Light for patient safety

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Light for patient safety: Impact of light on reading errors of medication labels

Mariëlle P.J. Aarts^{a,*}, Giel Craenmehr^a, Alexander L.P. Rosemann^a, Evert J. van Loenen^{a,b}, Helianthe S.M. Kort^{a,c}

^a Eindhoven University of Technology, Department of the Built Environment, Building Lighting, Eindhoven, the Netherlands

^b Philips, Department of Human Interactions & Experiences, Eindhoven, the Netherlands

^c Utrecht University of Applied Sciences, Research Group Technology for Healthcare Innovations, Utrecht, the Netherlands

A B S T R A C T

Background: In in-patient care facilities, 1 in 5 medication doses is administered incorrectly. A hospital environment which supports the performance of the health-care staff will positively impact patient safety.

Objectives: Determine which lighting leads to the least reading mistakes of medication labels.

Design: Experimental study with repeated measures.

Setting: Study was performed under controlled conditions in the Netherlands.

Participants: In total the data of 37 participants are analyzed and described. Inclusion criteria were: female, aged between either 18–30 years old ($M = 26.0$, $SD = 3.1$) or between 55 and 67 years old ($M = 57.9$, $SD = 2.7$) years old, with normal vision. Eligible participants were personally invited to participate.

Methods: Per participant, the readability of three different labels (Blister, Baxter and Orange) and four different font sizes (4.5 pt, 3.5 pt, 3.0 pt, and 2.5 pt Arial Capital) were assessed under nine different light conditions (three illuminances (E), 100lx, 500lx, and 1000lx and three correlated color temperatures (T_{cp}): 3000 K, 4000 K, and 6500 K). The participants had to read out loud text sequences of 10 letters per medication label. The numbers of errors were counted and analyzed.

Results: The results show a significant difference between numbers of errors related to: 1. Light condition, 2. Age, 3. Label material, 4. Font size. The impact of the light condition is not identical for the different types of label and the font sizes. The impact of the light conditions is the strongest for the smallest font size (2.5 pt) and participants with Visual Acuity < 1.

Conclusion: Lighting has an impact on the number of errors. Older people make more errors than younger people. The type of label has an impact on the number of errors made. The font size has an impact on number of errors made. For font sizes < 4.5 pt (Arial), reading medication labels (Blister, Baxter and Orange) under illuminance levels of 100lx, will lead to significantly more errors than $E \geq 500$ lx. The light condition that generates the least errors for the total test population, all font sizes, and all different materials was the one with an E of 1000lx and a T_{cp} of 4000 K. People with an insufficient Visual Acuity (VA) benefit most from a higher illuminance level, especially for the Orange labels. When the VA is well-adjusted (sufficient to good) and the font size is as recommended for medication labels (Arial Capital ≥ 4.5 pt) the impact of the lighting on number of errors is limited for all of the age groups.

1. Introduction

A hospital is a place where patients are being treated meaning to recover from a medical condition. Among others, medication is being used to support and accelerate the recovery process. In the process of the medication dispensing, many activities take place before the destined medication actually reaches the targeted patient; from prescribing, transcribing, order entry, preparation, administration, to dispensing the medication (Grissinger, 2012). In this process, mistakes can be made, potentially jeopardizing patient safety. In in-patient settings, an estimate of 1 in 5 medication doses is administered incorrectly (Keers et al., 2013).

Errors can be either failures related to human functioning, cognition and memory, or failures related to the given work condition and process. Together with task interruptions the main reason for errors related to medication are the common use of handwriting which can be unclear or illegible (Biron et al., 2009; J. H. Jones and Treiber, 2010). Jones (J. Jones, 2014) also indicates that the combination of small print, poorly lit environments and increasing age of nurses results in higher risk of errors. Age of the medical staff impacts errors; older medical staff is mostly experienced and therefore make fewer errors while on the other hand aging has a negative effect on physical and cognitive conditions, resulting in more errors (Fasolino and Snyder, 2012; Smither and Braun, 1994; Stichler, 2013). The physical work environment may

* Corresponding author. Building Lighting group, Department of the Built Environment, VRT. 6.11, PO Box 513, 5600, MB, Eindhoven University of Technology, Eindhoven, the Netherlands.

E-mail address: m.p.j.aarts@tue.nl (M.P.J. Aarts).

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positively or negatively influence nurses' stress and is sometimes not acknowledged as such by nurses (Applebaum et al., 2010) but also not by hospitals designers. For example, the duties of night shift nurses have to be performed under difficult conditions (silently, and under dim lighting conditions) when fatigue threatens the ability to make the right decisions and to ensure qualified care (Nilsson et al., 2008). Another example is the impact sound and noise distraction can have on the performance of especially more complex tasks (Reinten et al., 2017).

In current hospitals part of the activities related to medication handling is taken over by technology. Medication dispensing is typically a manual task. It has a large visual component, but it also requires concentration and distraction can lead to errors (Mayo and Duncan, 2004). Lighting is known for impacting both the visual performance as the non-visual performance (Kretschmer et al., 2012; Smolders et al., 2012).

The parameters visual size, contrast and color difference, retinal image quality and retinal illuminance interact with each other and together determine a part of the visual performance (Boyce, 2014). Several studies have researched these interactions but none was directly related to the specific application of medication labels. The visual performance is impacted by the contrast (Rea, 1981), letter size (Eklund et al., 2001) and therefore also related to the illuminance and luminance. The Relative Visual Performance (RVP) model by Rea and Ouellette (Rea and Ouellette, 1991) shows that the performance is most affected when the luminance and/or contrast is near the threshold. Studies regarding the color impression of the white light expressed in correlated color temperature (T_{cp}) are inconclusive whether it has an impact on the visual performance. Explanatory, a low T_{cp} indicates a warm, more reddish color impression, while a high T_{cp} represents a cooler, more bluish color impression. Berman and colleagues (Berman et al., 2006) found a better visual performance with a higher T_{cp} than with a lower, among schoolchildren. Another study (Boyce et al., 2003) found no improvement in performance among both younger and older people. Aarts et al. (Aarts et al., 2009) also found no significant increase in visual acuity when increasing the T_{cp} from 2700 K up to 12.000 K with illuminances of 500lx under normal working force (age between 20 and 65 years old). Regarding age, a literature review (Nylén et al., 2014) on vision, light and aging concluded that only few studies are available on this topic but that the visual conditions and lighting design have an impact on work performance of those over the age of 65. This is related to several aging processes (Mellerio, 1987). More light when ageing is recommended (Boyce, 2014).

In this paper, a study on the impact of lighting on the visual performance of nursing staff related to the process of medication handling will be described, focusing on the impact of the light condition on the readability of commonly used medication labels. The results will contribute to the development of the optimal lighting environment in hospitals with a focus on medication rooms.

This study aims at answering the question: Which light condition generates the least reading mistakes of medication labels?

For this, the following sub-questions have been defined:

Is there a difference in number of reading errors under different light conditions related to

- Age group?
- Material of the label?
- Font size?

2. Methodology

In this paragraph the set-up of the experiment is described. An overview and results of the methods to decide on the experimental set-up of this study is illustrated in Fig. 1.

2.1. Define issue

First, an observational study was performed focusing on the medication selection task in hospitals. This study was performed in two non-academic Dutch hospitals. In both hospitals, one nurse was shadowed during the process of medication selection to get a better understanding of the medication process. In this process, the medication is being prepared per patient per ward. Each ward has its own medication room where the most frequently used medication for that ward is stored. More specific medication is supplied by the hospital pharmacy. The nurse picks and collects the medication per patient for that specific day and stores this in a box, per distribution time. The shadowing-study concluded that various reading tasks take place in the process of medication selection, from reading text on a computer screen, reading labels stored in the ward, to reading handwritten text on medication labels. Many different medication labels are used from printed on the medication boxes, strips (Blister), and sachets (Baxter) to handwritten on colored labels (Yellow or Orange colored labels). The medication selection task exists both of inspecting but also calculating doses of medicines a patient needs. Besides the observational study, a visual performance test was conducted among nurses in hospital medication room under actual light conditions, which showed that the lighting conditions have a relevant impact on visual performance (Aarts et al., 2017). Light measurements and a survey was conducted which confirmed that nurses are not always aware of the lighting conditions and how they can influence it themselves (Aarts and Kort, 2017).

2.2. Determine the experimental set-up

2.2.1. Font size, font type and letter sequence

The EDTRS chart (Early Treatment Diabetic Retinopathy Study) is based on the design principles of the Bailey and Lovie Chart (Bailey and Lovie, 1976). The letters used in this EDTRS chart are the Sloan letters (S, K, H, N, O, C, D, V, R, Z), which show similarities to the Snellen chart but provide more accurate results (Shamir et al., 2016). Mathew and colleagues (Mathew et al., 2011) concluded that the different letters in the test show similar legibility, although some letters are more difficult than others, for example the letter C is more likely to be misread than the letter Z. This indicates that the difficulty of recognizing the different letters varies. To eliminate the impact of diverse difficulties, the text sequence in the experiment will contain every Sloan letter once, resulting in ten letters per text sequence. Since ten letters in a row could be pronounced in one breath. Additionally, the ten Sloan-letters were randomized for each text sequence. Sequences spelling out words or common acronyms were omitted. The non-serif font Arial Capital was used for the text sequences (Bailey and Lovie-Kitchin, 2013). The font size was based on the ETDRS chart, where the font sizes were given at the decimal equivalent values (minutes) of 0.5 (1.13 mm, 4.5 pt Arial), 0.63 (.9 mm, 3.5 pt Arial), 0.8 (0.76 mm, 3 pt Arial) and 1.00 (0.63 mm, 2.5 mm). The recommended font size for medication labels is minimum 8 pt (The European Commission, 2009), so larger than used in the test. The reading distance was set to 40 cm. This distance is the same as for the ETDRS chart. A head rest was used to ensure the same constant distance of the participant's eyes to the labels.

2.2.2. Materials for medication labels

Three typical materials for labels were used for the experiment. Throughout the experiment these label materials will be referred to as "Orange", "Blister" and "Baxter". It was not possible to print our own text (size and letter type) on original labels. Therefore, we mimicked the original ones. See Fig. 2. The luminance contrast calculated by the formula $(L_{\text{background}} - L_{\text{print}} / L_{\text{background}})$ between the material and the print in the experiment is for Blister > 0.96, Baxter > 0.95 and Orange > 0.92.

Identical text sequences were used to perform a direct comparison between the text sequences of each light condition independent of the

Fig. 1. Decision scheme to define the experimental set-up.

order of the characters in the text sequence. Repeating text sequences increase the chance that participants remember the text sequences later in the experiment. Therefore, also unique text sequences were added.

The four different font sizes, a repeating and unique text sequence for each font size (except font size 1.13 mm) and three materials, results in a total of 21 labels, bound in a booklet. Six different booklets were made for the experiment so each booklet was used at most twice. One booklet was used for the dummy test and the other five for the nine different light conditions. Each booklet consisted of 21 pages which

contained one label with a printed text sequence. Twelve pages contained an identical label (same text, font size and material) and eleven a unique label. To eliminate a potential order effect, the 21 labels were randomized by using a script in the data processing and analysis tool MATLAB, which resulted in a variance in order of materials, font sizes and text sequences in every booklet.

To ensure that fatigue from the test would not impact the results, the experiment was run with two participants under the same light condition. It showed no change in visual performance for the test

Fig. 2. Illustration of the experimental set-up.

duration of 60 min containing 10 booklets of each 21 different labels. In the experiment, the possible impact of fatigue was monitored by asking participants to score their sleepiness after each light condition according to the method from (Kaida et al., 2006).

2.3. Experimental design and procedure

This lab experiment focusses on the visual performance involving the printed medication labels. It therefore eliminates the potential influence of light coming from the computer screen. Handwritten labels are also excluded from this study as handwriting is not standardized.

Since the initial focus is on the visual performance, a methodology has been designed that simulates only the visual performance task. This is done by eliminating the cognitive and motor tasks such as the memory and calculation components of the medication selection task. Instead, participants are asked to read out loud not-logical, random offered text sequences printed on medication labels under different light conditions.

2.3.1. Experimental box

The experiment was performed in front of an experimental box ($0.8 \times 1.2 \times 0.8$ m) placed on a table. The box contains a luminaire (Philips Smartbalance tunable white, RC484B LED78S/TWH PSD W60L60 VPC PIP), an illuminance photospectrometer (Konica Minolta CL-500A), a sound level meter (Tenma Sound level meter) and a temperature and relative humidity logger (Rotronic) to monitor the indoor climate, a webcam to observe the participant during the experiment and a microphone to record the results. The luminaire is connected to a laptop from which the lighting is controlled via a DALI system (using program Digidim by Helvar). The experimental set-up is depicted in Fig. 2.

2.3.2. Light condition

For each participant, the number of errors under nine different light conditions was recorded (see Fig. 2). These nine light conditions are chosen based on recommendations and measurements in real hospital environments (Aarts et al., 2017). Measurements in a medication room showed a minimum horizontal illuminance of 195 lx and approximately 3000 K at the desk where the medication selection task is performed (Aarts and Kort, 2017). Since the staff blocks part of the light with their body when the medication is prepared, this value was even lower (< 100 lx). The lighting standard, NEN 12464-1 (NEN, 2011), recommends a task illuminance of 500 lx. An additional higher illuminance level is chosen to assess whether the visual performance improves over the recommended 500 lx.

The correlated color temperatures are also based on measurements in hospitals, with commonly used T_{cp} 's being 3000 K and 4000 K. Literature indicates that a higher T_{cp} may increase the visual performance especially at low illuminance levels (Aarts et al., 2009). Therefore, also a T_{cp} of 6500 K was included in the experiment.

The order of light conditions was randomized by the use of a Matlab script, to prevent any impact on the results.

During testing, continuous measurements were conducted to maintain the same light condition for each participant. The deviation of illuminance and T_{cp} from the initial values was less than 2%.

2.3.3. Participants

In literature no gender-related difference in visual performance was found, although a recent study (Chellappa et al., 2017) concluded that sex differences in light sensitivity and brightness perception exist. Specifically, the study stated that blue-enriched light induces a faster reaction time in men than in women. Because of that and since the majority of nurses in hospitals are women, it was decided to exclude male participants. People were asked to participate by via an e-mail invitation sent to all employees of our department, and by using personal (social media) networks. A total of 40 women participated on

voluntary basis without any financial compensation.

Assuming that medical staff working in hospitals have normal vision, this aspect was one of the inclusion criteria. If the participant had insufficient vision in accordance with the ETDRS-test (Visual Acuity (VA) < 1 or LogMAR > 0), glasses were provided to be used during the experiment. The visual acuity was determined for each participant with (additional) glasses or lenses. Participants with a VA < 0.63 (or LogMAR > 0.2) including corrective lenses, were excluded from the study. The VA (with additional glasses or lenses) of the older, included participants was: six participants had a VA < 1 , nine a VA = 1, and three VA > 1 . For the younger participants: one had a VA < 1 , four had a VA = 1, and 14 VA > 1 .

Older people benefit from more light and since the retirement age will increase further, the experiment was conducted distinguishing between two age groups; a younger (20–32 years old) and an older (54–66 years old). Each group consisted of 20 participants.

When testing for outliers, the data of three participants were excluded from analyses. A data point was considered an outlier when it varied for more than $3 \times$ the boxplot length. In total 18 older participants were included ($M_{age} = 57.9$ YO, $SD = 2.7$) and 19 younger participants ($M_{age} = 26.0$ YO, $SD = 3.1$) to analyze their data.

2.3.4. Test procedure

The total experiment took 60–90 min per participant and consisted of ten sessions in which a booklet with 21 labels consisting of 10 letters each, were read out loud. The reading errors were scored by the experimenter simultaneously. The sessions were also recorded to validate the scoring of the recorded errors afterwards. In-between these ten sessions, participants were asked to fill out a survey enquiring about their sleepiness and satisfaction with the current light condition.

Before starting the experiment, a short explanation about the procedure was given by the researcher and the signed informed consent form was collected. After that, the visual acuity test was performed to determine the VA of the participant. The experiment started with a 'dummy' test to allow participants to get accustomed to the experiment. After the dummy test, the lighting was changed and the real testing started. Every time a booklet was completed, the lighting setting was changed allowing the participant to adapt to the new light condition. During this adaptation time, participants had to complete a survey. This procedure was repeated nine times. The experiment ended with a final survey that also asked feedback on the test-procedure itself.

2.3.5. Surveys

A total of three different surveys were filled out by the participants. The first one was to identify the demographics of the participants, their opinion on the current indoor climate, and their self-rated sleepiness in accordance with the Karolinska Sleepiness Scale, KSS (Kaida et al., 2006). The second survey was filled out between each of the ten sessions and addressed visual inconveniences, a subjective lighting rating part of the Office Lighting Survey (Eklund and Boyce, 1996), and the KSS. The third and final one was similar to the previous survey, but additionally enquired participants if they experienced readability difficulties for the different labels and which of the three labels had their preference. For completeness, their opinion on the indoor climate was assessed again. The procedure of the surveys is illustrated in Fig. 3.

2.4. Outcome measure and errors scoring

A study by (Eklund et al., 2000) showed an experiment which measured errors and time, which were combined afterwards into one measure for visual performance. Since there is a large variance in pronunciation duration of text between the different participants and the extremely short length of each label to pronounce (< 5 s), in this experiment, only the number of errors is taken as a measure for the visual performance.

To determine the number of errors, a control sheet was designed.

Fig. 3. Illustration of the different surveys used in this experiment.

This control sheet contains all text sequences the participant has to pronounce. As the participant is pronouncing the text sequences, the researcher will read the text sequence on the control sheet simultaneously. When the participant reads a letter incorrectly, the experimenter will mark this letter on his control sheet marked with a number between 1 and 5 indicating the type of mistake. The numbers 1 to 5 refer to the following occurrences:

1. A letter was skipped by the participant;
2. An incorrect letter is pronounced by the participant;
3. The participant swaps two adjacent letters;
4. No letter is read by the participant as she indicates not to be able to read this letter;
5. A combination of the above.

This will be done for the entire experiment. The experiment is audio recorded and used to check for errors afterwards.

2.5. Data analyses

All the data was documented in Microsoft Excel. The data is organized in such a way that the letter read wrongly plus the type of error is noted down for all labels per participant. The data from the surveys are documented in the same file.

Statistical analyses were conducted with use of the software program IBM SPSS statistics 25.

The experiment consists of 108 within-subject factors (nine light conditions, three materials and four different font sizes) and one between-subject factors (age). The intended statistical analysis was a Mixed-ANOVA, but had to be rejected due to non-normality and the variance in sample sizes. The count was based on the number of errors per material and light condition.

Therefore, non-parametric tests were applied. For more than two independent variables, the Friedman Anova's tests are used. For post-hoc testing, Wilcoxon signed-rank test are used for pairwise comparison. In the rare cases the data was normally distributed, paired samples t-tests were used. For testing the independent variables, the Kruskal-Wallis test is used. A p-value < .05 is significant for the two-tailed tests.

Statistical tests performed per hypothesis:

- A. Light condition: Friedman Anova's test. Post-hoc testing with Wilcoxon signed-rank;
- B. Age: Kruskal-Wallis-test;
- C. Material: Friedman Anova's test. Post-hoc testing with Wilcoxon signed-rank;
- D. Font size: Friedman Anova's test. Post-hoc testing with Wilcoxon signed-rank.

Hypotheses tested are:

A. Light condition

H_0 : There is no effect of light condition on number of errors made.

H_1 : There is an effect of light condition on number of errors made.

B. Age

H_0 : Older people and younger people make the same number of errors.

H_1 : Older people and younger people make not the same number of errors.

C. Material

H_0 : There is no effect of material on number of errors made.

H_1 : There is an effect of material on number of errors made.

D. Font size

H_0 : There is no effect of font size on number of errors made.

H_1 : There is an effect of font size on number of errors made.

3. Results

This section presents the results of the study. First the variable 'light condition' is discussed, then age, material, and font-size.

Per participant, maximal 1890 errors could be made. The results are presented as percentage of the maximum number of errors possible, under that specific condition or situation. For example the maximal errors per participant per light condition was 210 (1890/9). For the statistical analyses, the numerical counted errors were used.

3.1. Results per light condition.; the mean percentage of errors per light condition

Table 1 shows the mean percentage of errors per light condition. The least errors ($M = 4.2\%$) were made for condition 8 ($E = 1000lx$, $T_{cp} = 4000K$), and more than twice as many ($M = 9.6\%$) for condition 1 ($E = 100lx$, and $T_{cp} = 3000K$).

Performing the same tests for the three different correlated color temperatures as done for the three illuminance values shows no significant difference in errors for the total test population.

3.2. Age

An overview of the total number of errors per participant per used material ranked per age is depicted in Fig. 4. The mean percentage of errors made by the younger population is lower ($M = 2.1\%$, $SD = 5.9\%$) than the number of errors by the older population ($M = 11.0\%$, $SD = 11.5\%$) see Table 1. The difference in errors between both age groups is significant, $H(1) = 19.434$, $p < .001$.

For the older population the difference in errors of the accumulated data show a significance for the same light conditions as for the total test population (see Table 2). For the younger population there was only a significant difference between light condition 3 ($Mdn = 1.00$) and 6 ($Mdn = 0.00$): $z = -1.970$, $p = .049$, $r = 0.32$). When analyzing the results of both age groups separately for the three different

Table 1

Mean percentage of errors per light condition (bold is most, underlined is least within that specific category).

		Mean percentage of errors, M(SD)									
light condition		All light conditions	1, 100lx & 3000K	2, 100lx & 4000K	3, 100lx & 6500K	4, 500lx & 3000K	5, 500lx & 4000K	6, 500lx & 6500K	7, 1 klx & 3000K	8, 1 klx & 4000K	9, 1 klx & 6500K
All, n = 37		6.4(9.5)	9.6	9.2	8.8	5.6	5.5	5.3	5.1	<u>4.2</u>	4.6
Age	Younger, n = 19	2.1(5.9)	3.2	2.3	2.6	1.9	2.3	1.7	2.0	1.7	<u>1.5</u>
	Older, n = 18	11.0(10.5)	16.3	16.4	15.3	9.6	8.9	9.1	8.5	<u>6.9</u>	7.9
Visual Acuity	VA < 1 n = 7	24.2(6.8)	33.8	31.8	30.5	22.7	22.5	20.8	21.0	<u>16.4</u>	18.0
	VA = 1 n = 13	3.9(2.7)	7.0	7.1	6.8	2.9	2.2	2.4	<u>2.0</u>	2.1	2.3
	VA > 1 n = 17	1.1(0.5)	1.5	1.5	1.4	<u>0.7</u>	1.0	1.1	1.0	0.8	0.9
Material	Blister	5.3(8.5)	7.2	7.6	6.4	5.2	5.1	4.6	4.2	4.0	<u>3.9</u>
	Baxter	6.4(9.7)	10.0	9.6	8.8	5.5	5.0	5.2	5.6	<u>3.3</u>	4.4
	Orange	7.6(10.5)	11.5	10.3	11.2	6.3	6.4	6.0	5.6	<u>5.3</u>	5.6
Font size	4.5 pt	0.4(1.3)	0.5	0.6	0.5	0.4	0.5	0.4	<u>0.2</u>	0.3	0.5
	3.5 pt	1.4(3.2)	1.1	1.6	1.9	<u>0.7</u>	1.4	1.1	1.1	2.0	1.7
	3 pt	3.1(8.3)	6.6	4.5	4.1	2.1	2.8	1.9	2.5	2.3	<u>1.4</u>
	2.5 pt	16.6(26.7)	24.1	22.7	24.2	15.5	14.2	13.9	12.3	<u>10.7</u>	12.1
Mean subjective scores from the surveys after each light condition M(SD)											
KSS			3.7(1.3)	3.7(1.3)	3.7(1.1)	3.6(1.1)	3.7(1.1)	3.7(0.8)	3.7(1.0)	3.6(1.2)	3.6(1.0)
1 = extremely alert 9 = very sleepy											
Contentment			3.4(1.8)	3.0(1.5)	<u>2.8(1.2)</u>	4.2(1.3)	4.3(1.5)	3.6(1.4)	4.3(1.4)	4.6(1.2)	4.6(1.3)
1 = very in content 7 = very content											
Amount of light			2.4(1.1)	2.3(0.9)	2.7(1.4)	3.6(1.1)	3.9(1.1)	3.5(1.2)	3.8(1.2)	4.6(1.1)	4.3(0.9)
1 = much too dim 7 = much too bright											
Color of the light			5.0(1.2)	4.0(1.2)	3.3(1.0)	4.9(1.0)	3.9(1.0)	3.3(1.1)	4.6(1.0)	4.1(1.2)	3.4(1.0)
1 = much too cold 7 = much too warm											

The difference in number of errors between the participants is large meaning that many participants made in total less than 1% errors and others more than 25% errors resulting in a non-normal distribution of the results. The light conditions have a significant effect on the number of errors ($\chi^2(8) = 48.94$, $p < .001$). Results of the post-hoc tests. Table 2, show the effect size and whether difference is significant.

illuminances, significance is only found between 100lx and 500lx for the older participants ($\chi^2(2) = 25.44$, $p < .001$) but not for the younger group. The three different correlated color temperatures show no significant differences, neither for the older population nor for the younger.

When analyzing, noticed was that a few younger participants showed a large number of errors, seemingly related to the VA under which they performed the test. To analyze the impact of the visual

acuity on the number of errors per light condition, three categories were distinguished: the insufficient (VA < 1, 7 participants), the sufficient (VA = 1, 13 participants) and the good (VA > 1, 17 participants). The analyses show that the total number of errors is significantly impacted by the VA, $H(2) = 24.49$, $p < .001$. The pairwise comparisons with adjusted p-values showed that there was a significant difference between all three VA groups. VA = 1 and VA < 1 ($p = .050$, $r = 0.54$). This is similar for the pairwise comparison between VA > 1 and VA = 1

Fig. 4. Total number of errors per participant ordered by the age of the participant.

Table 2

Effect size based (absolute values) on the Wilcoxon's rank test for the nine different light conditions (* = significant).

light condition	1, 100lx & 3000K	2, 100lx & 4000K	3, 100lx & 6500K	4, 500lx & 3000K	5, 500lx & 4000K	6, 500lx & 6500K	7, 1 klx & 3000K	8, 1 klx & 4000K	9, 1 klx & 6500K
1, 100lx & 3000K		0.00	0.13	0.42*	0.35*	0.44*	0.35*	0.44*	0.34*
2, 100lx & 4000K			0.08	0.43*	0.32*	0.46*	0.40*	0.46*	0.41*
3, 100lx & 6500K				0.42*	0.38*	0.51*	0.42*	0.47*	0.41*
4, 500lx & 3000K					0.02	0.05	0.12	0.20	0.18
5, 500lx & 4000K						0.03	0.07	0.24*	0.15
6, 500lx & 6500K							0.00	0.20	0.06
7, 1 klx & 3000K								0.19	0.12
8, 1 klx & 4000K									0.08

When analyzing the cumulated data of the three different illuminance values there is a significant difference, $\chi^2(2) = 16.76$, $p < .001$. The differences in number of errors between 500lx (4.7%) vs 100lx (9.2%) ($p = .003$, $r = 0.54$) and 1000lx (5.5%) vs 100lx ($p = .001$, $r = 0.57$) are significant. The difference between 500lx and 1000lx is not significant.

($p = .015$, $r = 0.51$). A very large effect is found between the participants with a good VA and an insufficient VA ($p = 0.000$, $r = 0.98$).

Table 1 and Fig. 5 provides the total number of errors per VA-group per light condition for all materials and font sizes.

Although the number of participants with a VA < 1 is rather low, a statistical analysis has been performed on the number of errors per light condition. Since the data were normally distributed, paired samples t-tests were performed for the nine different light conditions. The t-tests show a significant difference for the same lighting condition as for the cumulated data. The only addition is that the number of errors under light condition 4 ($M_4 = 47.57$, $SE = 5.09$) is significantly higher than under condition 8 ($M_8 = 37.86$, $SE = 3.05$) for the participants with a VA < 1 ($t(6) = 2.8$, $p = .03$, $r = 0.727$). For all significantly different paired light conditions the effect size is very large ($0.69 < r < 0.91$). When performing the same test for the participants with a VA = 1, the errors made under the light conditions with an illuminance of 100lx (1,2 and 3) and the rest (4,5,6,7,8 and 9) are also significantly higher. For the group with good vision (VA > 1) only the number of errors made under condition 4 is significantly lower than under condition 1 ($z = -2.87$, $p = .04$, $r = -0.50$).

3.3. Material

Subjectively, the 37 participants ranked the Blister material as most preferred (82% first rank) Baxter as second (16% first rank) and the Orange labels as least preferred (3% first rank). This ranking also

corresponds to the number of errors over the cumulated data: fewest for Blister, next for Baxter and most for Orange labels (see Table 1). The results show that there is a significant difference between the number of errors between the three materials, $\chi^2(2) = 22.22$, $p < .001$. This is similar for the pairwise comparison between Orange vs Baxter ($p = .032$, $r = 0.42$) and Orange vs Blister ($p < .001$, $r = 0.75$). The difference in number of errors between Baxter and Blister is not significant ($p = .126$, $r = 0.33$). When testing this for the older and younger group separately, the difference in errors is only significant between the Blister and Orange label, for both each groups.

The mean number of errors per light condition for the materials is shown in Table 1. No distinction is made between the different font sizes. The fewest errors for all three labels are made under the high E (1000lx) condition and the largest number of errors is made under the low E (100lx). Per material the number of errors is impacted by the T_{cp} . For Blister and Orange most errors are made under condition 1 and least under condition 8. For Baxter, condition 2 generates most errors and condition 9 the least. When performing pairwise comparisons between the different light conditions per material several light conditions show significant differences but the largest effect size is found for Baxter between condition 1 and 6 ($p < .001$, $r = 0.42$), for Blister between condition 4 and 9 ($p < .001$, $r = 0.42$) and for Orange between 1 and 8 ($p < .001$, $r = 0.49$).

When comparing the number of errors per material for different VA's, the impact of the light condition for the participants with a good VA for the total number of errors is relatively low. For participants with a sufficient VA, performance is much better under the light condition with a horizontal illuminance of 500lx and 1000lx than 100lx. Participants with a VA < 1 make on average the least errors for the Blister material under light condition 9 (1000lx and 6500 K) while for the Orange and Baxter the least errors occur under condition 8 (1000lx and 4000 K). Based on the statistical analyses by pairwise comparison, the difference in errors between the light conditions (VA < 1, Material is Baxter) is not significant between 1 and 8 (largest difference of errors, lde), but is significant for 2 and 9 ($z = -2.23$, $p = .026$), 3 and 8 ($z = -2.00$, $p = .046$), and between 4 and 9 ($z = -2.37$, $p = .018$). For Blister, only 4 and 9 show a significant difference in number of errors ($z = -2.37$, $p = .018$). For the Orange labels, 14 compared light conditions show significant different number of errors between 1 and 8 (lde, see Table 1).

When performing the same analyses for participants with a VA = 1, for Baxter, 11 compared light conditions show significant difference but not 1 and 8 (lde). Blister, 10 compared light conditions show a

Fig. 5. Mean percentage of errors per light condition per VA-group.

significant difference, of which 2 and 7 (Ide) and for Orange 14 of which 3 and 7 (Ide). For participants with a good VA (> 1), Baxter show significant differences in errors between five light conditions, including 2 and 6 (Ide), Blister between three, including 2 and 8 (Ide), and Orange between five, including 1 and 4 (Ide) and 1 and 8 (Ide).

3.4. Font size

Four different font-sizes are used to identify the impact of the light condition on the number of errors related to the font size (see Table 1). The analyses over the cumulated data show a significant difference in number of errors between the font sizes, $\chi^2(3) = 52.29$, $p < .001$. The pairwise comparison with adjusted p-values shows that the differences are only significant between the smallest font size, 2.5 pt, and all other three font sizes, $p < .001$, $r > 0.6$. The statistical analyses, show that for the 4.5 pt Arial, the light condition has no impact on the number of errors, $\chi^2(8) = 3.90$, $p = .87$. Also the errors with font sizes 3.5 pt ($\chi^2(8) = 10.03$, $p = .26$) and 3.0 pt ($\chi^2(8) = 12.7$, $p = .123$) are not significantly influenced by the light condition. The lighting has only an impact on the number of errors for the smallest font size, 2.5 pt ($\chi^2(8) = 71.00$, $p < .001$). When performing pairwise comparison of the cumulated data, excluding the labels with font size 2.5 pt, non-parametric tests show that only the number of errors under light conditions 1 and 2, 1 and 8, 2 and 4, 2 and 7, 4 and 8, and 7 and 8 are significantly different.

3.5. Surveys

Between the nine different light conditions, the subjective alertness was assessed by using the KSS. The average scores of the subjective alertness after each session were between 3 (=Alert) and 4 (Rather Alert) (see Table 1). The results show no significant differences between the scores at the beginning of the experiment and the end of the experiment. The alertness was also not different between the nine light conditions.

The contentment results show that participants were most content with light condition 8 (score 4.7) and least with light condition 3 (score 2.9).

4. Discussion

The study is conducted to examine the impact of light condition on the readability of medication labels, since such errors put patients at risk. In this study the number of reading errors in relation to light conditions and medication-label material, age and font size is tested under controlled conditions.

The first hypothesis, A, was that the light condition has an impact on the number of errors. The results show that there were significant differences between the numbers of errors made under the different light conditions. The light condition with the fewest errors (cond. 8) and the most errors (cond. 1) differs more than a factor two (4.2% vs 9.6%) Therefore the H_0 should be rejected. Based on the pairwise comparison between the different light conditions, the number of errors made under the three conditions with $E = 100\text{lx}$ are all significantly higher than the number of errors made under 500 and 1000lx. These results align with an earlier study (Buchanan et al., 1991) which concluded that the number of description-dispensing errors in an out-patient pharmacy were significantly lower under 1570lx than under 480lx. In our study, no significant difference was found between 500 lx and 1000lx for the accumulated data of all participants. This could imply that the 1000lx is too low. In the recommendations from an ergonomic perspective (Konz, 1998, 2000) the illuminance for a critical task with very low contrast and letter size is 1500 lx for younger people (< 40 years old) and 2000 lx for older people (> 55 years old). Since the participants with a good VA hardly made any reading mistakes, and the difference in errors between 500 lx and 1000lx was not significant,

the requirement of 1500 lx or 2000 lx task lighting is questionable. The Correlated Color Temperature T_{cp} shows no significant impact on the number of errors. Other studies relating the T_{cp} to the visual performance found inconclusive results although the range of illuminance in these studies were between 200 and 500lx (Aarts et al., 2009; Berman et al., 2006; Boyce et al., 2003; Hawes et al., 2012). This study confirms the conclusions of three out of these studies. An explanation why some studies do find a better visual performance under high T_{cp} is that stimuli that are rich in short wavelengths (e.g. expressed by a high T_{cp}) results in smaller pupil sizes, which produces a better quality retinal image (Boyce, 2014).

The second hypothesis, B, was that there is a significant difference between the number of errors made by the younger participants and the older participants. The results show that the older participants make significantly more errors than the younger participants, so the H_0 of B is rejected. When distinguishing between age, the older participants make the least errors under condition 8 (6.9%) and almost 2.5 times more under condition 2 (16.3%). All three conditions with $E = 100\text{lx}$ result in significantly more errors than all the other light conditions. Under light condition 8 (1000lx and 4000 K), older participants also performed significantly better than under condition 5 (500lx and 4000 K). For the younger population the number of errors is very low, although the difference between the average maximum number of errors (condition 1) and the minimum numbers of errors (conditions 9) is still more than a factor two (3.2% vs 1.5%). The statistical test only results in a significant difference in errors between condition 3 (100lx and 6500 K) and 6 (500lx and 6500 K). It is known that when age increases, human vision decreases due to several factors.

Since Visual Acuity might explain the number of errors between the younger and the older participants, three sub-groups were defined, based on the Visual Acuity tested with visual aid devices. The results show that there is a significant difference in number of errors between the three VA-groups. A very large effect size ($r = 0.98$) is found between the participants with a VA < 1 (insufficient) and a VA > 1 (good). The results of the analyses for the different VA-groups per light condition show that the same conditions show significance as for the results of the data of all 37 participants for the ones with a VA < 1 and VA = 1. The only exception is that light condition 5 and 8 are not significantly different for the participants with a VA = 1. For the participants with good vision, VA > 1 , the number of errors are significantly higher under condition 1 than under 4.

The difference in absolute number of errors per light condition is most for the participants having an insufficient VA (< 1). This group has on average the lowest number of errors under light condition 8 (1000lx and 4000 K, 18.0%), compared to condition 1 (100lx and 3000 K, 33.8%). For the participants with a VA = 1, the relative difference is with a factor three the largest. In absolute values, the lighting condition has the least impact on participants with a good VA (> 1), maximum errors 1.5%. Taken this into consideration, the VA seems to have an even bigger impact than age (max. difference is 9.5%). One may hypothesize that the difference in number of errors between age groups is explained by the VA. Unfortunately, this could not be tested since the data distribution did not allow for a multiple regression analyses.

The analyses on the different labels show that there is a significant difference in number of errors between the Orange labels and both the Blister and the Baxter label. Therefore, the 0-hypothesis of C should be rejected. When identifying whether these differences are related to age, the same difference is found significant for both younger and older, namely between Orange and Blister. Also when comparing the differences per VA-group per material, most significantly different numbers of errors are found for the Orange labels, and least for the Blister, independently of the VA-group. The explanation for this difference is most likely related to the contrast between the black print and the Orange background which is lower (0.92) than the other two materials (0.95 and 0.96). Rea (1981) concluded that the reading performance is

related to the task contrast. Other parameters like ink specularly and viewing angle have the least impact when the contrast is higher than 0.2, as in our study.

When testing the final hypothesis, whether font-size has an impact on the number of errors, again the H_0 hypothesis should be rejected. The number of errors for the smallest font size, 2.5 pt are significantly higher than that under the other font sizes. The light condition has only an impact for the smallest font sizes. When testing the different light conditions for all font sizes except the smallest, only seven conditions remain significant. A study on the task performance in relation to font size, illuminance, and contrast (Eklund et al., 2001) showed an increase in mean work speed for increasing character size and illuminance level. Furthermore, character size highly affects the mean work speed, where the illuminance level increases the work speed up to a certain level; where any further increase in the illuminance will not show much improvement at a certain level. Although the illuminance levels and the font sizes were different (> 6 pt) and speed was not an outcome measure, the results of our study show the same trend. Therefore the lighting condition has little impact on the number of errors when the conditions are 'normal' (high contrast, $pt > 6$ pt, and $VA \geq 1$) but it could impact the working speed.

4.1. Limitations

The tests were performed in a glare-free environment. In reality, this might not be the case, and therefore impact the readability of labels negatively. In addition, the print on the labels had a constant quality. Especially prints on the plastic Baxter material do not always give the same high quality of printing as used in the test. The specular reflectance of the sachets might impact the readability but this aspect was not tested. Normally, the text on the Orange labels is manually written. The individual handwriting impacts the readability as well but was for methodological reasons not subject of this study. Therefore, the number of errors of Baxter and the Orange labels are expected to be more under real conditions than reported in this paper. Since the test was set-up as a within subjects experiment, using only the number of errors as an outcome measure is justified. In a follow-up study, the time to complete each test under the different light conditions might most likely bring more nuance to the results.

In the set-up, only nine conditions are selected. Although for all cumulated data, 100lx generates most errors, and 1000lx the least, one optimum illuminance cannot be defined.

The test-set-up was such that it simulated on average the time it takes for nurses to typically sort out the medication per medication room (~ 45 min). The KSS-data show that the self-reported alertness did not change significantly over the test period nor after each individual light condition. This is in line with the initial aim of this study, namely to find the optimum light condition for visual performance. In a follow-up study, the impact of the lighting on the non-visual performance can be addressed. No multiple regression analyses could be executed to examine the impact of one parameters in relation to another on errors made.

5. Conclusions

Based on the hypothesis, the following conclusions can be drawn:
There is an effect of light condition on number of errors;

Older people and younger people make not the same number of errors;

There is an effect of material on number of errors made;

There is an effect of font size on number of errors made.

For font sizes < 4.5 pt (Arial), reading medication labels (Blister, Baxter and Orange) under illuminance levels of 100lx, will lead to significantly more errors than $E \geq 500$ lx. The impact of the absolute number of errors is largest for the older population. The light condition that generates the least errors for the total test population, all font sizes,

and all different materials was 1000lx and 4000 K. This was also the light condition the participants preferred the most. The light condition of 100lx and 6500 K was the least appreciated condition. People with an insufficient Visual Acuity (VA) benefit most from a higher illuminance level, especially for the Orange labels. When the VA is well-adjusted (sufficient to good) and the font size is as suggested for medication labels (Arial Capital ≥ 4.5 pt) the impact of the lighting on number of errors is limited for all of age groups. Since in reality the print quality is not always up to standard, the contrast is not always as high as used in the study, and the VA is not always good, we recommend to illuminate the task area of locations where medication sorting takes place (horizontally) and the cupboards where medication is stored (vertically) with a minimum maintained illuminance of 500lx and a correlated color temperature of 4000 K. The results show that the lighting design does not require age-related adjustments as long as the VA (including corrective lenses) is sufficient.

When people are more fatigue for example during night-shift or at the end of a shift, other light conditions might be beneficial to support total performance, not only the visual performance.

This study also demonstrates the large impact of especially font size but also the type of material. To prevent potential reading errors, using normal white, non-specular labels and a font size printing of > 4.5 pt is highly recommended. In this study the print quality was high and no handwritten labels were excluded, although this is common practice in hospitals and will most likely have an impact on the number of errors. It might be worthwhile to take this in consideration. Finally, being aware what the impact of a lower VA is on the visual performance is another point of attention and could be addressed by occupational health experts.

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