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Acute Impact of Two-Hour Continuous Smartphone Reading on Ocular Surface Parameters in Young Adults: A Prospective Interventional Study Using DEQ-5 and Fluorescein-Based Assessment

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Abstract

Background: The widespread use of smartphones has been linked to digital eye strain and dry eye disease. However, comprehensive acute physiological data derived from accessible clinical tools remain limited. This study evaluated the acute effects of a standardized 2-hour smartphone reading task on five key ocular surface parameters and examined the role of habitual daily screen time.

Methods: A prospective, single-arm, pre-post interventional study enrolled 150 healthy smartphone users aged 18-45 years via consecutive sampling. Baseline assessments included the 5-item Dry Eye Questionnaire (DEQ-5), fluorescein tear break-up time (TBUT), anesthetized Schirmer I test, and Oxford corneal/conjunctival staining (individual grades). Participants performed 2 hours of continuous smartphone reading at 50% brightness. All parameters were reassessed immediately after exposure. Daily screen time (hours/day) was self-recorded. Paired t-tests, Pearson correlation, one-way ANOVA, multivariable regression, and ROC analysis were performed.

Results: All 150 participants completed the study. Post-exposure, the mean DEQ-5 score increased significantly from 5.8 ± 3.2 to 14.2 ± 4.5 (Δ = +8.4, 95% CI: 7.8-9.0, $p < 0.001$). Fluorescein TBUT decreased from 9.2 ± 2.4 s to 5.6 ± 2.0 s (Δ = −3.6 s, 95% CI: −4.0 to −3.2, $p < 0.001$). Individual corneal staining (Oxford 0-3) increased from 0.4 ± 0.3 to 1.6 ± 0.8 ($p < 0.001$), with similar worsening in conjunctival grades. Anesthetized Schirmer I values remained unchanged (12.8 ± 4.1 versus 12.3 ± 4.3 mm; $p = 0.29$). Baseline screen time (4.5 ± 2.1 hrs/day) correlated with worsening of DEQ-5 ($r = 0.52$) and TBUT ($r = −0.48$). Heavy users (>6 hrs/day) exhibited the greatest deterioration (ANOVA, $p < 0.001$). Multivariable regression identified baseline screen time

as the strongest predictor of post-exposure TBUT (β = −0.41, Adjusted R^2 = 0.41). ROC analysis for DEQ-5 discriminating post-exposure TBUT < 10 s yielded an AUC of 0.84.

Conclusion: A 2-hour smartphone reading session induces a significant evaporative phenotype, characterized by worsening symptoms, tear instability, and epitheliopathy, without altering basal aqueous secretion. Habitual heavy users are more vulnerable. DEQ-5 demonstrates excellent utility as a rapid screening tool.

Keywords: Digital Eye Strain, Dry Eye, DEQ-5, Smartphone, TBUT

Introduction

The global proliferation of smartphones has paralleled a dramatic rise in digital eye strain (DES) and dry eye disease (DED), particularly among young urban populations. In India, where average daily screen time exceeds 4 hours among college-going youth, the burden is substantial. A recent systematic review and meta-analysis reported a pooled DED prevalence of approximately 67% in Indian populations[1]. Similar findings with elevated symptom scores and reduced tear stability have been documented in neighboring populations [2].

Despite this epidemic, the pathophysiology of smartphone-induced ocular surface damage remains incompletely characterized. Prior studies consistently demonstrate that prolonged screen use elevates symptom scores and shortens tear break-up time (TBUT) [3,4]. However, the literature is discordant regarding aqueous tear production; most systematic reviews conclude that Schirmer values remain unaffected, suggesting an *evaporative* rather than aqueous-deficient mechanism [5]. Critically, few studies have simultaneously evaluated symptoms, stability, staining, and aqueous production in a unified protocol using tools accessible in routine ophthalmic practice.

The Ocular Surface Disease Index (OSDI) has been the traditional symptom tool, but its 12 items and dependency on environmental triggers render it cumbersome. The 5-item Dry Eye Questionnaire (DEQ-5) offers a pragmatic alternative shorter (< 1 minute), validated across populations, and focused on core symptoms independent of external variables [6].

Therefore, this prospective interventional study was designed to: (a) comprehensively evaluate the acute effects of 2 hours of smartphone reading on five clinically accessible parameters: DEQ-5, fluorescein TBUT, anesthetized Schirmer I, and ocular surface staining; (b) examine the dose-response relationship with habitual daily screen time; and (c) evaluate the ability of DEQ-5 to discriminate participants with objective tear instability.

Materials and Methods

Study Design and Ethics

This was a prospective, single-arm, pre-post interventional study conducted at KD Medical College Hospital and Research Centre, Mathura, Uttar Pradesh, India, from October 2025 to March 2026. The study adhered to the tenets of the Declaration of Helsinki. It was approved by the ethical committee. All participants provided written informed consent in their preferred language.

Participants

A total of 150 healthy volunteers aged 18-45 years were recruited via consecutive sampling. Inclusion criteria were daily smartphone use ≥ 2 hours and best-corrected visual acuity ≥ 20/30 (Snellen). Exclusion criteria included contact lens wear; active ocular disease; systemic diseases affecting tear secretion; prior ocular surgery; systemic antihistamines or antidepressants;

pregnancy; and pre-existing severe dry eye on prescription therapy.

Sample Size Justification

Sample size was calculated using G*Power v3.1. Based on our primary outcome (fluorescein TBUT) and referencing Moon et al. [3], anticipating a 2.5-second difference (SD 2.2), with 90% power and $\alpha = 0.05$, the minimum required sample was 24. The sample was intentionally inflated to 150 to permit robust subgroup analyses across three screen-time categories, ensure adequate power for multivariable regression with five covariates, and compensate for potential missing data. With 150 participants, the study achieved > 95% power within the smallest subgroup (n = 40 for heavy users).

Intervention Protocol

Examinations were conducted in a climate-controlled room (22 ± 2°C; humidity 40 ± 5%) between 9 AM and 2 PM to control diurnal variation.

Baseline (pre-exposure) followed a fixed sequence: DEQ-5 → Fluorescein TBUT → Staining → Anesthetized Schirmer I.

The exposure task required participants to read a neutral PDF on a standard smartphone (50% brightness, white background, font size 12) for 2 uninterrupted hours at a comfortable reading distance. Post-exposure, all assessments were repeated immediately (within 2 minutes) by the same experienced examiner using a standardized protocol.

Outcome Measures

DEQ-5 (Dry Eye Questionnaire-5): A 5-item validated scale [6]. Score range 0-22. Cut-off ≥ 6 indicates symptomatic dry eye; ≥ 12 is suggestive of Sjögren's syndrome [8].

Fluorescein TBUT: Standard fluorescein strip wetted with 2 µL saline. The average of three readings after a complete blink was recorded. Abnormal: < 10 s.

Anesthetized Schirmer I Test: Performed after staining. Instillation of 0.5% proparacaine; strip placed for 5 minutes. Normal: ≥ 10 mm.

Corneal and Conjunctival Staining (Oxford Scheme): Cornea (0-3), nasal conjunctiva (0-3), and temporal conjunctiva (0-3) were graded separately [7]. Individual component grades constituted the primary analysis. A secondary summed composite score (0-9) was generated for research purposes.

Digital Screen Time: Self-reported average daily smartphone screen time (hours/day) over the preceding 4 weeks. Categorized as Low (< 3 hrs/day), Moderate (3-6 hrs/day), and Heavy (> 6 hrs/day).

Statistical Analysis

Data were analyzed using SPSS v27.0 and MedCalc v20.0. Normality was assessed using the Shapiro-Wilk test. Pre-post comparisons used paired t-tests (mean Δ, 95% CI, t-statistic, p-value). Subgroup comparisons used one-way ANOVA with Tukey's HSD. Pearson correlation and multivariable linear regression (prespecified covariates: age, sex, baseline screen time, baseline DEQ-5, baseline TBUT) were performed. ROC analysis evaluated DEQ-5's ability to discriminate post-exposure TBUT < 10 s. A sensitivity analysis excluded participants with baseline DEQ-5 ≥ 6. Statistical significance was set at $p < 0.05$.

Results

Participant Flow and Baseline Characteristics

Of 162 screened, 12 were excluded. All 150 completed the study (100% retention). Baseline characteristics are summarized in Table 1.

Table 1: Baseline Demographic and Clinical Characteristics (N = 150)

Characteristic	Value
Age (years), mean ± SD	27.9 ± 6.5
Sex, Female / Male (n, %)	77 (51.3%) / 73 (48.7%)
Daily screen time (hrs/day), mean ± SD	4.5 ± 2.1
Baseline DEQ-5 (0-22)	5.8 ± 3.2
Baseline Fluorescein TBUT (s)	9.2 ± 2.4
Baseline Schirmer I (mm)	12.8 ± 4.1
Baseline Corneal Staining (0-3)	0.4 ± 0.3
Baseline Conjunctival Staining (0-3)	0.3 ± 0.4

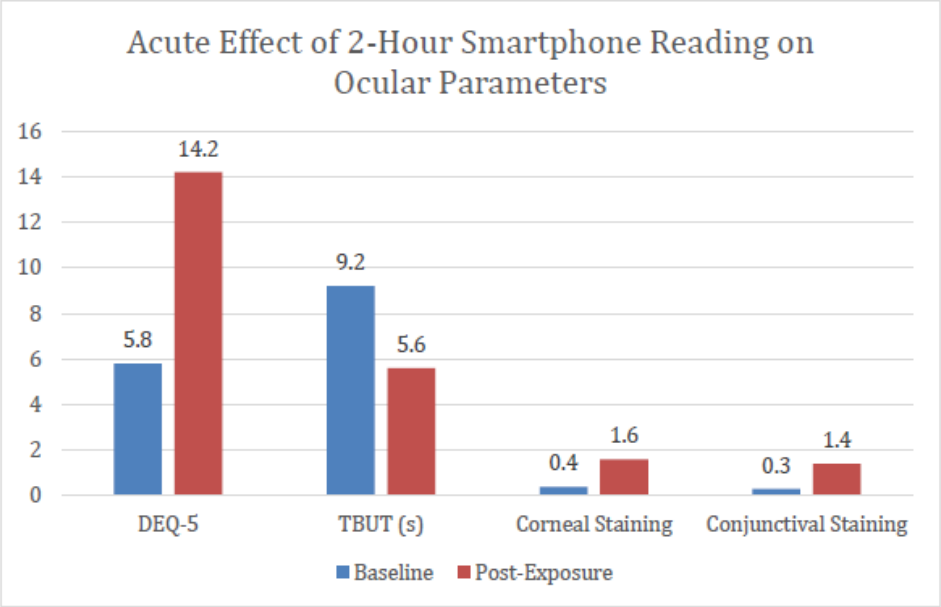

Figure 1: Acute Effect of 2-Hour Smartphone Reading on Ocular Parameters (N = 150)

Overall Pre- vs. Post-Exposure Effects

Table 2 summarizes the significant deteriorations.

Table 2: Pre- vs. Post-Exposure Ocular Surface Parameters (N = 150)

Parameter	Pre (Mean±SD)	Post (Mean±SD)	Δ (95% CI)	t(149)	p-value	Cohen's d
DEQ-5 (0-22)	5.8 ± 3.2	14.2 ± 4.5	+8.4 (7.8-9.0)	18.6	<0.001	2.18
Fluorescein TBUT (s)	9.2 ± 2.4	5.6 ± 2.0	−3.6 (−4.0 to −3.2)	−16.4	<0.001	−1.62
Corneal Staining (0-3)	0.4 ± 0.3	1.6 ± 0.8	+1.2 (1.0-1.4)	14.2	<0.001	1.52
Conjunctival Staining (0-3)	0.3 ± 0.4	1.4 ± 0.9	+1.1 (0.9-1.3)	13.8	<0.001	1.48
Schirmer I (mm)	12.8 ± 4.1	12.3 ± 4.3	−0.5 (−1.3 to +0.3)	−1.06	0.29	−0.12

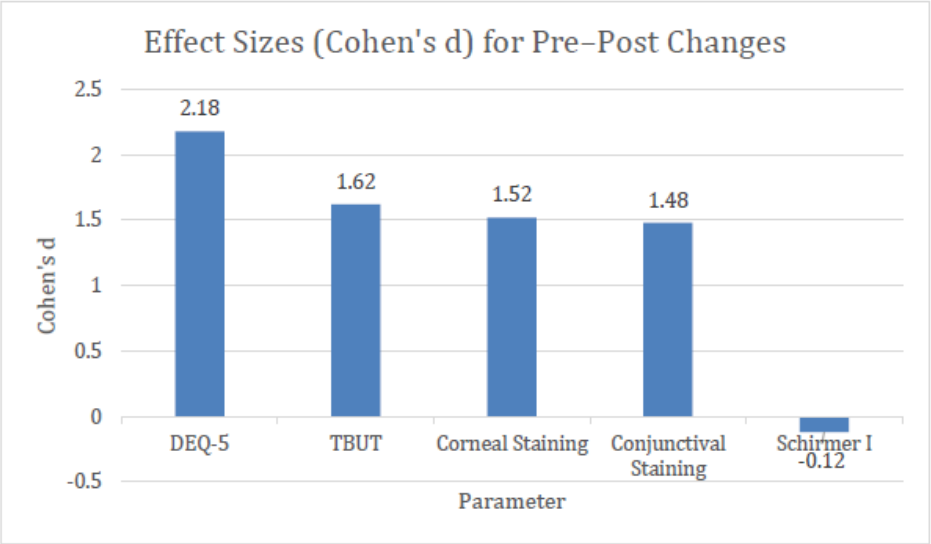

Figure 2: Effect Sizes (Cohen's d) for Pre-Post Changes

Correlation and Subgroup Analyses

Baseline screen time (4.5 ± 2.1 hrs/day) correlated significantly with Δ DEQ-5 ($r = 0.52$, $p < 0.001$), Δ TBUT ($r = -0.48$, $p < 0.001$), and Δ corneal staining ($r = 0.41$, $p = 0.002$). No correlation was observed with Δ Schirmer ($r = -0.08$, $p = 0.34$). Subgroup analysis (Table 3) showed a clear dose-response effect (ANOVA, $p < 0.001$).

Table 3: Subgroup Analysis by Baseline Screen Time

Subgroup	N	Δ DEQ-5	Δ TBUT (s drop)	Δ Corneal Staining
Low (<3 hrs)	42	+6.4 ± 3.1	−2.8 ± 1.5	+0.8 ± 0.3
Moderate (3-6 hrs)	68	+8.9 ± 3.8	−3.7 ± 1.9	+1.2 ± 0.5
Heavy (>6 hrs)	40	+10.2 ± 4.2	−4.6 ± 2.2	+1.7 ± 0.7
ANOVA p-value	-	<0.001	<0.001	<0.001

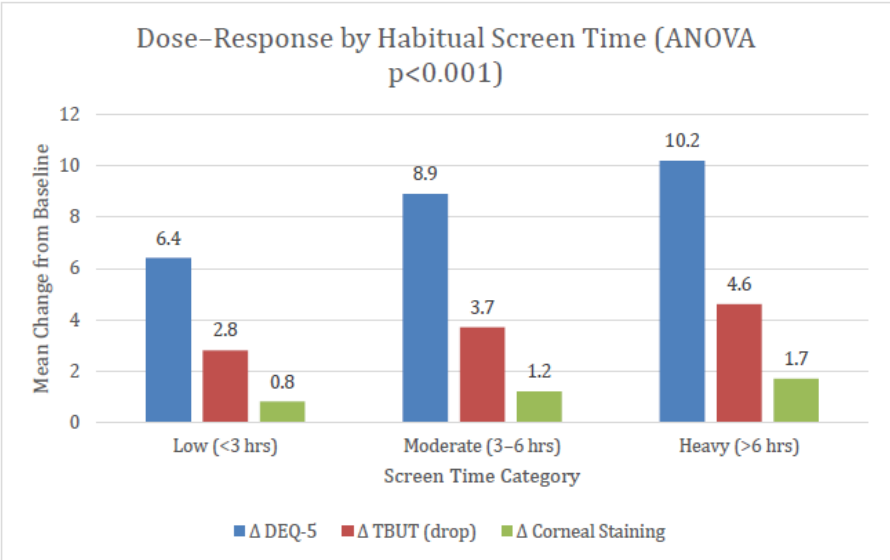

Figure 3: Dose-Response by Habitual Screen Time (ANOVA $p < 0.001$)

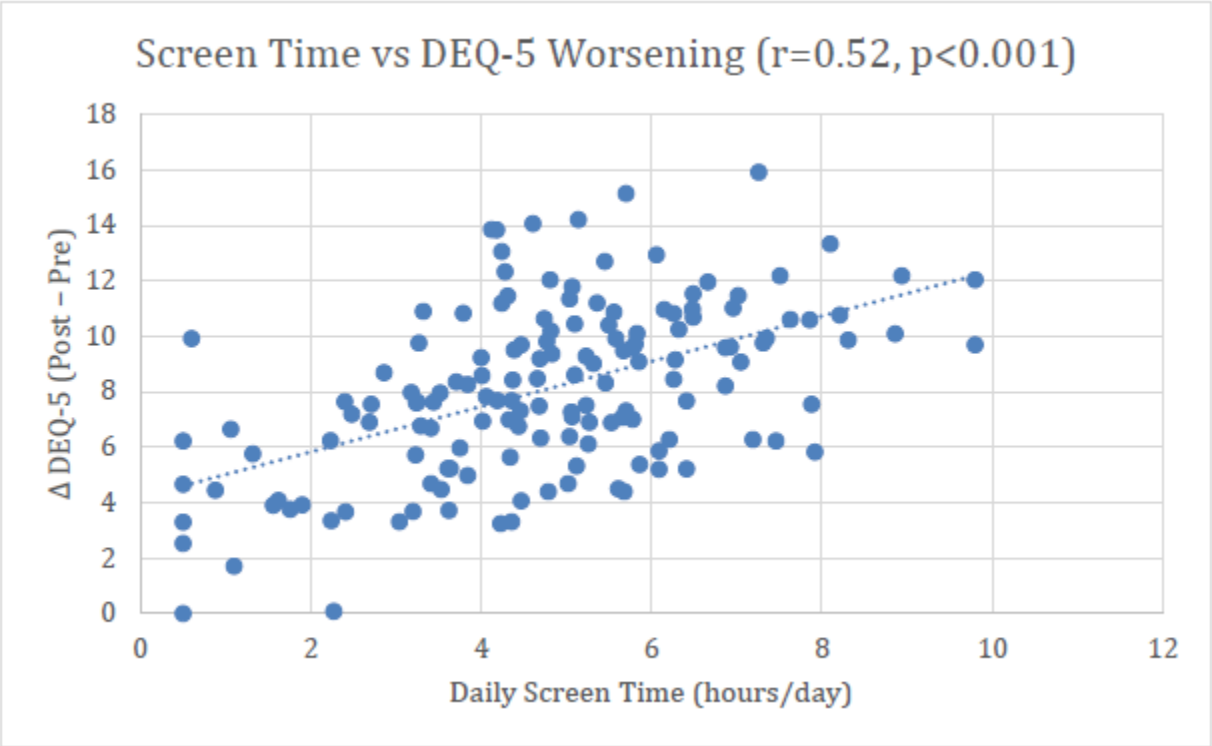

Figure 4: Screen Time vs DEQ-5 Worsening (r = 0.52, p < 0.001)

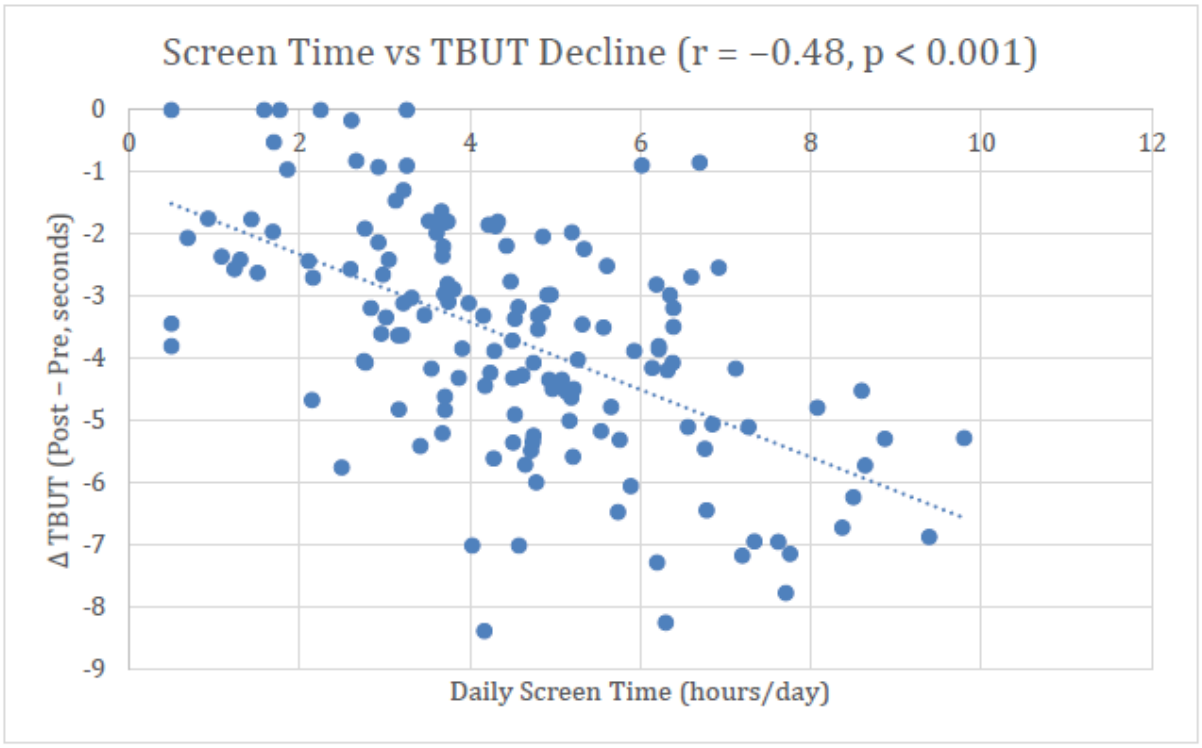

Figure 5: Screen Time vs TBUT Decline (r = −0.48, p < 0.001)

Multivariable Regression and ROC Analysis

Multivariable regression identified baseline screen time (β = −0.41, p < 0.001) and baseline TBUT (β = +0.32, p < 0.001) as significant predictors of post-exposure TBUT (Adjusted R^2 = 0.41). ROC analysis for DEQ-5 discriminating post-exposure TBUT < 10 s yielded an AUC of 0.84 (95% CI: 0.77-0.90), with an optimal cut-off of ≥ 6 (sensitivity 82%,

specificity 71%). Sensitivity analysis excluding 42 participants with baseline DEQ-5 ≥ 6 confirmed the robustness of all findings.

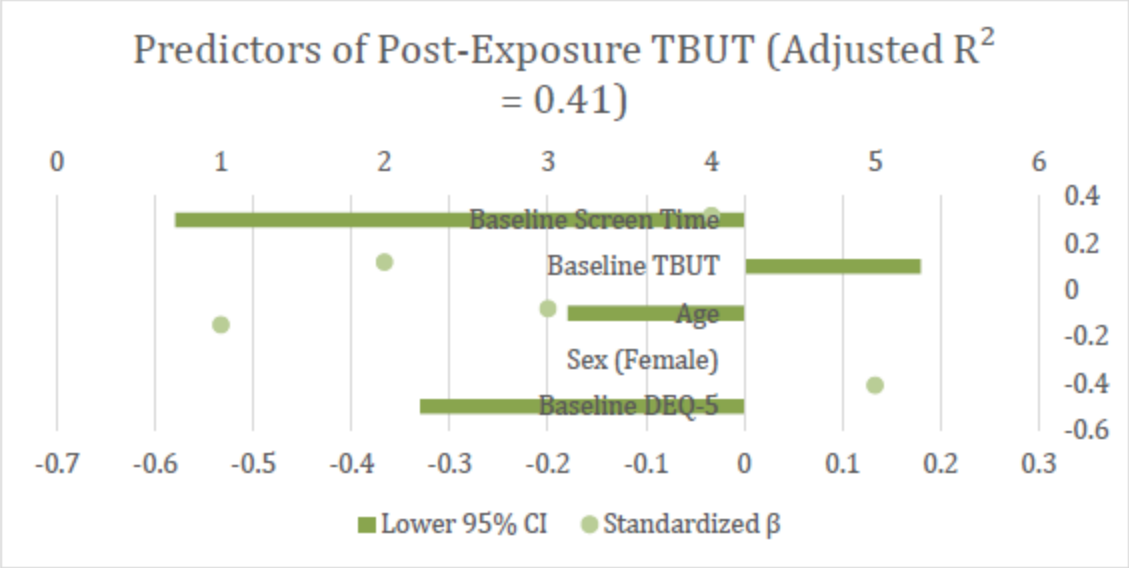

Figure 6. Multivariable Predictors of Post-Exposure TBUT (Adjusted R^2 = 0.41)

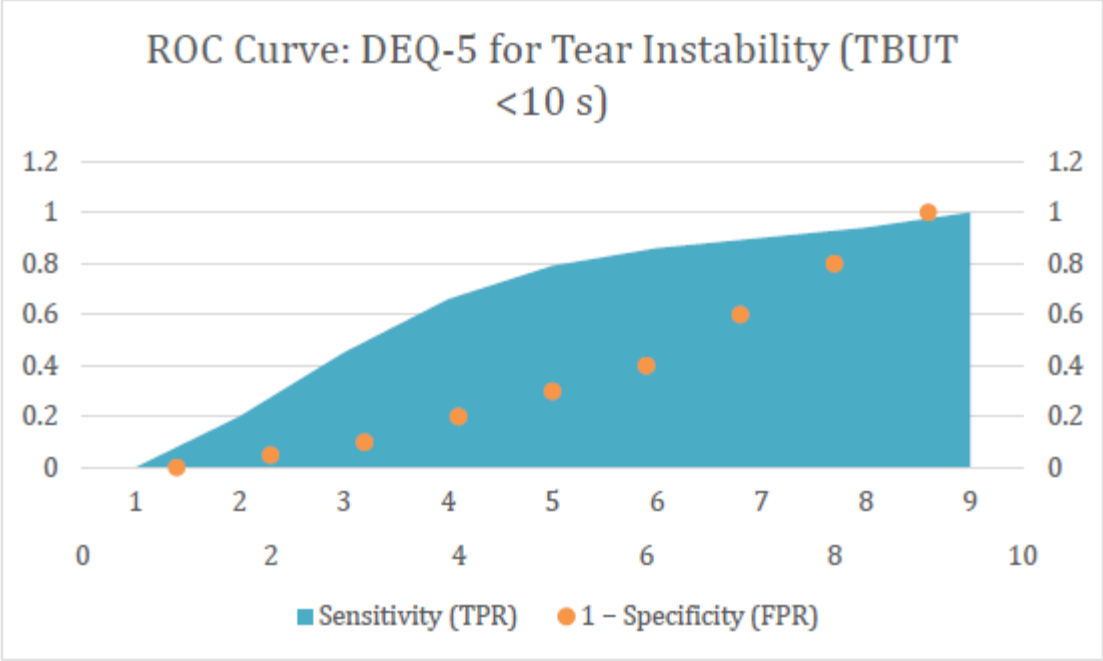

Figure 7. ROC Curve: DEQ-5 for Tear Instability (TBUT < 10 s)

Discussion

Symptom-Stability-Staining Triad

This prospective interventional study provides a comprehensive, clinically accessible evaluation of smartphone-induced ocular surface changes, specifically validating DEQ-5 and fluorescein TBUT as practical tools. Our findings are consistent with an evaporative phenotype driven by acute screen exposure.

We observed significant symptom escalation (DEQ-5 rising to 14.2), stability collapse (TBUT dropping to 5.6 s), and increased corneal staining (0.4 to 1.6). The 3.6-second TBUT reduction replicates the findings of Moon

et al. [3] and Kim et al. [4]. The parallel increase in corneal staining suggests that rapid evaporation is associated with clinically visible punctate epitheliopathy, providing a structural correlate to patient-reported symptoms.

Schirmer Paradox Reaffirmed

Consistent with systematic reviews [5] and cross-sectional data [1,2], our anesthetized Schirmer I values showed no significant change ($p = 0.29$). The lacrimal glands continue to produce adequate aqueous volume; the pathology appears to lie in accelerated evaporation. This supports an evaporative mechanism and suggests that lipid-containing lubricants may be considered in appropriately selected patients.

DEQ-5 Screening Utility

The DEQ-5 demonstrated excellent responsiveness (Cohen's $d = 2.18$) and diagnostic utility (AUC = 0.84). A DEQ-5 ≥ 6 demonstrated 82% of those with tear instability. This two-step screening-diagnostic algorithm may streamline clinical workflow, particularly in busy outpatient settings.

Dose-Response and Cumulative Risk

The dose-response relationship is striking. Heavy users were already more symptomatic at baseline and suffered the most severe acute deteriorations. This priming effect suggests cumulative subclinical dysfunction, making the ocular surface more vulnerable to acute challenges.

Mechanisms and Inference

Although we did not directly measure blink rate, the profound TBUT and staining changes in the absence of Schirmer alteration strongly implicate reduced blinking and evaporative loss as the primary mechanism. This inference is supported by Golebiowski et al. [9], who documented reduced blink rate during smartphone reading, and by Argilés et al. [10], who quantified incomplete blinks in visual display terminal users, establishing a direct mechanistic link between screen use, blink suppression, and tear film destabilization.

Limitations

This study has several limitations. First, the single-arm, pre-post design lacked a control group. Second, the exposure was acute only, so long-term sequelae remain unknown. Third, we did not measure osmolarity or perform meibography. Fourth, the cohort was young and healthy, limiting generalizability to older or diseased populations. Fifth, the study was single-center. Sixth, screen time was self-reported and therefore subject to recall bias. Future research should incorporate blink monitoring, objective screen-time tracking, and longer follow-up.

Conclusion

A 2-hour smartphone reading task induces a significant evaporative dry eye response characterized by worsening symptoms, tear instability, and corneal epitheliopathy without altering basal aqueous secretion. Habitual heavy users (> 6 hrs/day) exhibit disproportionately greater damage. DEQ-5 demonstrates excellent utility as a rapid screening tool (AUC = 0.84). These findings support an evaporative mechanism and suggest that lipid-containing lubricants may be considered in appropriately selected patients.

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