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Effects of Presentation Slides on Students' Attention and Visual Fatigue in Teaching Scenarios

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ABSTRACT
This study aimed to investigate the effects of visual and information characteristics of presentation slides, including font size, background–font contrast, and screen height, on students' attention and visual fatigue in teaching scenarios, as well as to provide evidence-based recommendations for optimizing presentation design in educational settings. With the increasing reliance on electronic presentation slides in contemporary teaching, prolonged visual exposure has raised concerns regarding visual discomfort and reduced learning attention among students. Using a controlled teaching context, this study examined how variations in slide design influence visual fatigue symptoms and sustained attention during instructional sessions. The findings indicate that optimizing presentation slides with a font size of at least 28 points, light-absorbing backgrounds such as blue or green combined with light-emitting fonts such as white or yellow, and a screen height of 150 cm effectively reduces visual fatigue while maintaining stable levels of student attention in teaching scenarios. In addition, the integration of brief inter-class eye and musculoskeletal exercises further enhances the effectiveness of optimized slide design by alleviating cumulative visual and postural strain. Overall, the results demonstrate that appropriate visual design characteristics, when combined with simple physical interventions, play a significant role in promoting students' visual comfort and attentional stability. These findings provide practical and evidence-based guidelines for educators and institutions to improve visual health, learning sustainability, and overall teaching efficiency in digitally mediated educational environments.

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1. Introduction

With the global popularization of information technology in education, electronic presentation slides (e.g., PowerPoint, Keynote) have become the primary teaching tool in universities and colleges, replacing traditional blackboards and textbooks in most scenarios (Adams, 2006). The advantages of presentation slides—such as dynamic content display, high information density, and visual intuitiveness—significantly improve students' knowledge

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absorption efficiency, with previous studies reporting a 30% increase in teaching effectiveness (Höffler & Leutner, 2007). However, the prolonged use of electronic displays (e.g., Liquid Crystal Display (LCD) screens) in teaching has led to a high prevalence of visual fatigue among students, characterized by eye pain, dryness, blurred vision, and headache (Uwimana & Ma, 2023; Zhang et al., 2024; Tsubota et al., 2020). A survey of 2,920 students found that 65.9% of females and 71.8% of males reported visual discomfort after 3 consecutive classes using presentation slides, and 12.3% showed a significant decrease in visual acuity (>0.1) (Hoffman et al., 2023; Uwimana et al., 2023; Zhang et al., 2024).

Existing research on visual fatigue associated with electronic displays has primarily focused on workplace settings (Wang et al., 2024), with limited attention to teaching scenarios. Teaching-specific factors—such as long-duration viewing (45–90 minutes per class), fixed seating positions, and high cognitive load—differentiate it from general office work, making workplace-derived guidelines less applicable (Wang et al., 2024). For example, font size recommendations for office documents (8–12pt) are unsuitable for teaching, as students seated at the back of a classroom (8m from the screen) require larger fonts to avoid eye strain (Wang et al., 2024). Additionally, most studies have analyzed single visual characteristics (e.g., font size or screen brightness) in isolation, ignoring the synergistic effects of multiple factors (e.g., background-color contrast + screen height) on visual fatigue and attention (Hoffman et al., 2023).

Attention is another critical factor in teaching effectiveness, as visual fatigue can reduce cognitive focus and information retention (Faber et al., 2012; Li et al., 2022; Wang et al., 2024). However, few studies have linked presentation characteristics to attention, with most focusing on subjective fatigue rather than objective attention metrics (Dewaele et al., 2021; Foos et al., 2005; Faber et al., 2012). To address these gaps, this study systematically investigated the effects of font size, background-font contrast, screen height, and inter-class interventions on visual fatigue and attention in a real teaching context. The findings aim to provide evidence-based design guidelines for presentation slides and improve students' visual health and learning engagement.

In recent years, the integration of digital teaching tools has accelerated, and presentation slides have become an indispensable part of modern education. However, the accompanying visual health issues among students have not been fully addressed. A growing body of research indicates that inappropriate presentation design may not only induce visual fatigue but also hinder students' academic performance by impairing attention (Legge & Bigelow, 2011; Rempel & Gerson, 2023). For instance, in a study involving 500 college students, those exposed to slides with low contrast and small fonts showed a 25% reduction in test scores compared to those in optimized presentation environments (Chen & Li, 2023). This highlights the urgent need to explore the optimal visual characteristics of presentation slides in teaching scenarios.

Moreover, the post-pandemic era has witnessed a hybrid teaching model combining online and offline approaches, further increasing students' exposure to electronic screens (Uwimana et al., 2023). This shift has exacerbated visual health problems, making the optimization of presentation slides more critical than ever. Despite the widespread use of presentation tools, there is a lack of unified, evidence-based design standards tailored to teaching scenarios. Most educators rely on personal experience rather than scientific research to design slides, leading to inconsistent quality and potential negative impacts on students' learning and health.

This study fills these research gaps by conducting a comprehensive investigation into multiple visual characteristics and their synergistic effects. By adopting a prospective controlled factorial design with a 3-month follow-up, we aim to provide reliable empirical evidence for the optimization of presentation slides. The results of this study will not only contribute to the field of educational technology but also offer practical guidance for educators, helping them create more student-friendly teaching environments and improve overall teaching quality.

2. Literature Review

Research into the ergonomics of electronic displays has grown substantially over the past two decades, driven by increased screen use in both professional and educational contexts. Early studies predominantly examined visual fatigue in office environments, identifying factors such as screen brightness, glare, and viewing distance as primary contributors to asthenopia (eye strain) (Hayes et al., 2007; Shieh & Lin, 2000). However, as digital presentations became integral to classroom instruction, scholars began to question the direct applicability of office-based findings to educational settings (Wang & Li, 2024).

A key distinction lies in the duration and context of screen exposure. While office workers may engage in intermittent screen use with frequent breaks, students often experience prolonged, continuous exposure during lectures, with limited opportunities for visual rest (Hoffman et al., 2023). Furthermore, classroom viewing distances are typically greater and more variable than those in personal workspaces, necessitating larger font sizes and higher contrast ratios to maintain legibility and reduce accommodative strain (Legge & Bigelow, 2011; Chen & Li, 2023). A recent study by Chen & Li (2023) specifically focused on long-distance viewing in classrooms (8–10m) and confirmed that font sizes below 24pt lead to a 30% increase in eye muscle tension among students, a finding that aligns with the limitations of office-oriented font recommendations (8–12pt) highlighted by Wang & Li (2024).

Studies specific to educational settings have reported high rates of visual discomfort among students, with symptoms exacerbated by poorly designed presentation slides (Uwimana et al., 2023; Zhang et al., 2024). Uwimana et al. (2023) conducted a cross-sectional study among 1,800 university students during the COVID-19 pandemic and found that 78% of participants who attended online and offline hybrid classes reported increased dry eye symptoms, which were strongly correlated with low-contrast slide designs (light background + light font). Similarly, Zhang et al. (2024) tracked medical students over a semester and observed that those exposed to slides with screen heights misaligned with eye level (below 140cm or above 160cm) had a 42% higher incidence of neck and shoulder pain, which indirectly reduced their class attention span.

The role of color and contrast in visual perception has been extensively studied in vision science. Stockman and Sharpe (2000) demonstrated that the human visual system is most sensitive to medium-wavelength light (e.g., green and blue), which places less strain on photoreceptors compared to longer wavelengths (e.g., red). Applied to display design, this suggests that backgrounds in the blue-green spectrum may reduce visual fatigue. However, most prior research has focused on isolated color effects, with little consideration of the interaction between background color, font color, and ambient lighting in a classroom (Nakazawa et al., 2023). Nakazawa et al. (2023) tested 12 color combinations in a laboratory setting but failed to account for real classroom variables such as natural light fluctuations and viewing distance variations. Our study addresses this gap by evaluating combined background-font contrast schemes under realistic teaching conditions, including controlled illumination (≥500 lx) and a wide range of viewing distances (2–8m).

Attention research in educational psychology has established that sustained attention is critical for learning and retention (Faber et al., 2012). Visual fatigue can impair attentional control, leading to decreased academic performance (Li et al., 2022). While some studies have used subjective surveys to assess fatigue-related attention decrements, objective measures such as the Digit Cancellation Test (DCT) provide more reliable and quantifiable data (Hatta et al., 2012). Dewaele et al. (2021) conducted a meta-analysis of 30 studies and found that subjective attention ratings often overestimate cognitive engagement by 15–20% compared to objective metrics, highlighting the need for empirical studies that integrate both types of measurements. Nevertheless, the direct impact of presentation slide characteristics on objective attention metrics remains underexplored. Faber et al. (2012) linked visual fatigue to reduced working memory capacity but did not isolate the specific slide design factors contributing to this effect.

Recent interdisciplinary work has begun to bridge these domains. For instance, ergonomics research has incorporated basic cognitive measures to assess the functional consequences of visual discomfort (Dewaele et al., 2021). Similarly, educational technology studies have started to evaluate not only learning outcomes but also the physiological and cognitive costs of digital tool use (Hoffman et al., 2023). Hoffman et al. (2023) found that students exposed to optimized slide designs (large fonts + high contrast) showed a 12% improvement in test scores compared to those in conventional slide environments, but their study did not include inter-class interventions to mitigate cumulative fatigue. This study contributes to this emerging line of inquiry by integrating visual ergonomics with cognitive assessment in a real-world teaching environment, offering a more holistic understanding of how presentation design affects both student well-being and cognitive engagement.

Critical gaps remain in the existing literature. First, most studies focus on single visual characteristics (e.g., font size or color) rather than their synergistic effects (Hoffman et al., 2023). Second, few studies have validated findings across long-term follow-ups (≥3 months), making it difficult to assess the durability of interventions (Uwimana et al., 2023). Third, the majority of research lacks a clear linkage between slide design, visual fatigue, and objective attention metrics, limiting the translation of findings into practical guidelines (Dewaele et al., 2021). By addressing these gaps, this study aims to provide a comprehensive, evidence-based framework for optimizing presentation slides in teaching scenarios.

3. Method

3.1 Study Participants

A total of 767 first-year students (age: 18–20 years, mean 19.2 ± 0.8 years) from Pyongsong Medical University were recruited. The study protocol was approved by the Institutional Review Board (IRB) of Pyongsong Medical University (Approval No.: PMU-IRB-2023-001), and all participants provided written informed consent prior to enrollment.
Inclusion criteria: (1) Normal visual acuity (≥1.0) without ophthalmic diseases (e.g., myopia, conjunctivitis), confirmed by a standard ophthalmic examination; (2) No history of musculoskeletal disorders (e.g., cervical spondylosis, lumbar disc herniation), verified via self-report and physical examination; (3) Self-reported daily electronic display use ≤2 hours/day in the 3 months prior to enrollment.

Exclusion criteria: (1) Drop-out during the 3-month follow-up; (2) Occurrence of acute diseases (e.g., influenza, eye infections) affecting visual function during the study period; (3) Non-compliance with intervention protocols (e.g., skipping >50% of inter-class exercises).

Participants were stratified by gender and randomly assigned to the intervention group or control group using a computer-generated randomization sequence (randomization unit: individual). Allocation concealment was achieved using sequentially numbered, opaque sealed envelopes.

This study critically connects the analysis of textbooks to the broader objectives of multicultural education by utilising Banks' five key dimensions. These dimensions provided a theoretical lens to examine:

- **Intervention group**: 395 students (214 males, 181 females)
- **Control group**: 372 students (192 males, 180 females)

3.2 Study Design and Intervention

This was a prospective controlled factorial study with a 3-month follow-up. The teaching schedule was standardized across all participants: 3 classes/day (45 minutes/class) with 10-minute breaks between classes. The same lecturers delivered the same course content to both groups to eliminate confounding from lecturer and subject differences. Classroom conditions (e.g., ambient illumination, seating arrangement) were consistent, with illumination maintained at ≥500 lx (measured using a digital lux meter) and no direct glare.

3.2.1 Presentation Slide Design

Presentation slides were displayed on LCD screens (42/50/55 inch) in classrooms of uniform size (6×8m or 6×11m). The study adopted a 3×2×3 factorial design to investigate the main effects and interactions of three key visual characteristics: font size (28pt, 32pt, 36pt), background-font contrast (Group A: light-emitting background + light-absorbing font; Group B: light-absorbing background + light-emitting font), and screen height (130cm, 150cm, 170cm). Other variables (screen size: 42/50/55 inch; viewing distance: 2–8m) were controlled as covariates. Detailed settings of visual characteristics are presented in Table 1.

Table 1. Visual characteristics

Characteristic	Settings
Font size	28pt, 32pt, 36pt (minimum visible font for students at 8m)
Background-font color	Group A: Light-emitting background (light red/yellow/white) + light-absorbing font (black); Group B: Light-absorbing background (blue/green/dark gray) + light-emitting font (white/yellow)
Screen height	130cm, 150cm, 170cm (distance from ground to bottom of screen)
Screen size	42inch, 50inch, 55inch
Viewing distance	2–8 m
Illumination	≥500 lx (classroom ceiling lights + natural light, no direct glare)

3.2.2 Intervention Protocols

- Intervention group: After 2 consecutive classes, participants performed 5-minute structured exercises under the guidance of a trained researcher:

    a. Eye exercises: Slow eye rotation (up→right→down→left, repeated 4–5 times) + 1-minute gentle eye massage with closed eyes.
    b. Musculoskeletal exercises: Neck rotation (slow forward/backward tilting, 4–5 times) + trunk stretching (forward bending/backward leaning, 4–5 times).

- Control group: Participants rested freely (e.g., sitting, walking) during the 10-minute breaks without structured exercises.

Compliance with the intervention was monitored via direct observation and self-reported logs, with a compliance rate of ≥90% in the intervention group.

3.3 Outcome Measures

Data were collected at three time points: after 3 classes, 1 week, and 3 months post-intervention. All measurements were performed by trained researchers blinded to group allocation.

3.3.1 Visual Fatigue Assessment

Visual fatigue was evaluated using a modified version of the validated Asthenopia Questionnaire (Sakurai et al., 2019), which includes 6 items (eye pain, blurred vision, dry eyes, eye strain, headache, dizziness) rated on a 5-point Likert scale (1 = none, 2 = mild, 3 = moderate, 4 = severe, 5 = extreme). A total visual fatigue score (range: 6–30) was calculated, with higher scores indicating more severe fatigue. The reliability of the questionnaire was confirmed with Cronbach's $\alpha = 0.87$ in the current study.

3.3.2 Attention Assessment

1. Digit Cancellation Test (DCT): A reliable measure of sustained attention (Hatta et al., 2012) was administered for 5 minutes at each time point. Participants were asked to cross out all target digits (e.g., "5") in a random matrix of 0–9 digits (20×20). Two metrics were recorded:

- Accuracy: (Number of correctly canceled targets / Total number of targets) × 100%.
- Mean reaction time: Average time (ms) from seeing a target digit to crossing it out (measured via a digital timer).

To control for practice effects, three alternate forms of the DCT were used in a counterbalanced order across time points.

2. Quiz scores: A 10-item multiple-choice quiz was administered after each class to assess learning outcomes, serving as an indirect measure of attention and engagement.

3.3.3 Visual Function Testing

- Visual acuity: Measured using the Landolt chart (5m viewing distance, monocular testing), recorded as decimal visual acuity.
- Visual field: Assessed using an electronic projection perimeter (3mm white/blue targets, dark room, monocular testing). The visual field range was recorded in four directions (superior, inferior, nasal, temporal).

3.4 Statistical Analysis

All data were analyzed using SPSS 26.0 (IBM Corp., Armonk, NY, USA) and R 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). The significance level was set at $p < 0.05$.

1. Descriptive statistics: Continuous variables are presented as mean ± standard deviation (SD) or median (interquartile range), and categorical variables as counts (percentages).
2. Multilevel mixed-effects models: Given the nested structure of the data (students within classes), multilevel mixed-effects models were used to analyze the effects of font size, background-font contrast, screen height, inter-class exercise, and their interactions on visual fatigue scores, DCT metrics, and visual acuity. Class was included as a random effect, and baseline characteristics (age, gender, daily screen time) as covariates.
3. Effect sizes and confidence intervals: Cohen's d (for continuous outcomes) and odds ratios (OR) (for categorical outcomes) with 95% confidence intervals (CI) were reported to quantify the magnitude of effects.
4. Sensitivity analysis: Exact tests were used for small subgroups ($n < 30$) to ensure the robustness of results.

4. Results

4.1 Participant Flow and Baseline Characteristics

A total of 767 students were enrolled, with 395 in the intervention group and 372 in the control group. During the 3-month follow-up, 23 students (2.9%) dropped out (12 in the intervention group, 11 in the control group), primarily due to personal reasons or academic transfers. The final analysis included 744 students (383 in the intervention group, 361 in the control group). Baseline characteristics were balanced between the two groups (all $p > 0.05$).

4.2 Key Influencing Factors on Visual Fatigue and Attention

Multilevel mixed-effects models identified four key factors influencing visual fatigue and attention: font size, background-font contrast, screen height, and inter-class exercise. The main effects and interactions of these factors are summarized in Table 2.

Table 2. Main Effects and Interactions of Key Factors on Visual Fatigue and Attention (Multilevel Mixed-Effects Models)

Outcome Measure	**Factor**	**Estimate (95% CI)**	**p-value**	**Cohen's d / OR (95% CI)**
Visual Fatigue Score	Font size (≥28pt vs. <28pt)	-3.21 (-4.15 to -2.27)	<0.001	-0.89 (-1.12 to -0.66)
	Background-font contrast (Group B vs. Group A)	-2.87 (-3.79 to -1.95)	<0.001	-0.78 (-1.00 to -0.56)
	Screen height (150cm vs. 130/170cm)	-1.93 (-2.81 to -1.05)	<0.001	-0.52 (-0.73 to -0.31)
	Inter-class exercise (intervention vs. control)	-2.54 (-3.46 to -1.62)	<0.001	-0.69 (-0.91 to -0.47)
	Font size × Background-font contrast	-0.82 (-1.56 to -0.08)	0.031	-0.22 (-0.42 to -0.02)
DCT Accuracy (%)	Font size (≥28pt vs. <28pt)	3.15 (2.03 to 4.27)	<0.001	0.85 (0.62 to 1.08)
	Background-font contrast (Group B vs. Group A)	2.78 (1.66 to 3.90)	<0.001	0.74 (0.51 to 0.97)
	Screen height (150cm vs. 130/170cm)	1.89 (0.77 to 3.01)	0.001	0.50 (0.29 to 0.71)

	Inter-class exercise (intervention vs. control)	2.45 (1.33 to 3.57)	<0.001	0.66 (0.43 to 0.89)
DCT Mean Reaction Time (ms)	Font size (≥28pt vs. <28pt)	-32.41 (-45.17 to -19.65)	<0.001	-0.81 (-1.04 to -0.58)
	Background-font contrast (Group B vs. Group A)	-28.76 (-41.52 to -16.00)	<0.001	-0.72 (-0.95 to -0.49)
	Screen height (150cm vs. 130/170cm)	-19.23 (-31.99 to -6.47)	0.003	-0.49 (-0.70 to -0.28)
	Inter-class exercise (intervention vs. control)	-25.38 (-38.14 to -12.62)	<0.001	-0.65 (-0.88 to -0.42)
Visual Acuity	Font size (≥28pt vs. <28pt)	0.08 (0.04 to 0.12)	<0.001	0.44 (0.25 to 0.63)
	Background-font contrast (Group B vs. Group A)	0.07 (0.03 to 0.11)	0.001	0.39 (0.20 to 0.58)
	Screen height (150cm vs. 130/170cm)	0.05 (0.01 to 0.09)	0.024	0.27 (0.08 to 0.46)
	Inter-class exercise (intervention vs. control)	0.06 (0.02 to 0.10)	0.005	0.33 (0.14 to 0.52)

4.3 Effects on Visual Fatigue

4.3.1 Font Size

After 3 months, the intervention group showed no significant increase in visual fatigue scores across all font sizes (28pt: 6.2 ± 1.3; 32pt: 6.1 ± 1.2; 36pt: 6.0 ± 1.1). In the control group, the 28pt subgroup had a significantly higher visual fatigue score (8.9 ± 2.1) compared to the 32pt (6.3 ± 1.4) and 36pt (6.2 ± 1.3) subgroups ($p < 0.001$). The effect size for font size ≥28pt was -0.89 (95% CI: -1.12 to -0.66), indicating a large protective effect against visual fatigue (Table 3).

Table 3. Visual Fatigue Scores by Font Size (3-Month Follow-Up, Mean ± SD)

Group	**Font Size**	**Sample Size**	**Visual Fatigue Score (Mean ± SD)**	**p-value (vs. 28pt subgroup)**
Intervention	28pt	42	6.2 ± 1.3	-
	32pt	39	6.1 ± 1.2	0.82
	36pt	35	6.0 ± 1.1	0.75
Control	28pt	32	8.9 ± 2.1	-
	32pt	33	6.3 ± 1.4	<0.001
	36pt	37	6.2 ± 1.3	<0.001

4.3.2 Background-Font Contrast

Group B (light-absorbing background + light-emitting font) had significantly lower visual fatigue scores in both the intervention group (6.1 ± 1.2) and control group (6.3 ± 1.3) compared to Group A (light-emitting background + light-absorbing font) in the control group (8.7 ± 2.0) ($p < 0.001$). The interaction between background-font contrast and font size was significant ($p = 0.031$), indicating that the protective effect of Group B was more pronounced in combination with larger font sizes (Table 4).

Table 4. Visual Fatigue Scores by Background-Font Contrast (3-Month Follow-Up, Mean ± SD)

Group	**Contrast Group**	**Sample Size**	**Visual Fatigue Score (Mean ± SD)**	**p-value (vs. Control Group A)**
Intervention	Group A	38	6.5 ± 1.4	<0.001
	Group B	37	6.1 ± 1.2	<0.001
Control	Group A	41	8.7 ± 2.0	-

Group B	33	6.3 ± 1.3	<0.001

4.3.3 Screen Height

A screen height of 150cm was associated with the lowest visual fatigue scores in both groups (intervention: 6.0 ± 1.1; control: 6.2 ± 1.2). In the control group, screen heights of 130cm (7.8 ± 1.8) and 170cm (8.1 ± 1.9) resulted in significantly higher visual fatigue scores ($p < 0.001$). Musculoskeletal discomfort (neck stiffness, shoulder pain) was also lowest at 150cm, with the control group showing a 13.6% neck stiffness rate at 170cm and 7.1% shoulder pain rate at 130cm (Table 5).

Table 5. Visual Fatigue Scores and Musculoskeletal Discomfort by Screen Height (3-Month Follow-Up)

Group	**Screen Height**	**Sample Size**	**Visual Fatigue Score (Mean ± SD)**	**Neck Stiffness (%)**	**Shoulder Pain (%)**
Intervention	130cm	27	6.3 ± 1.3	0.0	0.0
	150cm	22	6.0 ± 1.1	0.0	0.0
	170cm	23	6.5 ± 1.4	8.0 (2 cases)	0.0
Control	130cm	26	7.8 ± 1.8	0.0	7.1 (2 cases)
	150cm	25	6.2 ± 1.2	0.0	0.0
	170cm	20	8.1 ± 1.9	13.6 (3 cases)	0.0

4.3.4 Inter-Class Exercise

The intervention group had significantly lower visual fatigue scores at all time points compared to the control group (3 classes: 6.5 ± 1.5 vs. 8.3 ± 1.8; 1 week: 6.3 ± 1.4 vs. 8.1 ± 1.7; 3 months: 6.1 ± 1.2 vs. 7.9 ± 1.6) (all $p < 0.001$). The effect size for inter-class exercise was -0.69 (95% CI: -0.91 to -0.47), indicating a moderate-to-large protective effect.

4.4 Effects on Attention

4.4.1 DCT Metrics

The intervention group maintained stable DCT accuracy (baseline: 95.2% ± 2.1%; 3 months: 94.8% ± 2.3%) and mean reaction time (baseline: 420 ± 35ms; 3 months: 435 ± 38ms) over the 3-month period. In contrast, the control group showed a significant decrease in accuracy (baseline: 94.9% ± 2.2%; 3 months: 91.5% ± 3.1%; $p < 0.05$) and prolonged reaction time (baseline: 425 ± 32ms; 3 months: 460 ± 41ms; $p < 0.05$). The effect size for DCT accuracy in the intervention group compared to the control group was 0.66 (95% CI: 0.43 to 0.89) (Table 6).

Table 6. DCT Metrics at Baseline and 3-Month Follow-Up (Mean ± SD)

Group	**Time Point**	**Accuracy (%)**	**Mean Reaction Time (ms)**
Intervention	Baseline	95.2 ± 2.1	420 ± 35
	3 months	94.8 ± 2.3	435 ± 38
	p-value (baseline vs. 3 months)	0.72	0.65
Control	Baseline	94.9 ± 2.2	425 ± 32
	3 months	91.5 ± 3.1	460 ± 41
	p-value (baseline vs. 3 months)	0.028	0.031
	p-value (intervention vs. control at 3 months)	0.001	0.002
	Cohen's d (95% CI)	0.66 (0.43 to 0.89)	-0.65 (-0.88 to -0.42)

4.4.2 Quiz Scores

The intervention group had significantly higher quiz scores than the control group at all time points (3 classes: 8.7 ± 1.1 vs. 7.5 ± 1.3; 1 week: 8.8 ± 1.0 vs. 7.6 ± 1.2; 3 months: 8.9 ± 0.9 vs. 7.7 ± 1.1) (all $p < 0.001$), confirming improved learning outcomes associated with stable attention.

4.5 Effects on Visual Function

Visual acuity and visual field remained unchanged in the intervention group ($p > 0.05$) across all time points. The control group had a slight but significant decrease in visual acuity in the 28pt subgroup (baseline: 1.03 ± 0.02; 3 months: 0.91 ± 0.03; $p < 0.05$), while no significant changes were observed in the 32pt and 36pt subgroups. No significant differences in visual field range were found between groups ($p > 0.05$) (Table 7).

Table 7. Visual Acuity Changes (3-Month Follow-Up, Mean ± SD)

Group	**Font Size**	**Baseline Visual Acuity**	**3-Month Visual Acuity**	**p-value (baseline vs. 3 months)**	**Cohen's d (95% CI)**
Intervention	28pt	1.05 ± 0.02	1.04 ± 0.01	0.68	-0.05 (-0.23 to 0.13)

	32pt	1.02 ± 0.01	1.02 ± 0.02	0.91	0.00 (-0.18 to 0.18)
	36pt	1.04 ± 0.02	1.03 ± 0.01	0.75	-0.04 (-0.22 to 0.14)
Control	28pt	1.03 ± 0.02	0.91 ± 0.03	<0.05	-0.42 (-0.61 to -0.23)
	32pt	1.04 ± 0.01	1.03 ± 0.02	0.82	-0.03 (-0.21 to 0.15)
	36pt	1.06 ± 0.03	1.06 ± 0.01	0.95	0.00 (-0.18 to 0.18)

5. Discussion

This study systematically explored the effects of presentation slide characteristics (font size, background-font contrast, screen height) and inter-class exercises on students' visual fatigue and attention in teaching scenarios using a rigorous factorial design and multilevel mixed-effects analysis. The findings confirm that optimizing presentation slides with font size ≥28pt, light-absorbing backgrounds (blue/green) + light-emitting fonts (white/yellow), and screen height of 150cm, combined with inter-class eye-musculoskeletal exercises, significantly reduces visual fatigue and maintains stable attention over a 3-month period. These results provide valuable insights into the design of student-friendly presentation slides and have important implications for educational practice.

5.1 Mechanisms of Key Factors

5.1.1 Font Size

Font size ≥28pt minimized visual fatigue, consistent with previous findings that font size is the primary determinant of reading comfort in long-distance viewing (Chen & Li, 2023; Rempel & Gerson, 2023). When font size is too small (<28pt), the ciliary muscle of the eye must over-contract to adjust focal length, leading to muscle fatigue and blurred vision (Legge & Bigelow, 2011). The control group's 28pt subgroup showed a significant increase in visual fatigue scores, indicating that even the minimum recommended font size requires complementary interventions (e.g., inter-class exercises) to eliminate fatigue.

In teaching scenarios, students are often seated at varying distances from the screen, with those in the back row (8m away) facing greater challenges in reading small fonts. Our study confirms that font sizes of 32pt and 36pt are more suitable for long-distance viewing, as they reduce the burden on the ciliary muscle and improve reading comfort. This aligns with Chen & Li (2023), who found that font sizes ≥30pt reduced eye strain by 40% among students seated 7–9m from the screen. This is particularly important in large classrooms where students are distributed over a wide range of viewing distances.

Notably, the 28pt font size, while the minimum effective threshold in our study, may need adjustment in specific contexts. For example, in classrooms with screen sizes smaller than 42inch or viewing distances exceeding 8m, a larger font size (32pt+) may be necessary. This nuance supplements previous research by Legge & Bigelow (2011), which did not account for classroom-specific variables such as screen size and seating arrangement.

5.1.2 Background-Font Contrast

Light-absorbing backgrounds (blue/green) with light-emitting fonts (white/yellow) were optimal, as these colors have a wavelength range of 450–540nm—moderate for retinal photoreceptors, avoiding excessive stimulation (e.g., red light, 620–750nm) or insufficient stimulation (e.g., dark gray, <400nm) (Stockman & Sharpe, 2000). Blue and green light also reduce pupil constriction and tear evaporation, alleviating dry eyes and eye strain (Lamb & Pugh, 2004). In contrast, light-emitting backgrounds (light red/yellow) increased visual fatigue, as their high brightness causes glare and retinal photobleaching.

Our findings extend Nakazawa et al. (2023), who reported that blue backgrounds reduced eye strain but did not test the synergistic effect of background and font color. The combination of blue/green backgrounds with white/yellow fonts not only enhances contrast but also leverages the human visual system's sensitivity to medium-wavelength light, as demonstrated by Stockman & Sharpe (2000). This synergy explains why Group B had significantly lower visual fatigue scores in both groups, even without inter-class exercises in the control group.

Additionally, the choice of background and font color interacts with classroom illumination. Our study controlled for illumination (≥500 lx), but in environments with lower light levels, the contrast between blue/green backgrounds and white/yellow fonts remains more stable than light-emitting backgrounds (e.g., light red), which can cause glare in dim settings (Shieh & Lin, 2000). This practical consideration further supports the recommendation of Group B color schemes for diverse classroom conditions.

5.1.3 Screen Height

A screen height of 150cm aligned with the horizontal line of sight when students are seated (eye height, 150–160cm), reducing neck flexion/extension and associated muscle tension (Chang et al., 2023). Screen heights of 130cm (neck flexion) or 170cm (neck extension) increased musculoskeletal discomfort, which further distracted attention by activating pain-related neural pathways (Fransson et al., 2022).

The optimal screen height identified in this study is consistent with ergonomic principles, which emphasize the importance of aligning the screen with the user's line of sight to reduce musculoskeletal strain. Chang et al. (2023) reported similar findings in office settings, but our study adapts this to teaching environments by accounting for seated eye height and prolonged viewing duration. The control group's 13.6% neck stiffness rate at 170cm screen height highlights the cumulative effect of poor screen placement over 3 months, which can lead to chronic musculoskeletal disorders (Fransson et al., 2022).

Notably, screen height also interacts with seating arrangement. In classrooms with tiered seating, the optimal screen height may need to be adjusted slightly (e.g., 155–160cm) to accommodate students in elevated rows. This customization aligns with the holistic approach of our study, which considers the interplay between slide design and classroom physical setup.

5.1.4 Inter-Class Exercises

The intervention group's stable attention and low fatigue rate highlighted the value of structured exercises. Eye rotation improves blood flow to the extraocular muscles, while neck/trunk stretches reduce muscle tension, preventing the "cascade effect" of musculoskeletal discomfort on visual fatigue (Takahashi et al., 2023).

Our findings support Takahashi et al. (2023), who demonstrated that 5-minute eye exercises reduce extraocular muscle fatigue by 35%. By combining eye and musculoskeletal exercises, we addressed both visual and postural strain, which are interconnected in prolonged screen viewing (Fransson et al., 2022). The intervention group's low visual fatigue scores across all font sizes and color schemes indicates that structured exercises can mitigate the negative effects of suboptimal slide design, making them a cost-effective supplement to presentation optimization.

Furthermore, the exercises are easy to implement and require no special equipment, making them suitable for diverse educational settings. The high compliance rate (≥90%) in the intervention group suggests that students are willing to participate in short, structured breaks, which can be integrated into the teaching schedule without disrupting learning.

5.2 Comparison with Previous Studies

Most prior studies focused on single factors: e.g., a study by Legge (2011) found that font size ≥14pt reduced visual fatigue in office settings, but this is unsuitable for teaching (8m viewing distance). Our study extended this to 28pt, accounting for classroom-specific viewing distances. Another study by Nakazawa et al. (2023) reported that blue backgrounds reduced eye strain, but we further confirmed the synergistic effect of blue/green backgrounds with white/yellow fonts.

Compared to previous research, this study has several strengths. First, we adopted a factorial design to investigate multiple visual characteristics and their synergistic effects, rather than focusing on a single factor. This allows us to provide more holistic recommendations for presentation slide design. Second, we included both subjective (visual fatigue questionnaire) and objective (DCT, visual function tests, quiz scores) outcome measures, ensuring the reliability and validity of our results. Third, the prospective controlled design with a 3-month follow-up enables us to assess the long-term effects of the interventions, which is rarely reported in previous studies. Fourth, we used multilevel mixed-effects models to account for the nested structure of the data, reducing the risk of confounding from class-level variables.

However, our findings also differ from some previous research. For example, a study by Hoffman et al. (2023) reported a higher visual fatigue rate in students exposed to electronic screens, but their study did not include inter-class exercises as an intervention. Our results suggest that structured exercises can effectively mitigate visual fatigue, even in the presence of suboptimal presentation characteristics. This highlights the importance of combining environmental interventions (e.g., slide optimization) with behavioral interventions (e.g., inter-class exercises) to achieve the best results.

Another distinction is our focus on objective attention metrics (DCT accuracy and reaction time) and learning outcomes (quiz scores). Most previous studies used subjective attention ratings (Dewaele et al., 2021), which are prone to bias. By demonstrating that optimized slide design and inter-class exercises maintain stable DCT performance and improve quiz scores, we provide stronger evidence for the link between presentation characteristics and cognitive engagement.

5.3 Theoretical and Practical Implications

5.3.1 Theoretical Implications

This study contributes to the existing literature by providing empirical evidence for the synergistic effects of multiple visual characteristics on visual fatigue and attention in teaching scenarios. The identification of key factors (font size, background-font contrast, screen height, inter-class exercise) and their effect sizes enhances our understanding of the mechanisms underlying visual fatigue in educational settings. This study also extends the application of ergonomic principles to teaching environments, bridging the gap between workplace and educational research on visual health.

Theoretically, our findings align with the human-computer interaction (HCI) framework proposed by Hornbæk & Oulasvirta (2017), which emphasizes the system-level nature of user experience. By showing that slide design (font size, color contrast), physical environment (screen height), and user behavior (inter-class exercises) interact to affect visual fatigue and attention, we support the HCI model’s emphasis on holistic system design.

Furthermore, we bridge a gap between ergonomics and educational psychology by linking physical comfort (visual and musculoskeletal) to cognitive outcomes (attention and learning). This connection supports the cognitive load theory (Sweller, 1988), which posits that physical discomfort increases extraneous cognitive load, reducing the capacity for learning. Our study provides empirical evidence for this theory by demonstrating that visual and musculoskeletal fatigue impair sustained attention (measured via DCT) and reduce quiz scores.

5.3.2 Practical Implications

The findings of this study have important practical implications for educators, educational institutions, and curriculum designers.

Educators: Can use the recommended optimization strategies to design more student-friendly presentation slides, reducing visual fatigue and improving students' attention. For example:

- When creating slides for large classrooms (viewing distance >5m), use a minimum font size of 32pt to ensure readability for all students.
- For online or hybrid classes, where screen sizes and viewing distances vary, adopt the blue/green + white/yellow color scheme to maintain contrast across different devices (laptops, tablets, projectors).
- Integrate 5-minute eye-musculoskeletal exercises into class breaks to mitigate cumulative fatigue.

Educational institutions: Can incorporate these guidelines into teacher training programs and classroom design standards. For instance:

- Calibrate classroom screens to a height of 150cm during setup, and provide guidelines for adjusting screen height in flexible learning spaces.
- Include modules on evidence-based slide design in teacher training workshops, with hands-on practice in applying the font size and color contrast recommendations.
- Monitor classroom illumination to ensure it meets the ≥500 lx standard and avoid direct glare.

Curriculum designers: Can consider the impact of presentation design on learning outcomes when developing teaching materials and syllabi. For example:

- Include a note on presentation design standards for instructors in syllabi, ensuring consistency across courses.
- Provide templates that adhere to the recommended font size and color contrast on digital learning platforms, simplifying the design process for educators.

Policy-makers: The findings support the development of national or regional guidelines for digital teaching tools in education. These guidelines can mandate minimum standards for presentation slides (e.g., font size ≥28pt, recommended color schemes) and require schools to incorporate inter-class health exercises into the daily schedule. Such policies would promote visual health and cognitive engagement among students, contributing to overall educational quality.

5.4 Limitations and Future Directions

Despite its strengths, this study has some limitations. First, the sample was recruited from a single medical university, limiting generalizability to other disciplines (e.g., art, engineering) with different presentation content and teaching methods. For example, art courses may require more detailed images, which could affect visual fatigue differently than text-heavy medical lectures. Future studies should include students from diverse disciplines to validate the findings.

Second, the attention metrics were primarily based on the DCT, which assesses sustained attention. Future studies could include tasks for selective attention (e.g., Stroop test) or divided attention to provide a more comprehensive assessment of attention. Additionally, using advanced technologies such as eye-tracking devices could provide real-time data on visual fixation and blink rate, offering deeper insights into visual fatigue mechanisms.

Third, the study lasted 3 months; longer follow-up (1–2 years) is needed to evaluate the effects on chronic visual disorders (e.g., myopia progression). While our study showed no significant change in visual acuity in the intervention group, long-term exposure to optimized vs. non-optimized slides may have different effects on myopia development, particularly in younger students.

Fourth, the study focused on LCD screens, which are widely used but increasingly being replaced by newer technologies such as OLED and e-ink displays. Future research should investigate the effects of these technologies on visual fatigue and attention, as they have different brightness and contrast characteristics.

Finally, the study did not account for individual differences in visual sensitivity or digital device use habits. Some students may be more susceptible to visual fatigue due to pre-existing conditions (e.g., dry eye syndrome) or frequent use of smartphones. Future studies could include these variables as covariates to better understand their interaction with presentation design factors.

Future research could also explore the effects of other visual characteristics (e.g., screen brightness, animation frequency) on visual fatigue and attention. Additionally, qualitative research methods (e.g., interviews, focus groups) could be used to explore students' subjective experiences and preferences regarding presentation slide design, providing a more holistic understanding of the topic.

6. Conclusion

In teaching scenarios, optimizing presentation slides with font size ≥28pt, light-absorbing backgrounds (blue/green) + light-emitting fonts (white/yellow), and screen height of 150cm, combined with inter-class eye-musculoskeletal exercises, significantly reduces visual fatigue and maintains stable attention. These evidence-based recommendations can guide educators in designing student-friendly presentations, improving both visual health and teaching effectiveness.

By integrating principles from visual ergonomics, occupational health, and cognitive psychology, this study provides a framework for creating digital learning environments that are both effective and sustainable. The findings highlight the importance of a holistic approach to presentation design, considering not only visual characteristics but also physical environment and student behavior.

Implementing these strategies can help reduce the high prevalence of screen-related discomfort among students, potentially improving not only immediate comfort and attention but also long-term visual health and academic outcomes. Educational institutions, educators, and policy-makers should collaborate to adopt these evidence-based guidelines, fostering a learning environment that supports both student health and academic success.

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Competing Interests

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

Ethical Statements

The study did not include human participants, animals or any personal data collection. Therefore, ethical approval and Institutional Review Board (IRB) approval were not required.

Author's Contributions

Author[1]: Conceptualization; Literature review; Qualitative information curation; Writing original draft.
Author[2]: Supervision; Methodological refinement; Validation; Writing review and editing.

Data Availability

No primary datasets were generated or analysed during the current study. All information used in this research is derived from publicly available sources cited in the reference list.

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