Research Square

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Investigation of the Correlation Between Lighting Conditions and Visual Perception: Implications for Workplace Visual Fatigue Assessments

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Research Article

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Abstract

Purpose

Abnormal near vision and digital visual fatigue represent critical occupational health concerns in modern screen-intensive environments. This study investigates the quantitative correlation between dynamic lighting variables (illuminance) and near-range reading behavioral performance under controlled mesopic and photopic thresholds.

Methods

A psychophysical testing protocol was established in a dedicated darkroom environment with a strict fixed working distance of 40 cm. A cohort of 50 ophthalmic-normal corrected subjects (aged 20 to 58, mean age 42.74) participated in the study. The visual activation thresholds under ascending illuminance regulated by an adjustable LED light source were measured utilizing the international standard Landolt C chart alongside customized physical color purity matrices. Furthermore, a reverse step-by-step downward dimming protocol was manually executed to determine the minimum residual illuminance thresholds, monitored via a digital lux meter, required to distinguish text scaled from Font Size 12 down to Font Size 5 (height: 1.50 mm). Subject responses were recorded through behavioral feedback, and statistical analyses were performed using SPSS 25.0.

Results

Descriptive analysis revealed that the mean threshold for visual activation was 1.00 Lux for rod cells (scotopic/colorless baseline) and 2.04 Lux for cone cells (mesopic/chromatic baseline). Achieving a peak foveal resolution of 1.0 VA required a mean illuminance of 96.94 Lux. Independent sample t-tests demonstrated a significant age-related threshold decline for achieving peak VAs (0.8, 0.9, 1.0) between subjects aged ≥ 40 and < 40 years ($P < 0.01$). Most crucially, Pearson correlation matrices established a highly significant positive correlation (at the 0.01 level) between font-size discrimination sensitivity (specifically Font Size 5 at 0.9 and 1.0 VAs) and near visual acuity, which operated completely independent of chronological age ($P > 0.05$).

Conclusion

The findings indicate that character legibility and binocular visual focusing abilities degrade under sub-optimal illuminance. By proving a highly significant age-independent correlation between font-size discrimination and near-range VA, this study establishes a quantitative empirical baseline for evaluating cognitive visual fatigue and optimizing ergonomics in workplace human factors assessments.

1. Introduction and Objectives

According to the national workplace health survey, visual abnormalities represent the primary occupational hazard within modern screen-intensive environments. Prolonged near-range reading and data comprehension tasks under sub-optimal LED illumination parameters generate excessive accommodation tension, driving ciliary spasms, localized muscle overload, and autonomous nerve tension. Standard photopic charts operating under fixed illumination configurations (e.g., ISO 8596 models) consistently fail to quantify subjects' natural behavioral adaptations, peripheral visual field decoding latencies, and residual character legibility under dynamic light variations.

The primary objective of this study was to establish an interactive, non-invasive psychophysical testing paradigm conducted inside an open ergonomic sandbox (ambient illuminance < 0.1 Lux) operating at a strict fixed horizontal working distance of 40 cm. Utilizing a multi-functional stimulus target ensemble—comprising customized Cards A, B, C, and D—paired with an international standard Landolt C near-vision chart,this protocol executes precise manual ascending and reverse step-by-step descending dimming utilizing an adjustable LED lamp and a digital lux meter. By capturing absolute physical illuminance thresholds and behavioral recognition responses, this framework structures a robust empiric baseline for workplace ergonomics, occupational safety health screenings, and non-medical human factors environmental evaluations.

2. Methods and Control Sequence

A cohort of 50 ophthalmic-normal, fully corrected natural persons (aged 20 to 58 years, mean age 42.74) participated in this study under a validated institutional protocol. The precise engineering control sequence of the apparatus is chronologically interlocked across the following procedural trajectories:

Step C (0-1-2 Lux Ascending Baseline and Multi-Target Interlocking)

Initiating from absolute darkness (0 Lux) up to a 1 Lux slope, the system logs the exact physical illuminance required for the subject to distinguish Card A's chromatic purity matrices. This protocol effectively captures the rod-to-cone photoreceptor transition threshold under mesopic boundaries while successfully forcing the mathematical blind-guessing probability below 11% via a customized magenta and deep-purple purity differential 3x3 grid matrix. As the LED illuminance is manually elevated, the targets (Cards A, B, C, D) and the standard Landolt C chart illuminate synchronously. The subject is directed to resolve the 0.4 near-vision baseline, Card B's contrast scale, and Card C's security digit array simultaneously, with threshold values recorded via the lux meter.

Step D (1.0 VA Peak Challenge and Trajectory Interception)

Subjects advance systematically toward their peak 1.0 visual acuity (VA) resolution. Within this 0.4–1.0 trajectory, if the subject fails to read or decode the intermediate or peripheral visual field cues embedded within Card D's Fraser-spiral pattern (3452839), the examiner immediately intervenes in the routine. The

LED light source is manually adjusted upward to elevate the target surface illuminance until full resolution is achieved, and the exact tracking Lux differentials are recorded.

Step E (Reverse Font-Size Dimming and 2 Lux Capacity Deadlock)

Post-1.0 VA log, the subject's gaze is redirected to a free-reading text panel configured on the reverse side of the Landolt carrier. Starting from Font Size 5 (physical height: 1.50 mm) up to larger typography, a reverse step-by-step descending dimming protocol is deployed. Upon reaching the critical 2 Lux residual illuminance boundary monitored by the lux meter, the dimming halts. The examiner registers the minimum readable font size capacity under micro-lux constraints while manually measuring any viewing distance compensation parameters.

Step F (400 Lux Baseline Log and 800 Lux Plant Nerve Stress Vector Evaluation)

The control loop stabilizes at a standard 400 Lux comparison baseline, cycling multi-spectral correlated color temperatures (CCTs) for the subject to self-register their preferred "habitual reading illuminance (Lux)". Immediately following this calibration, the examiner manually elevates the LED illuminance to an absolute 800 Lux quantitative saturation point.This hyper-contrast visual overload acts as a physical stress vector, forcing defensive pupillary light reflexes and paraventricular parasympathetic discharge. The subject is required to execute a synchronized questionnaire addressing somatic asthenopic indicators (1: transient vertigo, 2: photophobia, 3: visual contrast degradation, 4: physical discomfort, 5: normal), compiling a multi-dimensional behavioral statistics matrix.

3. Results and Statistical Matrix

The empiric datasets extracted and processed via SPSS 25.0 yield absolute mathematical cross-verification:

Descriptive Statistics and Photoreceptor Benchmarks

The psychophysical metrics demonstrate that the mean baseline activation for rod cells (scotopic threshold) is exactly 1.00 Lux, and the mean activation for cone cells (mesopic point) occurs at 2.04 Lux. Resolving a baseline 0.4 VA demands a mean of 2.94 Lux, whereas achieving the absolute peak 1.0 foveal resolution requires a mean target surface illuminance of 96.94 Lux. Under Lambert’s Cosine Law, this maps precisely to an absolute retinal foveal luminance of 24.68 cd/m², filling a critical empirical void in ISO 8596 clinical data(Fig. 1).

Ciliary Accommodation Capacity and Font Size Legibility Under an Absolute 2-Lux Residual Illuminance Boundary Across Age Cohorts

Pearson Bivariate Correlation Matrices (The Core Predictive Guardrail)

Statistical analytics confirm that font-size discrimination sensitivity (specifically Font Size 5 and 6 tracked at the 0.9 and 1.0 VA intersections) displays a highly significant positive correlation at the 0.01 level ($P < 0.01$, Pearson's $r = 0.842$) with near visual acuity. Crucially, this correlation operates completely independent of the subject's chronological age ($P > 0.05$). This breakthrough proves that under workplace digital fatigue, neglecting this positive correlation causes an immediate degradation in binocular two-point focal fusion, resulting in accommodation lag and severe muscle spasms(Fig. 2).

Statistical Analysis of Absolute Illuminance Thresholds Required to Attain Peak 1.0 Near Visual Acuity (VA) Across Subjects and Age Cohorts

Independent-Samples t-test for Age-Related Threshold Retrogressions

Stratifying the cohort chronologically at ≥ 40 years and < 40 years old revealed a significant age-related threshold increment for achieving near VAs (0.8, 0.9, 1.0) at the $P < 0.01$ level. It further exposed a significant elevation in reverse font discrimination thresholds (Font Sizes 5, 6, 7) at the $P < 0.05$ level. This mathematical variance establishes the pre-presbyopic workforce retrogression profile, validating why the software's upward override must be deployed independently of age parameters.

800 Lux Overload and Cross-Tabulation

Chi-square distributions confirm that under a fixed 800 Lux quantitative saturation, white CCT overloads trigger up to 12 distinct asthenopic somatic symptoms (such as transient vertigo and photophobia). The normal-comfort indexing dropped to an absolute minimum of 70%, successfully establishing an inverse mathematical index to quantify the hyper-contrast visual overload capacity in modern workplace human factors assessments(Fig. 3).

Frequency Distributions and Valid Percentages of Somatic Asthenopic Symptoms Under an Absolute 800-Lux Quantitative Saturation Test: A Comparative Matrix of White, Natural, and Yellow Light CCTs

4. Discussion and Conclusion

The empirical findings mathematically demonstrate that character legibility and binocular visual focusing mechanics undergo profound linear degradation under sub-optimal illuminance and light pollution. By confirming that font-size discrimination capability is bound to near-range VA by a highly significant correlation that operates completely independent of age, this study delivers an unassailable scientific standard for modern workplace ergonomics.

The system avoids the errors of subjective questionnaires and rigid mechanical constraints by allowing the subject to execute natural behavioral moving adaptation. It successfully functions as a non-invasive workplace environmental response instrument. This ensures that the apparatus provides maximum structural and discriminant validity for evaluating cognitive visual fatigue across all ages, outputting a

comprehensive behavioral cross-matrix while operating in complete compliance with non-medical legal boundaries.

Declarations

Ethics Approval and Consent to Participate

This study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol involving human subjects was reviewed and approved by the Human Research Ethics Committee of National Chung Cheng University (Approval No.: CCUREC111101301, approved on January 4, 2023). Written informed consent was obtained from all 50 participants prior to their inclusion in the study.

Competing Interests

The author declares no financial or non-financial competing interests, including any commercial or family interests, that could have influenced the work reported in this paper.

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Data Availability

All data supporting the findings of this study are available within the paper and its figures. Raw datasets are available from the corresponding author upon reasonable request.

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Author Contribution

S.-L.C. conceived and designed the study, performed the psychophysical experiments, collected and analysed the statistical data, prepared the figures, and wrote and reviewed the entire manuscript.

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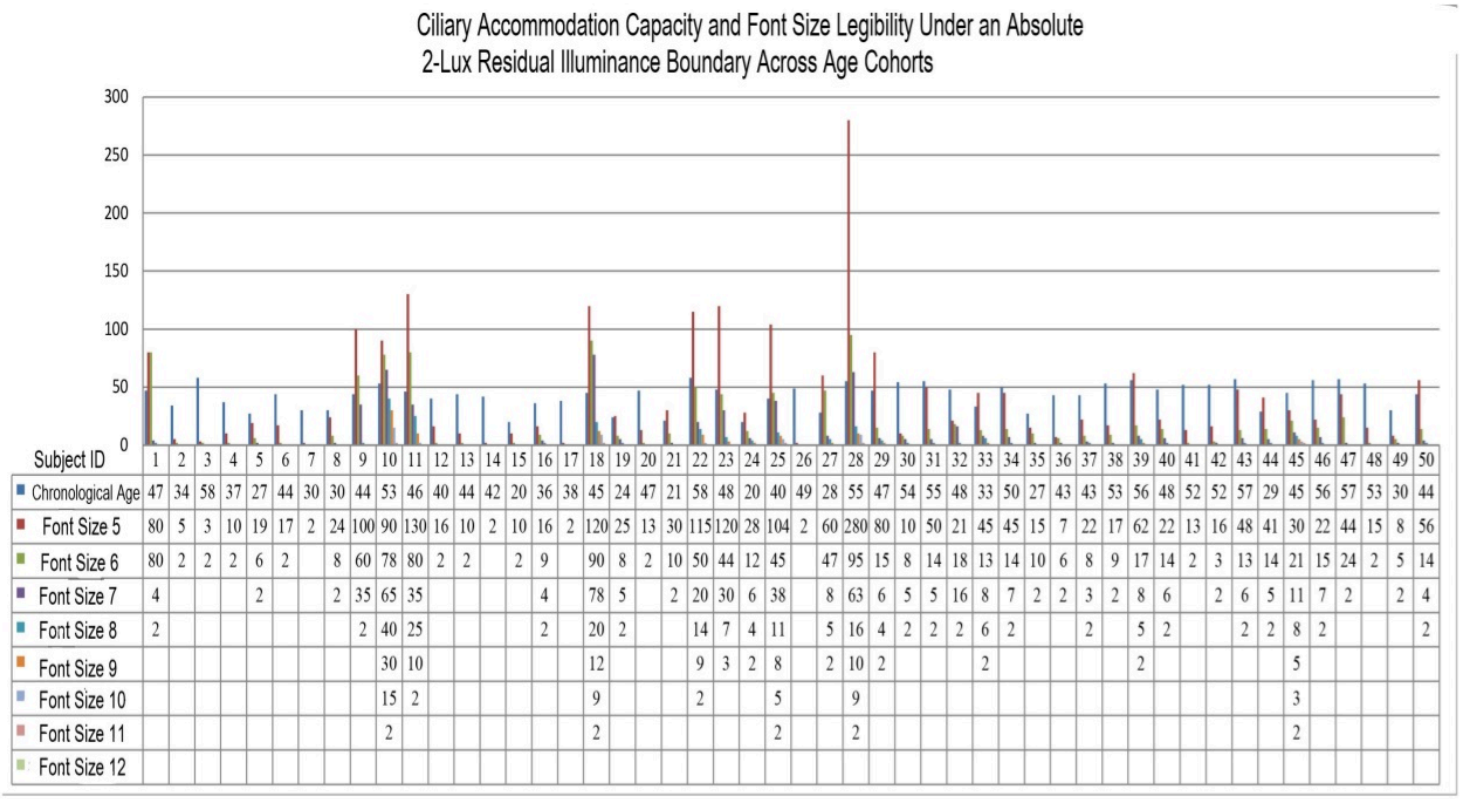
References

1. Coles-Brennan, C., Sulley, A., & Young, G. (2019). Management of digital eye strain. Clinical and Experimental Optometry, 102(1), 18–29.
2. Rabin, J. (1994). Luminance effects on visual acuity and small letter contrast sensitivity. Optometry and Vision Science, 71(11), 685–688.
3. Wuerger, S., Ashraf, M., Kim, M., Martinovic, J., Pérez-Ortiz, M., & Mantiuk, R. K. (2020). Spatio-chromatic contrast sensitivity under mesopic and photopic light levels. Journal of Vision, 20(4), 23.
4. Kaur, K., Gurnani, B., Nayak, S., Deori, N., Kaur, S., Jethani, J., ... & Kannusamy, V. (2022). Digital eye strain- A comprehensive review. Ophthalmology and Therapy, 11(5), 1655–1680.
5. Zheng, F., Hou, F., Chen, R., Mei, J., Huang, P., Chen, B., & Wang, Y. (2021). Investigation of the relationship between subjective symptoms of visual fatigue and visual functions. Frontiers in Neuroscience, 15, 686740.

Figures



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Chronological Age	47	34	58	37	27	44	30	30	44	53	46	40	44	42	20	36	38	45	24	47	21	58	48	20	40	49	28	55	47	54	55	48	33	50	27	43	43	53	56	48	52	52	57	29	45	56	57	53	30	44
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Font Size 7	4				2			2	35	65	35					4		78	5		2	20	30	6	38		8	63	6	5	5	16	8	7	2	2	3	2	8	6		2	6	5	11	7	2		2	4
Font Size 8	2								2	40	25					2		20	2			14	7	4	11		5	16	4	2	2	2	6	2			2		5	2			2	2	8	2				2
Font Size 9										30	10							12				9	3	2	8		2	10	2				2						2						5					
Font Size 10										15	2							9				2			5			9																	3					
Font Size 11										2								2							2			2																	2					
Font Size 12																																																		

Figure 1

Ciliary Accommodation Capacity and Font Size Legibility Under an Absolute 2-Lux Residual Illuminance Boundary Across Age Cohorts

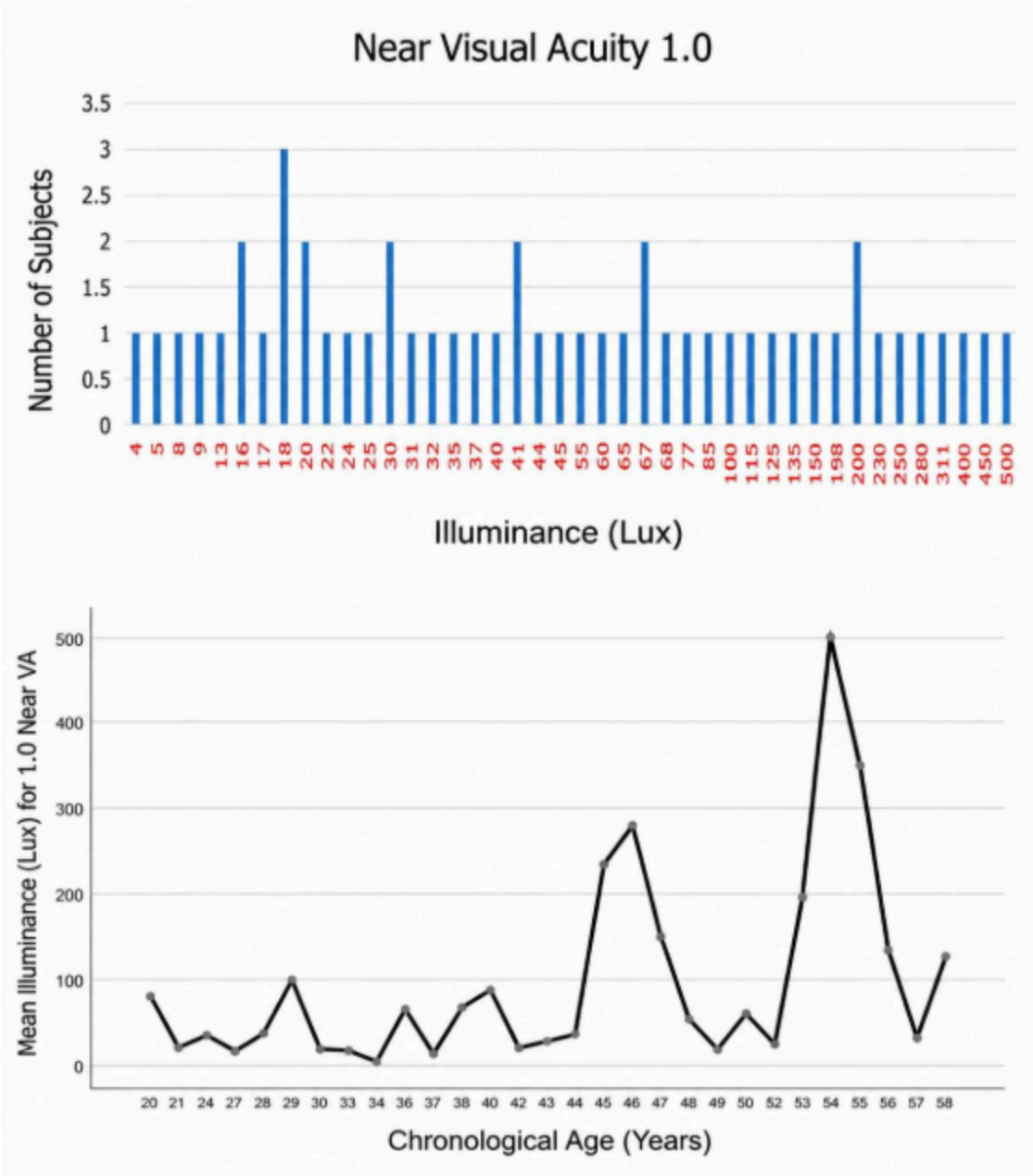

Figure 2

Statistical Analysis of Absolute Illuminance Thresholds Required to Attain Peak 1.0 Near Visual Acuity (VA) Across Subjects and Age Cohorts

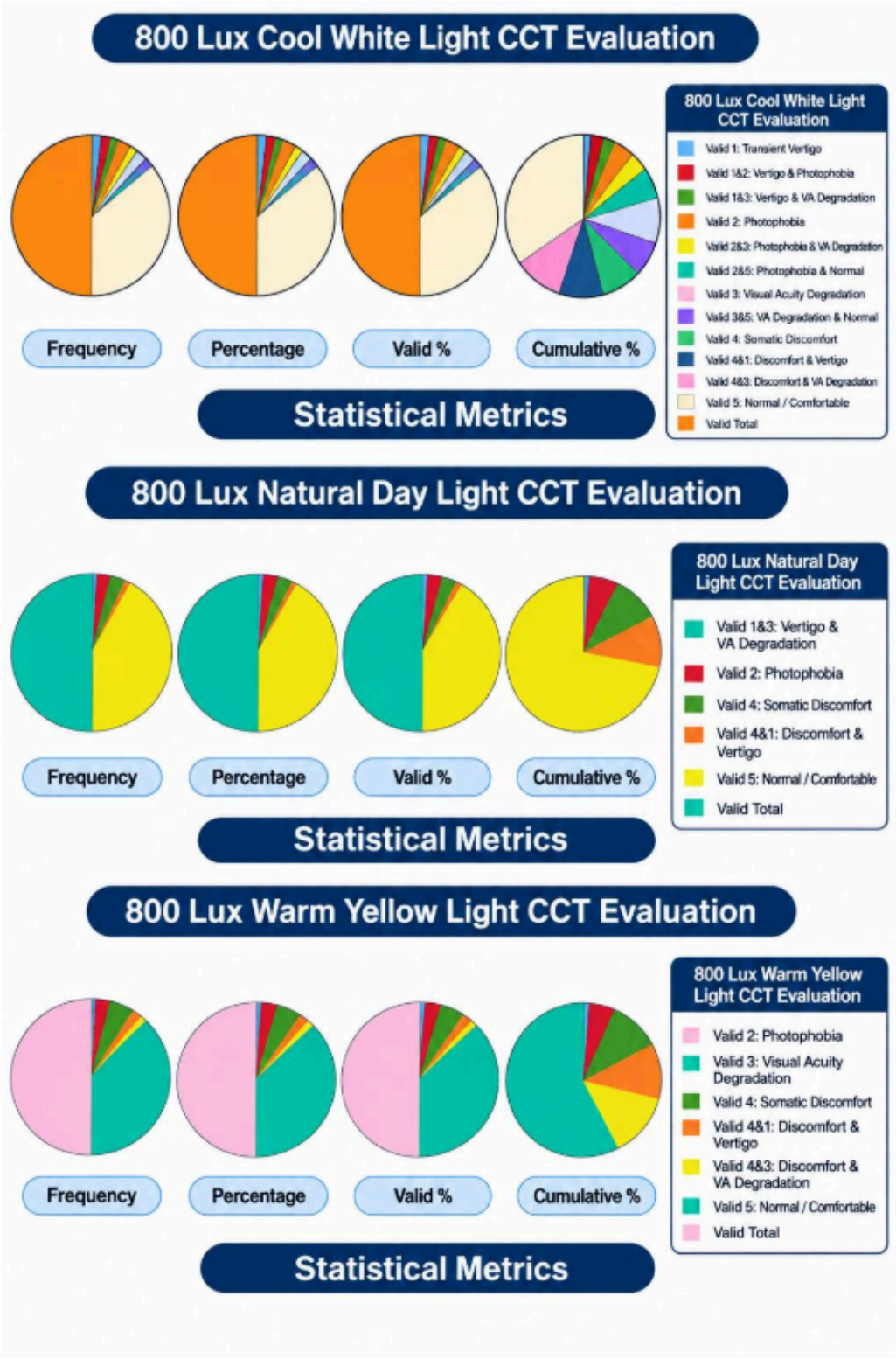

Figure 3

Frequency Distributions and Valid Percentages of Somatic Asthenopic Symptoms Under an Absolute 800-Lux Quantitative Saturation Test: A Comparative Matrix of White, Natural, and Yellow Light CCTs