaucoom, cataract, maculadegeneratie, diabetische retinopathie, diabetes etc.)

O Nee

O Ja, omschrijf uw conditie en sinds wanneer______________________

____

Hoeveel cafeïne houdende drankjes heeft u vandaag genuttigd?

_________________ kopjes koffie anders, ________________________

Hoe ervaart u de luchtkwaliteit in de ruimte waarin u zich bevindt?

Fris O O O O O O O *Benauwd*

How ervaart u de luchtstromingen in de ruimte waarin u zich bevindt?

Veel te stil O O O O O O O *Veel te tochtig*

Hoe ervaart u de relatieve luchtvochtigheid in deze ruimte?

Veel te droog O O O O O O O *Veel te vochtig*

Hoe ervaart u het achtergrondgeluid in de ruimte waarin u zich bevindt?

Veel te lawaaierig O O O O O O O *Veel te stil*

Hoe ervaart u de temperatuur in de ruimte waarin u zich bevindt?

Veel te koud O O O O O O O *Veel te warm*

Hoe ervaart u het binnenklimaat in de ruimte waarin u zich bevindt?

Zeer onaangenaam O O O O O O O *Zeer aangenaam*

Hoe zou u uw alertheid op dit moment beoordelen?

- O Extreem alert
- O Erg alert
- O Alert
- O Redelijk alert
- O Noch alert, noch slaperig
- O Enige symptomen van slaperigheid
- O Slaperig, maar geen moeite om wakker te blijven
- O Slaperig, enige moeite om wakker te blijven
- O Erg slaperig, veel moeite om wakker te blijven; vechtend tegen de slaap

F3 - Repeating Survey

Session nr:

Heeft u enig hinder ondervonden aan uw ogen tijdens het afgelopen experiment?

- O Nee
- O Ja
  - O Droge ogen
  - O Prikkende ogen
  - O Brandende ogen
  - O Dubbel zicht
  - O Vermoeide ogen
  - O Wazig zicht
  - O Anders, namelijk ____________________

Hoe ervaart u de hoeveelheid licht op het werkvlak?

Veel te laag O O O O O O O *Veel te hoog*

Hoe ervaart u de kleur van het licht op dit moment?

Veel te koel O O O O O O O *Veel te warm*

Hoe ervaart u de huidige lichtconditie?

Zeer onprettig O O O O O O O *Zeer prettig*

Hoe zou u uw alertheid op dit moment beoordelen?

- O Extreem alert
- O Erg alert
- O Alert
- O Redelijk alert
- O Noch alert, noch slaperig
- O Enige symptomen van slaperigheid
- O Slaperig, maar geen moeite om wakker te blijven
- O Slaperig, enige moeite om wakker te blijven
- O Erg slaperig, veel moeite om wakker te blijven; vechtend tegen de slaap

Heeft u op dit moment op- en/of aanmerkingen op het experiment?

F4- End-Survey

Heeft u enig verschil ondervonden in de leesbaarheid door de lettergroottes, materiaal of reflecties van het licht tijdens de verschillende lichtcondities? Hierbij zijn meerdere antwoorden mogelijk. Zo ja, kunt u deze beschrijven?

O Nee

O Ja
- O Lettergrootte
- O Materiaal
- O Reflectie van het licht van het materiaal
- O Anders namelijk, ____

____

____

____

____

____

____

____

Rangschik de materialen die zijn gebruikt in het experiment van 1 tot 3, waar 1 de meeste voorkeur heeft en 3 die minste

___ Zwart-witte label ____ Oranje label _____ Plastic materiaal

Heeft u op dit moment op- en/of aanmerkingen op het experiment?

____

____

____

____

____

Hoe ervaart u de luchtkwaliteit in de ruimte waarin u zich bevindt?

Fris	o	o	o	o	o	o	o	*Benauwd*

How ervaart u de luchtstromingen in de ruimte waarin u zich bevindt?

Veel te stil	o	o	o	o	o	o	o	*Veel te tochtig*

Hoe ervaart u de relatieve luchtvochtigheid in deze ruimte?

Veel te droog	o	o	o	o	o	o	o	*Veel te vochtig*

Hoe ervaart u het achtergrondgeluid in de ruimte waarin u zich bevindt?

Veel te lawaaierig	o	o	o	o	o	o	o	*Veel te stil*

Hoe ervaart u de temperatuur in de ruimte waarin u zich bevindt?

Veel te koud	o	o	o	o	o	o	o	*Veel te warm*

Hoe ervaart u het binnenklimaat in de ruimte waarin u zich bevindt?

Zeer onaangenaam	o	o	o	o	o	o	o	*Zeer aangenaam*

Appendix H. Experimenter Control Sheet

Participants Code	
Participants Number	

Date	
Time	

Session Number

Booklet number

Lighting Condition

		1	2	3	4	5	6	7	8	9	10
Order Booklet	BOOK	D	3	5	2	1	4	2	5	4	3
Order Lighting	SETTING	5	9	2	8	7	1	5	4	3	6
	LUX	500	100	500	100	1000	1000	500	1000	100	100
	CCT	3000	4000	6500	6500	4000	6500	3000	3000	6500	3000

Visual Acuity Control sheet

Bi-ocular ETDRS	Visual Acuity test	
ZRKDC	COHZV	0.050
DNCHV	SZNDC	0[illegible]
CDHNR	VKCNR	[illegible]
RVZOS	KCRHN	[illegible]
OSDVZ	ZKDVC	0.12
NOZCD	HVORK	0.16
RDNSK	RHSON	0.20
OKSVZ	KSVRH	0.25
KSNHO	HNKCD	0.32
HOVSN	NDVKO	0.40
VCSZH	DHOSZ	0.50
CZDRV	VRNDO	0.63
SHRZC	CZHKS	0.80
DNOKR	ORZSK	1.00
HZSCV	SCNDZ	1.25
CKRDZ	NDHKC	1.60
RDONK	VKORH	2.00

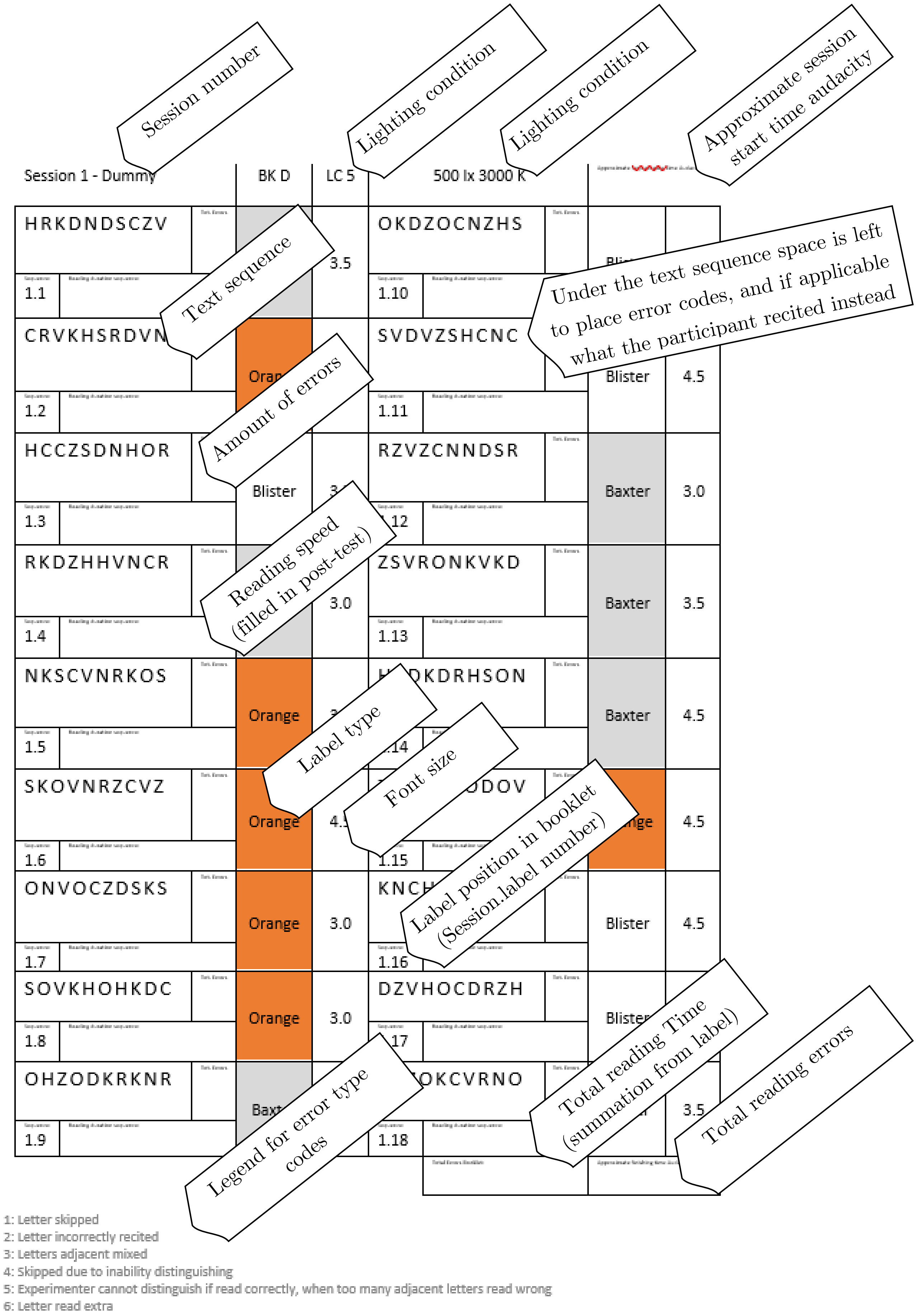
Participated with glasses? Yes / No

Remarks

Mic Ready	
Webcam Ready	
Spectrometer Ready	
Background noise Ready	
Temperature + RH Ready	
Timer Ready	
New audacity file	
New Folder Participant	
General Info filled in 1x	
Lighting Questionnaire 10x	
Amsler Test	

Overview duration phases in experiment

2	Explanation of the experiment
4	General Survey
5	Visual Acuity Test + AMSLER
3.5	Dummy test
3	Repeating Survey
3.5	Session 1
3	Repeating Survey
3.5	Session 2
3	Repeating Survey
3.5	Session 3
3	Repeating Survey
3.5	Session 4
3	Repeating Survey
3.5	Session 5
3	Repeating Survey
3.5	Session 6
3	Repeating Survey
3.5	Session 7
3	Repeating Survey
3.5	Session 8
3	Repeating Survey
3.5	Session 9
5	Final Survey


Session number
Lighting condition
Lighting condition
Approximate session start time audacity
Session 1 - Dummy
BK D
LC 5
500 lx 3000 K
Text sequence
Under the text sequence space is left to place error codes, and if applicable what the participant recited instead
Amount of errors
Reading speed (filled in post-test)
Label type
Font size
Label position in booklet (Session.label number)
Total reading Time (summation from label)
Total reading errors
Legend for error type codes
HRKDNDSCZV
1.1
3.5
OKDZOCNZHS
1.10
CRVKHSRDVN
1.2
Orange
SVDVZSHCNC
1.11
Blister
4.5
HCCZSDNHOR
1.3
Blister
RZVZCNNDSR
1.12
Baxter
3.0
RKDZHHVNCR
1.4
3.0
ZSVRONKVKD
1.13
Baxter
3.5
NKSCVNRKOS
1.5
Orange
1.14
Baxter
4.5
SKOVNRZCVZ
1.6
Orange
1.15
4.5
ONVOCZDSKS
1.7
Orange
3.0
1.16
Blister
4.5
SOVKHOHKDC
1.8
Orange
3.0
DZVHOCDRZH
1.17
OHZODKRKNR
1.9
1.18
3.5
1: Letter skipped
2: Letter incorrectly recited
3: Letters adjacent mixed
4: Skipped due to inability distinguishing
5: Experimenter cannot distinguish if read correctly, when too many adjacent letters read wrong
6: Letter read extra

Appendix I. Measurement Equipment

An overview of all equipment used during the experiment is given in Table 15.

Table 15: Measurement devices in the experiment setup. The BPS ID is the device-id as given by the laboratory of the unit Building Physics & Services

	Device	Specification	BPS ID
1	Laptop	Dell Latitude E5530, OS: Windows 10 Sound Recording software: Audacity 2.3.0 Lighting Control software: Helvar Digidim	3600
2	Microphone	Devine M-Mic XLR USB	3628
3	Camera	Trust Spotlight Webcam	-
4	Spectrometer	Konica-Minolta CL500A	2984
5	Datalogger for Eltek climate sensors	Eltek Squirrell RX250AL	1621
6	Temperature-/ Relative humidity-/ CO_2-Sensor	Eltek GW-47	2499
7	Temperature-/ Relative humidity-Sensor	Eltek GEN-II Transmitter GC-13E	1502
	Air Humidifier	Boneco Ultrasonic Humidifier 7147	3648
	Visual Acuity Chart	Precision Vision Logarithmic Visual Acuity Chart 2000 “New ETDRS”, cat no. 2106	437

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