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The Impact of Lighting and Typography on Medication Prescription Reading Errors: An Experimental Study

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Abstract

Background: Medication errors, particularly those related to prescription and label reading, pose a significant challenge in healthcare, affecting patient safety and the quality of care.

Objectives: This study aimed to identify lighting conditions and typographic features (font size and type) that reduce reading errors in printed medication prescriptions and to evaluate their combined effects on error rates.

Methods: This cross-sectional study involved 30 female nurses (aged 25 - 40) and used repeated measures to assess reading errors in standardized prescriptions under controlled conditions. The independent variables included light intensity (150 lx, 500 lx), correlated color temperature (CCT: 2700 K, 4000 K, 6500 K), font types (Tahoma, Zar, Yekan), and font sizes (9 pt, 11 pt, 13 pt). A linear mixed-effects model was used to analyze the data.

Results: Light intensity significantly influenced reading errors [$F(5, 1404) = 17.39$, $P < 0.001$, $\eta^2_p = 0.058$], with 500 lx reducing errors by up to 28.2% compared to 150 lx (e.g., optimal lighting conditions: 500 lx & 6500 K vs. current conditions: 150 lx & 4000 K, as implemented in the studied hospital). Font size also had a significant effect [$F(2, 1404) = 44.65$, $P < 0.001$, $\eta^2_p = 0.060$], with 11 pt and 13 pt reducing errors by 12.5% and 15%, respectively, compared to 9 pt. The results indicated that CCT and font type had no significant impact on reading errors. Furthermore, participants preferred the 500 lx & 6500 K lighting condition for its pleasantness and perceived adequacy.

Conclusions: Higher light intensity (500 lx) and larger font sizes (≥ 11 pt) significantly enhance prescription readability, offering practical solutions to reduce medication errors. These findings underscore the need for optimized lighting and typography in healthcare settings to improve patient safety. However, because this study was limited to Persian fonts, young, healthy females, and printed medication prescriptions, further research is needed to assess generalizability across different ages, genders, writing systems, and handwritten prescriptions.

Keywords: Medication Errors, Lighting Conditions, Typography, Prescription Readability, Patient Safety

1. Background

Medication errors threaten patient safety and healthcare quality, with substantial clinical and economic consequences (1, 2). The growing complexity of medication production has exacerbated this issue (3). In the U.S., such errors contribute to 7,000 - 9,000 annual deaths, impact 7 million patients, and incur costs exceeding $40 billion, alongside significant patient harm (4). Addressing this pressing global challenge requires rigorous research into its root causes and effective mitigation strategies to enhance healthcare outcomes. A critical factor in medication errors is the poor legibility of medication labels and

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prescriptions, frequently stemming from inadequate lighting or suboptimal typography. Unreadable text increases the risk of misinterpretation, potentially leading to incorrect medication administration and severe adverse outcomes, including life-threatening consequences. Therefore, optimizing labels, prescription design, and environmental conditions is essential to enhance readability and reduce errors (5-7).

Despite progress in e-prescribing systems, handwritten and printed prescriptions remain common in healthcare settings. Healthcare professionals rely on them for medication information, highlighting the need to optimize prescription design and contextual usage factors (8, 9). Existing evidence has revealed that optimal lighting conditions, characterized by appropriate light intensity (10, 11) and correlated color temperature (CCT), which describes the color appearance of light (12-14), can improve visual performance. Additionally, research has shown that typography, including font type and size, is a key determinant of readability (15). For example, Dogusoy et al. have revealed that sans-serif fonts, such as Arial or Helvetica, are generally more readable than serif fonts (16). Also, another study showed that larger font sizes improve readability and comprehension of text compared to smaller font sizes (17, 18).

While lighting and typography independently affect visual performance, their combined impact remains underexplored, especially in healthcare. Only Aarts et al. have examined this interaction, finding that light intensity, font size, and age influence medication label errors (11). Further research is needed to assess these effects in other critical healthcare contexts, such as medication prescription writing, to mitigate reading errors and enhance patient safety.

This study aimed to address existing gaps by conducting experimental assessments of various lighting and typographical configurations to optimize printed medication prescription readability and minimize errors. The investigation systematically assessed light intensity (150 lx and 500 lx, reflecting typical and recommended hospital illuminance levels), CCT (warm, neutral, cool), font type (Tahoma, Zar, Yekan), and font size (9 pt, 11 pt, 13 pt). The selected light levels align with prior findings that 150 lx represents current Iranian hospital conditions (19), while 500 lx adheres to visual task standards (20). Typographical variables were chosen based on existing practices (Tahoma 9 pt in hospital prescriptions) and literature-supported font type legibility (21, 22).

2. Objectives

This study aimed to identify lighting conditions and typographic features (font size and type) that reduce reading errors in printed medication prescriptions and evaluate their combined effects on error rates.

3. Methods

This study was conducted at a prominent university hospital in Iran in 2022. Figure 1 illustrates the study design. The following sections outline each stage of the experimental process, including the testing procedures.

3.1. Participants

This study recruited 30 healthy female nurses (mean age: 33.35 ± 6.01 years) using a predetermined experimental protocol. The required sample size was calculated using G*Power software (v3.1.9.2), based on an assumed effect size of 0.25, an alpha level of 0.05, and a statistical power of 0.95. This calculation indicated that a minimum of 27 participants was necessary. To account for potential attrition, the sample size was increased by 10%, resulting in a final cohort of 30 individuals.

Participants were selected through availability sampling from hospital bulletin boards and virtual networks, with strict adherence to inclusion criteria: A minimum of two years of nursing experience, no physical or psychological disorders, no current medication use, and normal vision (20/20), as confirmed by the Snellen Eye Chart and Ishihara color blindness tests. To minimize the influence of fatigue and circadian disruptions, participants followed a standardized sleep schedule, going to bed between 10:00 and 11:00 p.m. and waking by 7:00 a.m. Additionally, they abstained from caffeine and alcohol for 12 hours before testing and consumed a meal 60 - 90 minutes before the experiment to reduce metabolic variability (23).

Age restrictions (25 - 40 years) were applied to control for age-related variations in ocular spectral transmittance and circadian regulation (24), aligning with the typical demographic profile of Iranian hospital nurses. Although existing literature indicates minimal gender-based differences in visual performance (25), this study exclusively enrolled female participants to

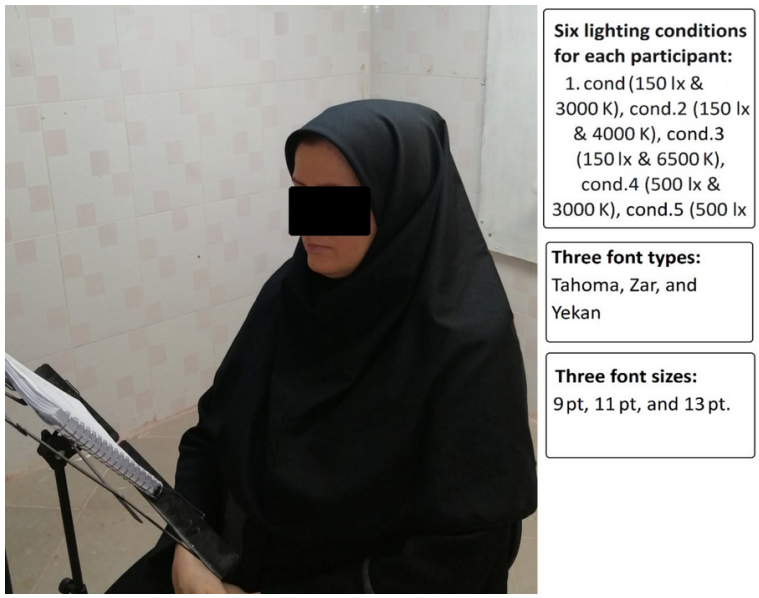

Figure 1. The overview of the experimental study design

maintain methodological consistency and reflect the predominance of women in the nursing workforce (26).

Ethical approval was obtained from the university's ethics committee, and all participants provided written informed consent without financial compensation.

3.2. Interview and Observational Study

Experienced nurses with expertise in medication practices were interviewed, and three nurses were closely observed during medication dispensing to understand prescription and dispensing practices across various hospital settings. Based on the interviews and observations, each hospital ward had a designated medication room for frequently prescribed medications, with additional medications supplied by the hospital pharmacy. In the medication room, nurses prepared individual medication boxes for each patient based on printed prescriptions. Although rare, some medications were derived from handwritten physician prescriptions; however, these prescriptions were excluded from the present study due to their non-standardized format (11). In addition to evaluating medication practices, light levels were measured in all medication rooms within the hospital. Based on the light measurements, the medication rooms exhibited a minimum horizontal illuminance of 150 lx and a CCT of approximately 4000 K.

3.3. Font Sizes and Font Types

Guided by relevant literature (21, 22), we selected six commonly used Persian fonts: Zar, Nazanin, Yekan, Lotus, Traffic, and Titr, and conducted a pilot study involving three participants. The findings revealed that Zar and Yekan exhibited the highest levels of readability. Consequently, these two fonts were chosen for further investigation alongside the Tahoma font, which was tested in 9-point, 11-point, and 13-point sizes. Notably, the 9-point Tahoma font is currently used for printed medication prescriptions in the hospital setting under study.

3.4. Generate Printed Medication Prescriptions

We developed sample printed prescriptions that mirrored real-life documents to ensure objectivity. These prescriptions maintained consistent parameters, including word counts, alphanumeric codes, syllable counts, character counts, reading lengths, text alignment, line spacing, contrast between text and background (black ink on white paper), and sheet sizes that were representative of those utilized in the hospital

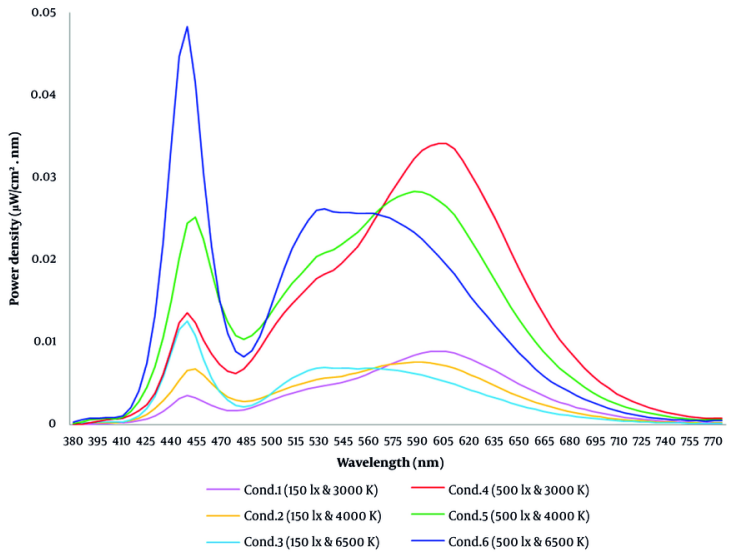

Figure 2. The spectral power distribution of white LED panels

Table 1. Technical Details and Photometric Values for Six Studied Light Conditions

Variables	Cond. 1 (150 lx and 3000 K)	Cond. 2 (150 lx and 4000 K)	Cond. 3 (150 lx and 6500 K)	Cond. 4 (500 lx and3 000 K)	Cond. 5 (500 lx and 4000 K)	Cond. 6 (500 lx and 6500 K)
Horizontal illumination level (lx)	152	153	151	511	501	499
Vertical illumination at eye level (lx)	87	88	87	326	318	317
Nominal CCT (K)	3000	4000	6500	3000	4000	6500
Actual CCT (K)	2885	4003	6270	2893	4003	6274
Color rendering Index (CRI Ra)	84.1	83.9	79.2	84.3	84	79.2
Chromaticity coordinates (x, y) 1931 CIE chromaticity coordinates	X : 0.4451; Y: 0.4063	X : 0.3795; Y: 0.3735	X : 0.3170; Y: 0.3303	X : 0.4451; Y: 0.4073	X : 0.3795; Y: 0.3735	X : 0.3169; Y: 0.3302
luminance at eye level (Cd/m ^{2})	13.9	14.2	14	46.9	46.2	46.2
Photopic illuminance (lx)	87	88	87	326	318	317
Cyanopic lx (α-opic lx)	29	55	90	108	197	334
Melanopic lx (α-opic lx)	43	63	77	160	225	285
Rhodopic lx (α-opic lx)	52	68	81	196	247	298
Chloropic lx (α-opic lx)	72	80	85	271	290	311
Erythropic lux (α-opic lx)	85	87	84	323	311	303
Photon density (photons.cm $^{-2}$. s $^{-1}$)	0.81×10^{14}	0.79×10^{14}	0.77×10^{14}	2.97×10^{14}	2.8×10^{14}	2.78×10^{14}
Irradiance (μW cm $^{-2}$)	27.4	28.3	28.04	100.7	99	102.2

Abbreviation: CCT, correlated color temperature.

setting under investigation. We used the MATLAB software package to assign medications randomly and their order within each prescription, eliminating potential order effects (11).

3.5. Lighting Settings

The experiment was conducted in a temperature-controlled (23°C - 25°C) laboratory, using light-blocking curtains to minimize the effects of natural light fluctuations on study results. The experimental room was lit by a ceiling dimmable LED panel (OSRAM, LED slim panel/40W) with nominal CCTs of 4000 K, 2700 K,

and 6500 K. Vertical and horizontal illuminance levels were measured at 1.2 m and 0.75 m above the floor using an illuminance meter (Hagner, model E2), demonstrating uniformity exceeding 0.8, which indicates high homogeneity in illuminance distribution. The mean luminance within the participants' field of view, also at 1.2 m, was assessed using a luminance meter (Hagner Screen Master). A spectrometer (C7000 SpectroMaster) measured the actual CCT, Color Rendering Index, and chromaticity coordinates at eye level. The spectral power distribution of the white LED panels used in the present study is shown in Figure 2. Additionally, Table 1 provides technical details and photometric values based on supplementary materials from Lucas et al. (27).

3.6. Questionnaire

In this study, participants completed two questionnaires that assessed various factors. The first questionnaire assessed subjective sleepiness using Karolinska's Self-Report Sleepiness Scale (KSS), which consists of nine ratings from "extremely alert" at 1 to "very sleepy" at 9 (28). The KSS has demonstrated acceptable validity and reliability in prior studies (29). The second questionnaire assessed visual inconveniences through participants' subjective satisfaction ratings with the lighting conditions. It consisted of six questions using a 5-point scale. The first four questions measured pleasantness and were confirmed to be reliable, with a Cronbach's alpha of $\alpha = 0.8$. These questions included options ranging from unpleasant to pleasant, uncomfortable to comfortable, annoying to not annoying, and glaring to not glaring. The last two questions evaluated the adequacy and color of the lighting, using a scale from insufficient to sufficient (30).

3.7. Test Procedure and Data Collection

The test set consisted of seven sessions that lasted about 20 minutes, with lighting conditions assigned randomly. The 20-minute session duration was informed by interviews and observational studies indicating that nurses spend an average of 20 minutes in the medication room. Participants were scheduled to arrive at the laboratory at approximately 9:00 a.m. Upon arrival, they received a brief explanation of the study protocol and provided informed consent. The study commenced with a “dummy” test (Session 1) to familiarize participants with the experimental setup (11). After the dummy test, the actual testing sessions began.

Each experimental session started with a light adaptation period (11). During this time, participants filled out questionnaires to evaluate their sleepiness levels. They then read printed medication prescriptions aloud while an experimenter noted any mistakes on a control sheet. Audio recordings of the readings were used to verify the accuracy of the error scoring. After reading, participants completed additional questionnaires regarding their sleepiness, overall perception, and satisfaction with the lighting. Subsequently, the lighting settings were adjusted, and a new session began following the same procedure. Participants received a ten-minute break with apple juice and graham crackers between the fourth and fifth sessions.

Our study used a tracking sheet to monitor reading errors while reading medication prescriptions. These errors included word deletions, mispronunciations, letter substitutions, failures to read a word thoroughly, and combinations of these errors (11).

3.8. Data Analysis

This study utilized linear mixed models (LMMs) to examine the effects of light conditions, font types, and font sizes on reading errors, self-reported sleepiness, and subjective lighting evaluations. Separate LMMs were fitted for each dependent variable, incorporating fixed effects for experimental conditions while accounting for participant-level random effects. Covariates such as general health, sleep duration, visual acuity, background lighting, and caffeine/alcohol intake were controlled to mitigate confounding factors. Baseline sleepiness measurements were included as covariates in the reading errors and sleepiness analyses. In contrast, subjective lighting evaluations assessed only at the end of each session were analyzed independently of covariates. Optimal variance-covariance structures were selected for model fit. Statistical analyses were conducted using IBM SPSS Statistics (v26), with Bonferroni-adjusted pairwise comparisons (significance threshold: $P \leq 0.05$). Data visualization was performed using GraphPad Prism (v8.2.1).

4. Results

4.1. Light Condition

Significant main effects of the light conditions [F (5, 1404) = 17.39, P < 0.001, η^2_p = 0.058] were observed in the number of reading errors in printed medication prescriptions. Post-hoc pairwise comparisons (Table 2) indicated that participants made significantly more errors under a light intensity of 150 lx than 500 lx. However, the same table revealed that the CCT did not significantly impact the number of errors. The analysis revealed no significant effects of the light conditions [F (5, 127) = 1.26, P = 0.287, η^2_p = 0.047] on subjective sleepiness scores. In simpler terms, participants' self-reported sleepiness was not significantly different when exposed to different lighting conditions.

The lighting conditions had a significant main impact on participants' subjective evaluation of lighting, including pleasantness [F (5, 111) = 4.775, P = 0.001, η^2_p = 0.177] and adequacy of light [F (5, 115) = 46.335, P < 0.001, η^2_p = 0.666]. The adequacy of the lighting color variable did not have significant main effects [F (5, 107) = 1.879, P = 0.104, η^2_p = 0.080]. Table 3 displays the results of the post-hoc pairwise comparisons for the subjective light evaluation variables. Furthermore, Figure 3 illustrates the estimated marginal means (EMM) ± standard error (SE) for subjective light evaluation scores across the various lighting conditions. Notably, as depicted in Figure 3, participants rated Cond. 6 (500 lx & 6500 K) as the most pleasant, while Cond. 5 (500 lx & 6500 K) was ranked second in pleasantness.

4.2. Font Size

The results revealed significant main effects of the font sizes [F (2, 1404) = 44.65, P < 0.001, η^2_p = 0.060] on the number of reading errors. This indicates a significant variation in the number of errors when reading printed medication prescriptions across different font sizes. Post-hoc analysis showed that there were significant differences between the 9 pt font size and both the 11 pt (P < 0.001) and 13 pt (P < 0.001) font sizes, while no other comparisons showed significant differences.

4.3. Font Type

The results show no significant main effects of font types [F (2, 1404) = 1.062, P = 0.346, η^2_p = 0.0015] on the number of reading errors. Furthermore, the findings indicate no significant interactions between light conditions × font types [F (10, 1404) = 0.12, P = 0.999, η^2_p = 0.0008], light conditions × font sizes [F (10, 1404) = 0.74, P = 0.690, η^2_p = 0.0052], font types × font sizes [F (4, 1404) = 0.49, P = 0.741, η^2_p = 0.0014], or light conditions × font types × font sizes [F (20, 1404) = 0.43, P = 0.987, η^2_p = 0.0061] on the number of reading errors. The regression coefficients for the effects of lighting and typography are presented in Table 4. Additionally, Table 5 displays the EMM ± SE of reading errors for each light condition, font type, and font size. As shown in Table 5, participants committed the fewest reading errors under condition 6 (500 lx & 6500 K), which was associated with a 28.2% reduction in reading errors compared to condition 3 (150 lx & 4000 K), the lighting currently implemented in the studied hospital. Furthermore, the analysis revealed that font sizes 11 and 13 resulted in a 12.5% and 15% reduction in reading errors, respectively, compared to font size 9, which is presently used for printed medication prescriptions in the hospital setting.

5. Discussion

This study sought to identify the lighting conditions and typographic characteristics (font size and font type) that minimize reading errors in printed medication prescriptions and to evaluate how these factors interact to influence error rates. The results revealed that lighting significantly impacted error rates, with the fewest errors occurring under lighting conditions of 500 lx & 6500 K. In comparison, the highest error rates were observed under 150 lx & 3000 K. Pairwise comparisons confirmed that error rates were significantly elevated at 150 lx compared to 500 lx, consistent with previous research (11). Furthermore, multiple studies indicate that increased light intensity enhances visual performance and acuity (10, 31, 32), reinforcing the positive correlation between illumination and visual function.

Table 2. Pairwise Comparisons (Post-hoc) for the Number of Reading Errors in Medication Prescriptions Between Lighting Conditions [a]

Pairs	Effect Sizes (EF)	P-Value
Cond.1 - Cond.4	0.99	< 0.001
Cond.2 - Cond.4	0.87	< 0.001
Cond.3 - Cond.4	0.66	0.002
Cond.1 - Cond.5	1.26	< 0.001
Cond.2 - Cond.5	1.13	< 0.001
Cond.3 - Cond.5	0.9	0.001
Cond.1 - Cond.6	1.34	< 0.001
Cond.2 - Cond.6	1.21	< 0.001
Cond.3 - Cond.6	0.98	0.001

[a] Cond.1 (150 lx & 3000 K), Cond.2 (150 lx & 4000 K), Cond.3 (150 lx & 6500 K), Cond.4 (500 lx & 3000 K), Cond.5 (500 lx & 4000 K) and Cond.6 (500 lx & 6500 K).

Table 3. Pairwise Comparisons (Post-hoc) of the Subjective Light Evaluation Variables Between Lighting Conditions [a]

Pairs	Effect Sizes (EF)	P-Value
Pleasantness		
Cond.1 - Cond.4	0.45	0.021
Cond.1 - Cond.5	0.78	0.001
Cond.2 - Cond.5	0.57	0.004
Cond.1 - Cond.6	0.87	< 0.001
Cond.2 - Cond.6	0.65	0.001
Cond.3 - Cond.6	0.62	0.004
Adequacy of light		
Cond.1 - Cond.4	2.16	< 0.001
Cond.2 - Cond.4	2.3	< 0.001
Cond.3 - Cond.4	2.51	< 0.001
Cond.1 - Cond.5	2.06	< 0.001
Cond.2 - Cond.5	2.09	< 0.001
Cond.3 - Cond.5	1.99	< 0.001
Cond.1 - Cond.6	2.09	< 0.001
Cond.2 - Cond.6	2.06	< 0.001
Cond.3 - Cond.6	1.89	< 0.001

[a] Cond.1 (150 lx & 3000 K), Cond.2 (150 lx & 4000K), Cond.3 (150 lx & 6500 K), Cond.4 (500 lx & 3000 K), Cond.5 (500 lx & 4000 K) and Cond.6 (500 lx & 6500 K).

The present study found that CCT did not significantly influence reading errors in printed medication prescriptions, aligning with prior research by Aarts et al., Mehri et al., and Kraneburg et al., which similarly reported no significant impact of CCT on reading errors or visual acuity (11, 33, 34). However, conflicting evidence exists, as Amouzadeh et al. reported that higher CCT could enhance visual acuity and color recognition, attributing this effect to pupil constriction under short-wavelength light, thereby improving retinal image quality (14). Supporting this, Dong et al. found that elevated CCT in LED lighting improved visual performance under mesopic conditions (35), while Vicente et al. observed faster visual reaction times in off-axis vision under high CCT (1870 - 6350 K) conditions (36).

Research on the effects of CCT on visual performance yields mixed results. In summary, while highly CCT lighting may enhance visual performance in specific scenarios, its effectiveness is influenced by factors such as illuminance level, age-related visual decline, retinal adaptation, and the specific nature of the visual task (36-38). Careful consideration of these factors is essential when designing lighting environments to optimize

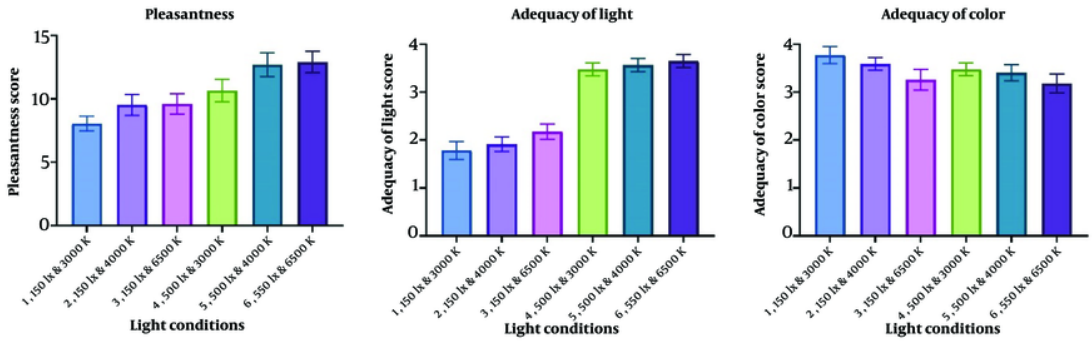

Figure 3. Means and standard error (SE) of the subjective light evaluation

Table 4. Regression Coefficients for Lighting and Typography Effects

Variables	Coefficient	Std. Error	*t*-Value	P-Value	95% CI (Lower-Upper)
Intercept	0.465	0.0889	5.236	< 0.001	(0.291, 0.640)
Light = 1	0.458	0.1136	4.036	< 0.001	(0.236, 0.681)
Light = 2	0.398	0.1149	3.460	0.001	(0.172, 0.623)
Light = 3	0.316	0.1169	2.707	0.007	(0.087, 0.546)
Light = 4	0.131	0.1218	1.072	0.284	(-0.108, 0.370)
Light = 5	0.045	0.1243	0.366	0.715	(-0.198, 0.289)
Light = 6	Reference	-	-	-	-
Font type = 1	-0.024	0.1261	-0.187	0.852	(-0.271, 0.224)
Font type = 2	0.089	0.1181	0.753	0.452	(-0.143, 0.321)
Font type = 3	Reference	-	-	-	-
Font size = 1	0.190	0.1087	1.748	0.081	(-0.023, 0.403)
Font size = 2	0.131	0.0923	1.416	0.157	(-0.050, 0.312)
Font size = 3	Reference	-	-	-	-

visual performance (Rossi et al., 2024) (48). Therefore, further research is necessary to determine the ideal CCT in various contexts and to explore the underlying mechanisms involved, including retinal melanopic and photopic effects.

The study found significant differences in prescription error rates based on font size, with 9 pt yielding more errors than 11 pt and 13 pt. These results align with Bianchi et al., where 8 pt fonts caused higher errors than 12 pt and 16 pt (39). Similarly, Wallace et al. demonstrated that fonts below 10 pt reduce readability, increasing reading time and errors (40). Hou et al. (also noted a preference for larger fonts due to improved legibility (41). These findings collectively suggest that smaller font sizes (< 10 pt) compromise prescription accuracy, supporting the use of larger fonts to minimize errors.

This study found no significant interaction between light conditions and font sizes (9 pt, 11 pt, 13 pt) on prescription reading errors. Limited to Aarts et al., existing literature reported light effects only on tiny fonts (2.5 pt - 4.5 pt), unlike the larger fonts examined here (11). Thus, while extreme font sizes may interact with lighting, typical prescription fonts appear unaffected.

The study's findings revealed that neither the type of font used nor the interaction between lighting conditions and font type significantly impacted the frequency of reading errors. These results align with research by Daxer et al., who found no significant

Table 5. The Estimated Marginal Means ± Standard Error of the Number of Reading Errors in Each Light Condition, Font Types, and Font Size [a]

Variables	All Light Conditions	Cond.1 (150 lx and 3000 K)	Cond.2 (150 lx and 4000 K)	Cond.3 (150 lx and 6500 K)	Cond.4 (500 lx and 3000 K)	Cond.5 (500 lx and 4000 K)	Cond.6 (500 lx and 6500 K)
Light conditions	2.18 ± 0.024	2.6 ± 0.05	2.51 ± 0.06	2.37 ± 0.05	1.98 ± 0.07	1.83 ± 0.05	1.8 ± 0.05
Font types							
Tahoma	2.19 ± 0.04	2.62 ± 0.09	2.58 ± 0.12	2.38 ± 0.08	2.01 ± 0.13	1.83 ± 0.08	1.74 ± 0.09
Zar	2.22 ± 0.04	2.63 ± 0.08	2.54 ± 0.08	2.42 ± 0.09	2.01 ± 0.12	1.85 ± 0.07	1.87 ± 0.1
Yekan	2.13 ± 0.04	2.54 ± 0.1	2.42 ± 0.01	2.31 ± 0.08	1.91 ± 0.09	1.81 ± 0.08	1.78 ± 0.09
Font sizes							
9 pt	2.4 ± 0.04	2.8 ± 0.09	2.67 ± 0.09	2.67 ± 0.09	2.17 ± 0.12	2.07 ± 0.09	1.99 ± 0.1
11 pt	2.1 ± 0.04	2.48 ± 0.09	2.51 ± 0.01	2.25 ± 0.081	1.89 ± 0.1	1.74 ± 0.08	1.76 ± 0.09
13 pt	2.04 ± 0.04	2.51 ± 0.09	2.37 ± 0.11	2.2 ± 0.081	1.88 ± 0.12	1.69 ± 0.07	1.63 ± 0.07

[a] Values are expressed as EMM ± SE.

differences in reading errors between Helvetica and Times New Roman (42). Similarly, another study reported that font type and line spacing did not significantly affect reading speed (43).

The relationship between typography and lighting on visual performance is complex and influenced by several factors, such as light intensity, glare, and distribution, alongside typographic variables like font size, line spacing, paper dimensions, text alignment, overall layout, and the contrast between text and background, as well as cognitive factors, including perceived attractiveness and memorability of the text, reader characteristics, and the nature of the reading task (44-49). Therefore, the variability of these elements across studies may explain the discrepancies in findings concerning typography and lighting's impact on visual performance.

Notably, in the present study, we carefully controlled lighting conditions, ensuring uniform illuminance and minimizing glare at eye level while maintaining consistency in the design of medication prescriptions, which suggests that potential confounding variables had minimal impact on results. The existing literature underscores the need for comprehensive design strategies incorporating environmental lighting as a fundamental aspect of typographic design (48). Thus, further research is essential to optimize typography in various lighting contexts, particularly healthcare settings, to enhance visual performance and reduce medication errors.

The KSS scores indicated that sleepiness levels did not vary significantly across the six lighting conditions studied. This finding supports the research's overall goal of identifying the optimal lighting conditions for improving visual performance. The results suggest that sleepiness did not affect the study's conclusions about visual performance. Subjective evaluations showed a clear preference for a light intensity of 500 lx, which was more adequate than a lower intensity of 150 lx. These results align with prior research by Avcı and Memikoğlu, who found 500 lx optimal for visual comfort and reading performance, as well as studies by Weng et al. and Oscco et al., which reported superior satisfaction under similar illumination (50-52). Overall, the 500 lx & 6500 K conditions were preferred over the other tested settings, which supports the findings of Lee et al., who reported a similar preference in both screen- and paper-based tasks (53). Evidence suggests that satisfying lighting conditions may enhance visual performance, underscoring the importance of user preferences in occupational lighting design (11, 54). Future research should prioritize personalized lighting solutions to better accommodate individual needs, optimizing comfort and productivity in workplace environments.

Based on this study's findings concerning the frequency of reading errors and participants' lighting preferences, it is recommended that medication prescription reading environments maintain a minimum light intensity of 500 lx. This aligns with workplace lighting standards for tasks requiring high visual acuity (20). Although some evidence suggests higher light intensities could improve accuracy in medication preparation environments (55), practical constraints such as energy costs and system

maintenance must be considered. Nevertheless, ensuring a minimum of 500 lx is crucial for maintaining safety and efficiency in these critical healthcare settings.

This study's findings should be interpreted in light of several inherent limitations. First, age-related variations in eye spectral transmittance can influence visual performance (56). To minimize these variables, participants were limited to those aged 25 to 40 with 20/20 vision and no visual impairments, restricting the generalizability of results to individuals outside this demographic. Second, the study exclusively involved female participants, despite evidence suggesting minimal gender effects on visual performance (25); future studies might incorporate both genders for a comprehensive assessment. Third, the research focused on three Persian-specific fonts (Tahoma, Zar, and Yekan), limiting applicability to other writing systems such as Latin or Cyrillic scripts. Finally, handwritten prescriptions were excluded due to their variability (11). Given their prevalence in healthcare and potential legibility challenges (9), future investigations should assess the readability of handwritten prescriptions under varying lighting and typography conditions.

5.1. Conclusions

This study emphasizes the crucial influence of light intensity and font size in minimizing medication prescription errors. In contrast, CCT and font type did not significantly affect error rates. Furthermore, the lack of significant interactions between lighting and typography suggests that these factors function independently within the tested ranges. Higher light intensity (500 lx) and larger font sizes (≥ 11 pt) significantly enhance printed prescription readability, offering practical solutions to reduce medication errors. These findings underscore the need for optimized lighting and typography in healthcare settings to improve patient safety. However, because this study was limited to Persian fonts, young, healthy females, and printed medication prescriptions, further research is needed to assess generalizability across different ages, genders, writing systems, and handwritten prescriptions.

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Footnotes

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