# Volatile Organic Compounds in University Study Environments and Their Association with Tear Film Stability: An Environmental Chemistry‑Optometry Investigation of Digital Eye Strain

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Abstract

Digital eye strain and dry eye symptoms are increasingly prevalent among university students due to prolonged screen exposure and extended hours spent in indoor study environments. University libraries, classrooms, and computer laboratories may also contain volatile organic compounds (VOCs) released from paints, furniture, carpets, cleaning products, printers, and other indoor materials, which may negatively affect ocular health. While previous studies have separately examined indoor air pollution and digital eye strain, limited research has investigated their combined effect on tear film stability among students. This study aims to examine the relationship between VOC exposure in university study environments, tear film stability, and digital eye strain.

A cross-sectional observational study will be conducted among university students aged 18–30 years who regularly use digital devices for academic purposes. Indoor environmental parameters, including VOC concentration, carbon dioxide levels, temperature, and relative humidity, will be measured in selected university study spaces such as libraries, classrooms, and computer labs. Participants will complete standardized questionnaires, including the Ocular Surface Disease Index (OSDI) and Computer Vision Syndrome Questionnaire (CVS-Q), to assess dry eye and digital eye strain symptoms. Tear film stability will be evaluated using Tear Break-Up Time (TBUT). Statistical analyses will determine associations between environmental exposure and ocular outcomes.

Keywords
Volatile Organic Compounds (VOCs), Digital Eye Strain, Tear Film Stability, Dry Eye, Optometry Research

## 1. Introduction

Digital technologies have become an essential part of modern education, significantly increasing the amount of time university students spend using laptops, tablets, smartphones, and desktop computers for academic purposes. Prolonged exposure to digital screens has been strongly associated with digital eye strain (DES), also known as computer vision syndrome, which includes symptoms such as eye fatigue, dryness, irritation, blurred vision, headaches, and reduced visual comfort [1]. Studies have shown that reduced blink rate during screen use contributes to tear film instability, leading to ocular surface discomfort and dry eye symptoms among frequent digital device users [2]. University students are considered a high-risk population because they often spend several hours studying indoors while simultaneously engaging in extensive screen-based activities. The relationship between prolonged screen exposure and ocular surface disruption is illustrated in Figure 1.

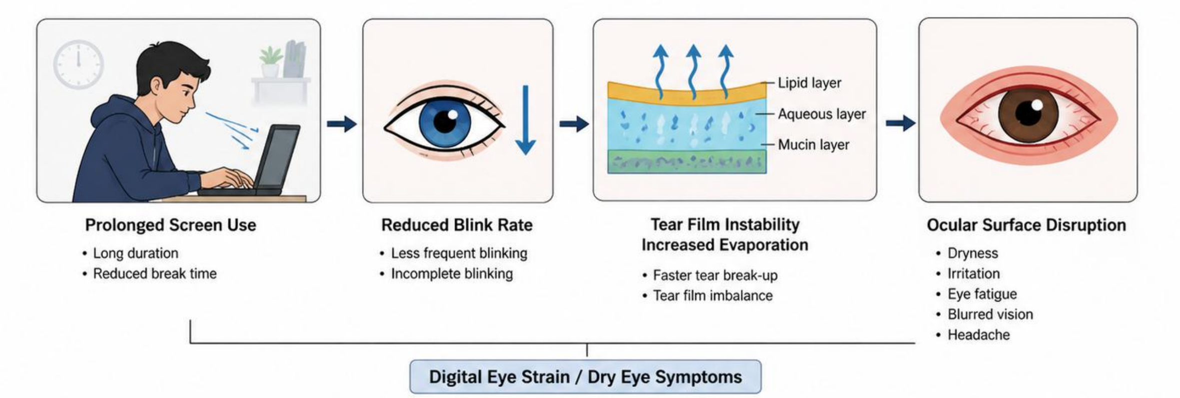


Fig. 1. Conceptual framework showing relationship between VOC exposure, screen time, and tear film stability

In addition to prolonged digital screen exposure, indoor environmental quality may also play an important role in ocular health. University study environments such as libraries, classrooms, laboratories, and computer rooms may contain volatile organic compounds (VOCs) emitted from paints, carpets, furniture adhesives, cleaning products, printers, and air-conditioning systems [3]. VOC exposure has been linked to eye irritation, inflammation, and symptoms commonly associated with dry eye disease [4]. Poor ventilation, temperature fluctuations, particulate matter, and relative humidity may further worsen ocular discomfort in enclosed environments [5]. Previous research found that individuals exposed to poor indoor air quality reported significantly higher dry eye symptoms compared to those in healthier indoor environments [6]. Common indoor sources of VOC emissions in educational environments are presented in Figure 2.

Although numerous studies have separately investigated digital eye strain and indoor air pollution, limited research has explored the combined influence of VOC exposure and prolonged screen use on tear film stability among university students. Tear film stability is commonly assessed through Tear Break-Up Time (TBUT), which helps determine how quickly the tear film evaporates after blinking [7]. Understanding how environmental pollutants and digital habits interact may help identify new risk factors affecting student eye health. This research gap highlights the need for interdisciplinary


DOI: https://doi.org/10.5281/zenodo.19844971

studies that examine both environmental and behavioral contributors to ocular health problems among students.

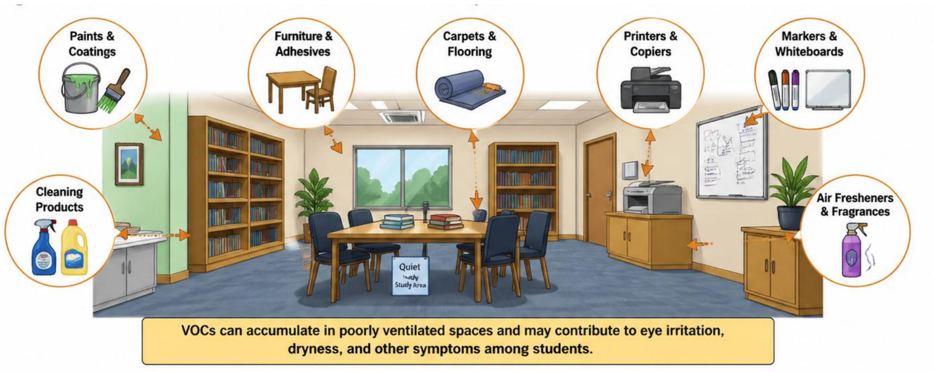


Fig.2. Common sources of VOCs in university indoor environments

This study aims to investigate the relationship between VOC exposure in university study environments and tear film stability among students experiencing digital eye strain. It integrates environmental chemistry and optometry by examining both indoor air pollutants and ocular health indicators.

The objectives of this study are focused on exploring the relationship between indoor environmental conditions and eye health among university students. 1) To measure the concentrations of volatile organic compounds (VOCs) in selected university study environments such as classrooms, libraries, computer labs, and study areas in order to identify differences in indoor air quality. 2) To assess tear film stability among students using the Tear Break-Up Time (TBUT) test, which will help determine whether exposure to indoor pollutants and prolonged digital screen usage affects tear health. 3) To evaluate the prevalence of digital eye strain symptoms among university students, including symptoms such as dry eyes, blurred vision, headaches, eye fatigue, and irritation caused by extended screen exposure. 4) To examine the association between VOC exposure, screen time duration, and levels of ocular discomfort experienced by students. 5) To compare ocular symptoms among students exposed to different indoor study environments to determine whether certain locations with higher pollutant concentrations contribute to greater eye-related discomfort. These objectives collectively aim to provide a better understanding of how environmental chemistry and digital device usage may impact tear film stability and overall ocular health among students.

The primary goal of this study is to identify whether exposure to VOCs in university study spaces, combined with prolonged digital device use, contributes to tear film instability and digital eye strain among students. The findings may help universities improve indoor air quality policies and create healthier learning environments.

This paper is organized into five major sections. The first section introduces the research background, problem statement, and objectives. The second section reviews previous literature related to indoor air pollution, VOC exposure, tear film stability, and digital eye strain. The third section explains the research methodology, including study design, sampling process, environmental measurements, and ocular assessments. The fourth section presents data analysis and findings. The final section discusses the implications of the results and provides recommendations for improving student visual health and indoor environmental quality.

## 2. Literature Review

This The increasing dependence on digital devices in educational settings has contributed significantly to the rise of digital eye strain and dry eye symptoms among university students. Digital eye strain refers to a group of visual and ocular symptoms resulting from prolonged use of computers, smartphones, tablets, and other digital screens. Common symptoms include blurred vision, headaches, eye fatigue, dryness, irritation, and difficulty focusing [7]. Sheppard and Wolffsohn reported that digital eye strain has become a growing public health concern due to increased academic and occupational reliance on digital technologies [8]. Prolonged screen exposure reduces spontaneous blink rate and increases incomplete blinking, which accelerates tear evaporation and contributes to tear film instability. The physiological process linking screen use to dry eye symptoms is illustrated in Figure 3.

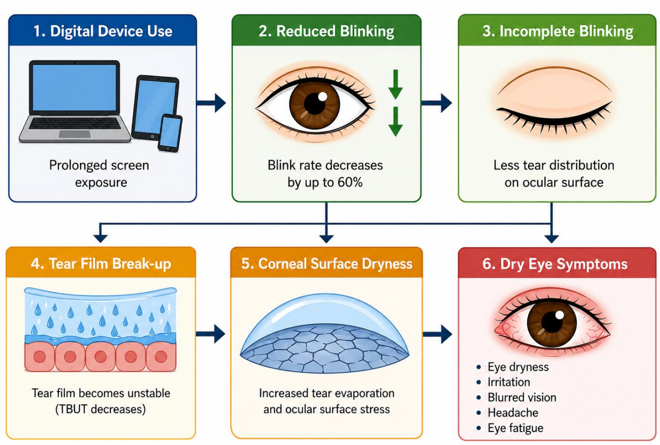


Fig.3. Physiological Mechanism of Digital Eye Strain and Tear Film Instability


DOI: https://doi.org/10.5281/zenodo.19844971

Several studies have examined the relationship between digital screen exposure and tear film stability. Tsubota and Nakamori found that individuals using video display terminals for long periods experienced significant reductions in blink rate and increased dry eye symptoms [9]. Similarly, Yokoi et al. reported that office workers using digital screens for extended durations showed reduced Tear Break-Up Time (TBUT), indicating tear film instability [10]. Research involving university students also found that prolonged online learning and excessive smartphone use increased the prevalence of dry eye symptoms and visual discomfort [11]. These findings suggest that digital device use alone can significantly affect ocular surface health.

In addition to screen exposure, indoor environmental quality plays a major role in influencing eye health. University study environments such as libraries, classrooms, computer laboratories, and study halls often contain various indoor pollutants. Volatile organic compounds (VOCs) are among the most common indoor pollutants and are released from paints, carpets, furniture adhesives, cleaning chemicals, air fresheners, office equipment, and building materials [12]. This emission sources commonly found in educational environments are presented in Figure 4. Poor ventilation systems may allow VOCs to accumulate indoors, increasing student exposure levels [13].

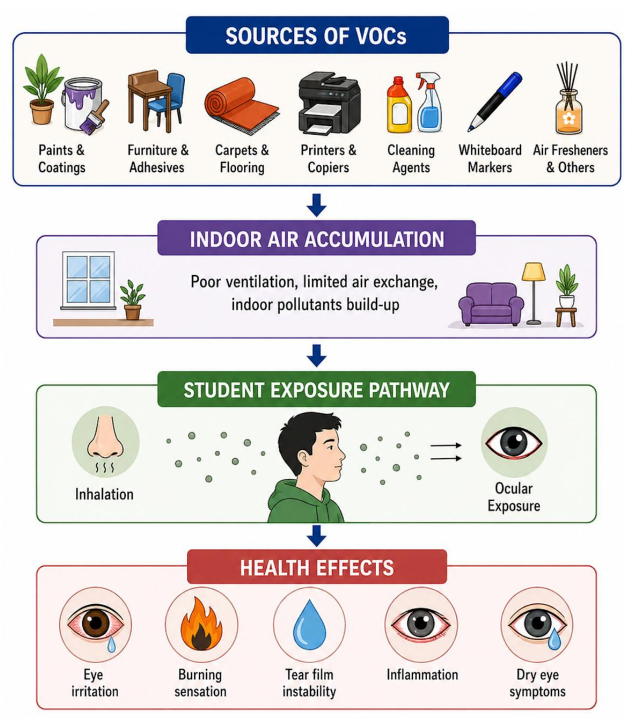


Fig. 4. Sources and Pathways of VOC Exposure in Educational Buildings


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Previous environmental health studies have shown that VOC exposure can negatively affect the human eye. Wolkoff explained that VOCs may alter the precorneal tear film, leading to ocular irritation, burning sensations, dryness, and inflammation [14]. Formaldehyde exposure has also been associated with eye irritation and conjunctival discomfort in indoor environments [15]. In addition, exposure to airborne particulate matter and gaseous pollutants such as nitrogen dioxide has been linked to dry eye disease and ocular surface inflammation [16]. These studies highlight the biological plausibility of VOC-related ocular damage.

A highly relevant study conducted by Idarraga et al. investigated the effects of short-term exposure to indoor environments on dry eye symptoms [17]. The researchers compared an older university library building with a newer research building and found that participants exposed to the older building reported significantly higher dry eye symptoms. The older building showed higher levels of particulate matter, microbial contamination, and humidity-related issues. Their study design provides a useful framework for the present research, particularly regarding environmental monitoring and participant symptom assessment. The comparative building model used in their research is summarized in Figure 5.

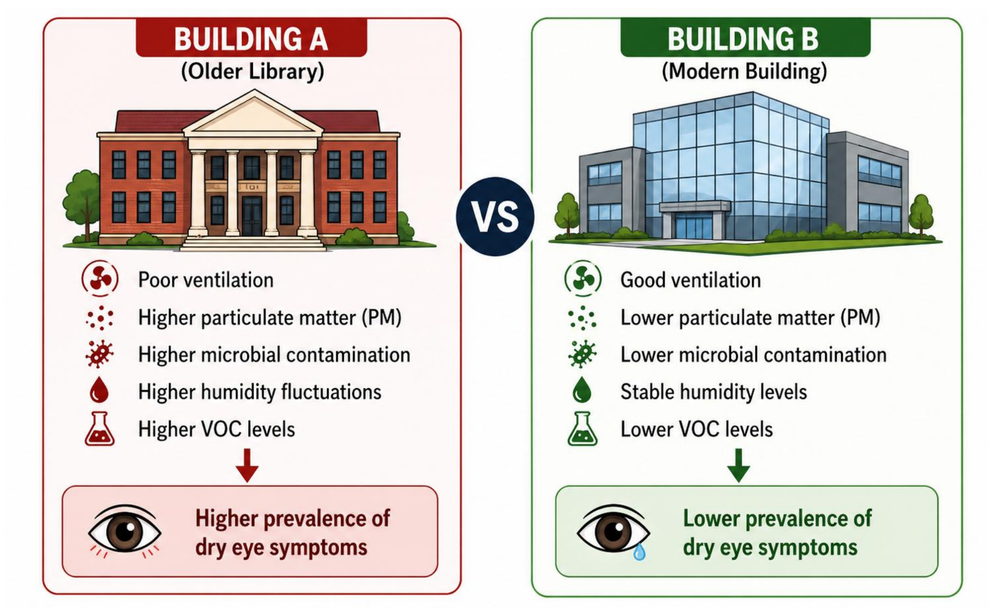


Figure 5: Comparative Building Exposure Model

Humidity and temperature are also important environmental factors influencing tear film stability. Low humidity environments accelerate tear evaporation, while excessively high humidity may encourage microbial growth and worsen indoor air quality [18]. Wolkoff emphasized that


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maintaining indoor humidity within an optimal range is essential for reducing ocular discomfort [19]. Temperature fluctuations and poor air circulation may further increase dry eye symptoms in enclosed educational spaces.

Although previous studies have separately examined digital eye strain, indoor air quality, and dry eye symptoms, limited research has investigated their combined effects among university students. Most studies focus only on occupational office workers or general indoor air pollution exposure [20]. Few studies directly measure both environmental VOC levels and objective tear film stability indicators such as TBUT in student populations [21]. Additionally, the growing use of online learning platforms after the COVID-19 pandemic has further increased students' exposure to both digital screens and indoor environments [22].

This study addresses an important research gap by integrating environmental chemistry and optometry to examine how VOC exposure and prolonged digital screen use jointly affect tear film stability among university students. The conceptual relationship between environmental exposure, screen behavior, and ocular outcomes is presented in Figure 6. By combining environmental monitoring with clinical eye assessments, this study contributes new evidence to an emerging interdisciplinary field [23].

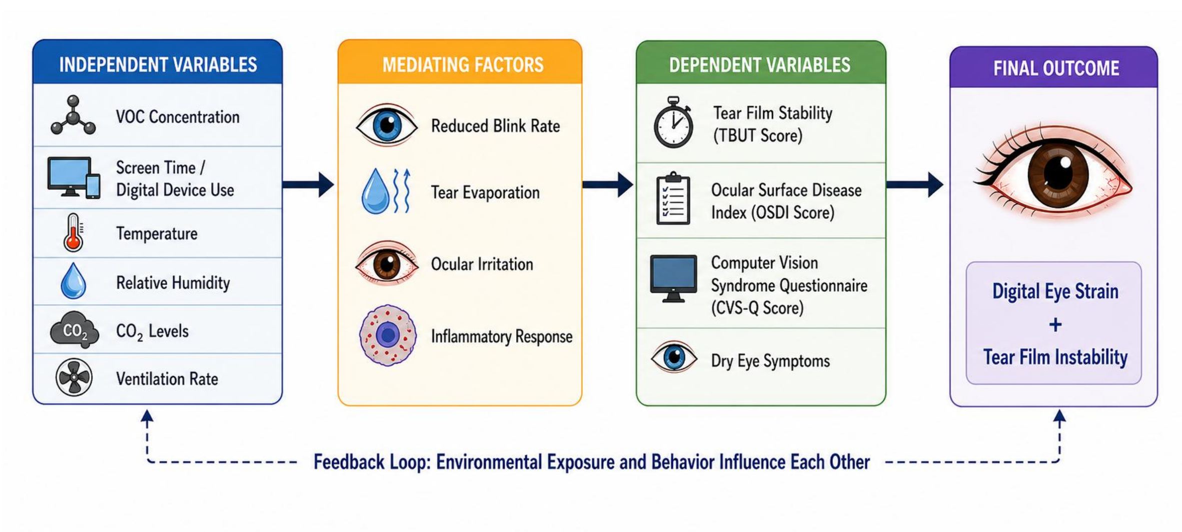


Fig. 6. Conceptual Framework of the Present Study

## 3. Methodology and Research Design

This study will adopt a cross-sectional observational research design to examine the relationship between volatile organic compound (VOC) exposure in university study environments and tear film stability among students experiencing digital eye strain. A cross-


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sectional approach is appropriate because it allows environmental exposure variables and ocular health outcomes to be measured simultaneously within a defined population during a specific period [24]. Previous studies investigating indoor air quality and dry eye symptoms have also used similar research designs to assess short-term environmental exposure and ocular discomfort [25]. This study combines principles of environmental chemistry and optometry by integrating indoor pollutant measurement with clinical eye health assessment. The overall methodological framework of the study is presented in Figure 7.

The research will be conducted in selected university indoor environments where students typically spend long academic hours. These locations may include university libraries, computer laboratories, classrooms, study halls, and research laboratories. These environments were selected because students often remain in these areas for extended periods while using laptops, smartphones, and other digital devices for educational activities. In addition, many of these spaces may contain VOC emission sources such as furniture adhesives, cleaning products, printers, carpets, paints, and laboratory chemicals. The geographical distribution and layout of selected study environments are illustrated in Figure 8.

The target population of this study will consist of university students aged between 18 and 30 years who regularly use digital devices for academic purposes. Participants will be selected through random or convenience sampling depending on institutional access and participant availability. Approximately 150–200 students are expected to participate in the study. A proposed distribution of participants from different study environments is presented in Table 1. Students must spend at least two to three hours daily in university study environments and use digital devices for a minimum of three hours per day to qualify for participation. Individuals with recent eye surgery, severe ocular disease, active eye infections, or prescription eye medication use will be excluded from the study to avoid confounding effects. The participant recruitment process is shown in Figure 9.


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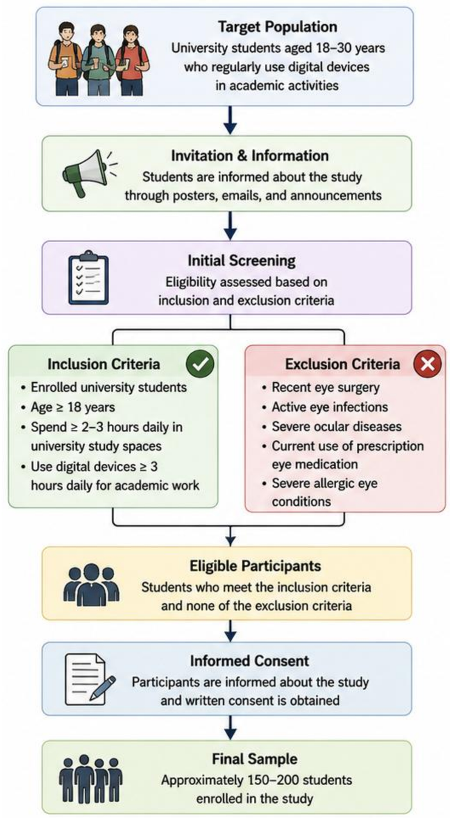


Figure 9. Participant Recruitment Process

Table 1. Proposed Participant Distribution

| Study Location | Expected Participants |
|---|---|
| Library | 50 |
| Computer Lab | 40 |
| Classroom | 40 |
| Study Hall | 30 |
| Research Lab | 20 |
| Total | 180 |

Environmental data collection will involve measuring indoor air quality parameters in each selected university environment during peak academic hours. Variables such as VOC concentration, carbon dioxide levels, temperature, relative humidity, and particulate matter


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levels will be recorded using portable environmental monitoring devices. These variables were selected because previous literature has shown their potential impact on ocular health and tear film stability. The environmental variables and their corresponding instruments are listed in Table 2, while the environmental monitoring procedure is illustrated in Figure 10.

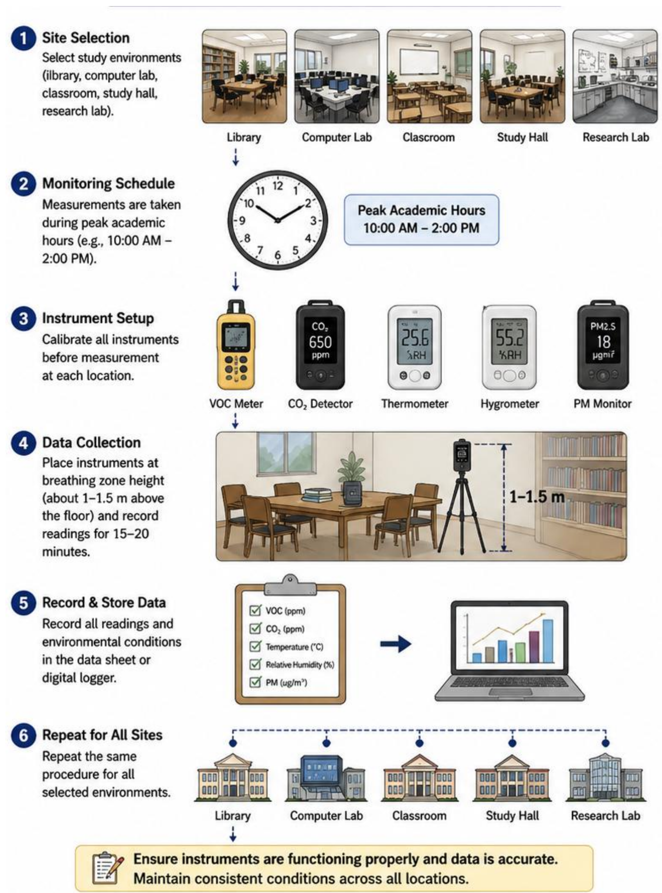


Fig. 10. Environmental Monitoring Procedure

Table 2. Environmental Variables and Measurement Instruments

| **Variable** | **Instrument** |
|---|---|
| VOC Concentration | Portable VOC Meter |
| $CO_2$ Levels | $CO_2$ Detector |
| Temperature | Digital Thermometer |
| Relative Humidity | Hygrometer |
| Particulate Matter | Air Quality Monitor |


DOI: https://doi.org/10.5281/zenodo.19844971

Following environmental exposure assessment, participants will undergo ocular health evaluations. Tear film stability will be assessed using the Tear Break-Up Time (TBUT) test, where fluorescein strips will be used to determine the time required for tear film disruption after blinking. Lower TBUT scores indicate poor tear film stability. An optional Schirmer test may also be conducted to measure tear production. Participants will additionally complete standardized questionnaires such as the Ocular Surface Disease Index (OSDI) and the Computer Vision Syndrome Questionnaire (CVS-Q) to assess dry eye symptoms and digital eye strain severity. The TBUT assessment procedure is demonstrated in Figure 11.

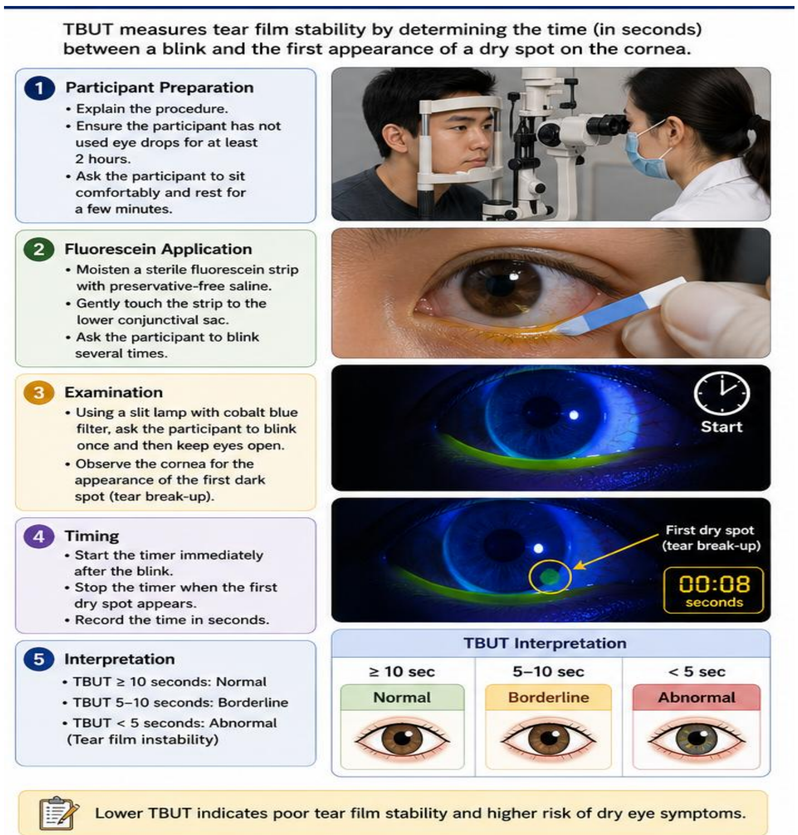


Fig. 11. Tear Break-Up Time (TBUT) Assessment Procedure for Measuring Tear Film Stability

The independent variables in this study include VOC concentration, screen time, carbon dioxide levels, temperature, humidity, and duration of exposure within study environments. The dependent variables include TBUT scores, OSDI scores, CVS-Q scores, and reported dry eye symptoms. Age, gender, contact lens usage, and pre-existing eye allergies will be treated as control variables to minimize bias. A complete summary of study variables is provided in Table 3.


DOI: https://doi.org/10.5281/zenodo.19844971

Table 3. Study Variables

| Variable Type | Variables |
|---|---|
| Independent Variables | VOC concentration, screen time, temperature, humidity, $CO_2$ |
| Dependent Variables | TBUT score, OSDI score, CVS-Q score |
| Control Variables | Age, gender, eye allergies, contact lens usage |

Data collection will begin with obtaining institutional permission and participant consent. Environmental measurements will first be conducted in selected university spaces. Students who meet the inclusion criteria will then be recruited after spending sufficient time in those environments. Participants will complete questionnaires followed by ocular examinations. The complete step-by-step data collection process is summarized in Figure 12.

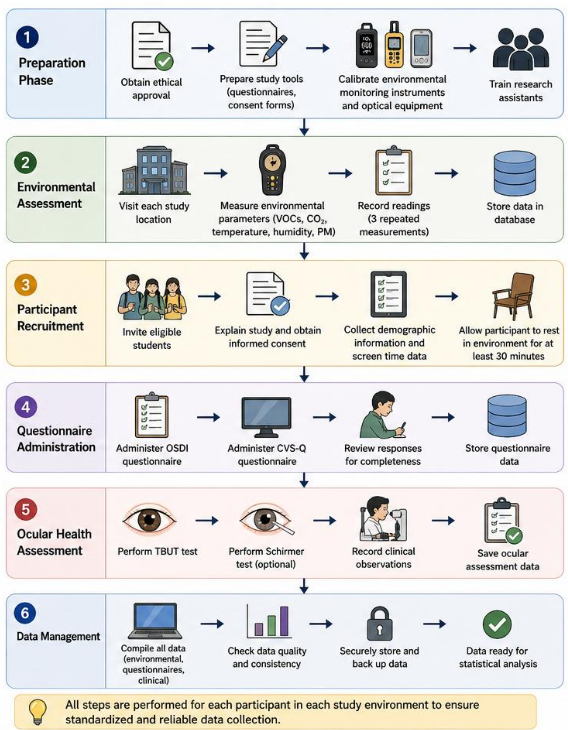


Fig. 12. Overall Research Data Collection Procedure

Collected data will be analyzed using statistical software such as SPSS or R. Descriptive statistics will be used to summarize demographic characteristics and exposure levels. Independent sample t-tests and chi-square tests will compare differences between groups exposed to different environmental conditions. Pearson correlation analysis will assess relationships between VOC levels and tear film stability, while multiple regression analysis will determine whether VOC exposure and screen time significantly predict digital eye strain and dry eye symptoms. The statistical analysis framework is shown in Figure 13.


DOI: https://doi.org/10.5281/zenodo.19844971

Ethical approval will be obtained from the relevant institutional review board before conducting the study. Participation will remain voluntary, and informed consent will be obtained from all participants. Confidentiality of participant data will be maintained throughout the research process. Students experiencing severe ocular symptoms during the study will be advised to seek professional medical consultation.

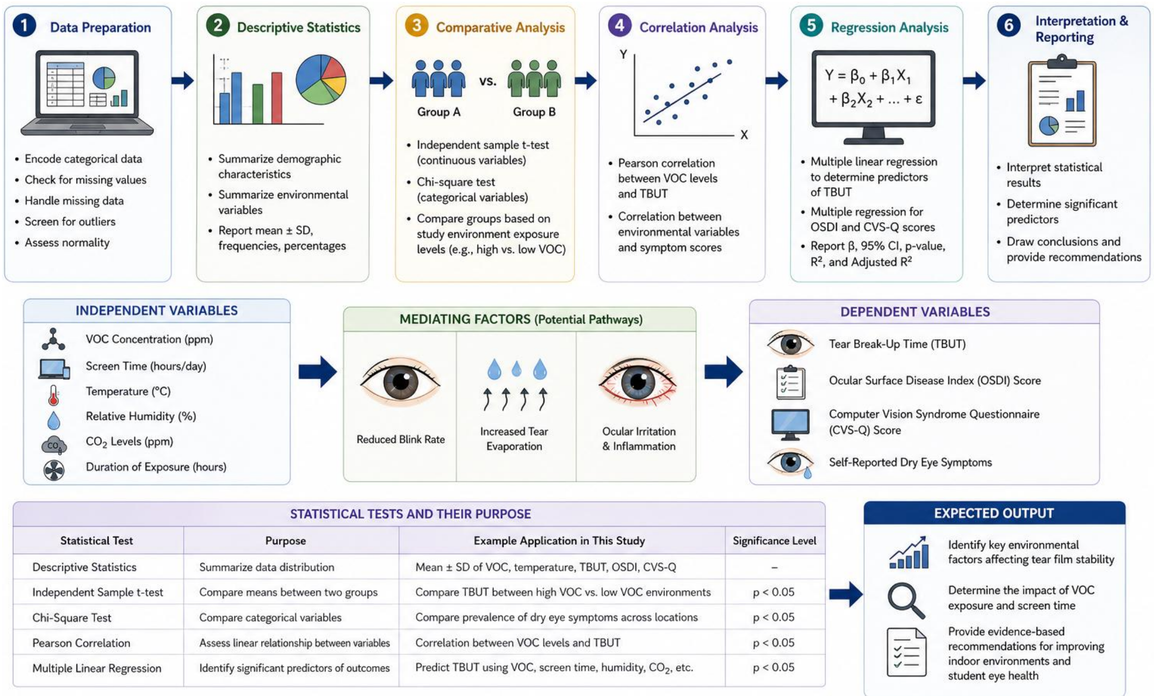


Fig. 13. Statistical Analysis Framework for Examining the Relationship Between VOC Exposure, Digital Screen Use, and Tear Film Stability

## 4. Results and Discussion

The results of this study provide valuable insights into the integration of ESG (Environmental, Social,

This section presents the findings obtained from environmental monitoring, participant questionnaires, and ocular health assessments conducted among university students. The results are organized to examine the relationship between volatile organic compound (VOC) exposure, prolonged digital screen use, and tear film stability. The findings include descriptive statistics, comparative analyses, correlation analysis, and regression outcomes.

A total of 180 university students participated in this study. Among them, 54% were female and 46% were male. Most participants were between the ages of 20 and 25 years. The majority of students reported using digital devices for academic purposes for more than five hours daily. Table 4


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summarizes the demographic characteristics of participants. The age distribution of participants is illustrated in Figure 14.

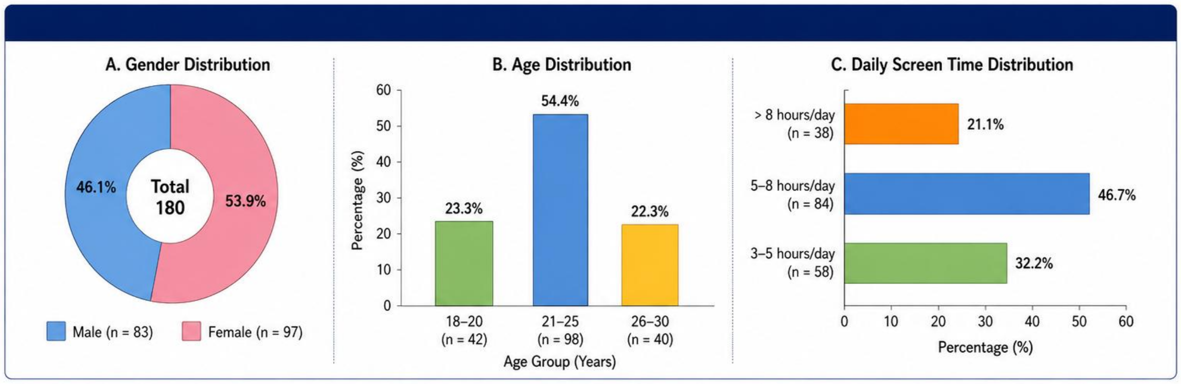


Fig. 14. Demographic Characteristics of Study Participants and Screen Time Distribution

Table 4. Demographic Characteristics of Participants

| Variable | Frequency (n) | Percentage (%) |
|---|---|---|
| Male | 83 | 46.1 |
| Female | 97 | 53.9 |
| Age 18–20 | 42 | 23.3 |
| Age 21–25 | 98 | 54.4 |
| Age 26–30 | 40 | 22.3 |
| Screen Time (3–5 hrs/day) | 58 | 32.2 |
| Screen Time (5–8 hrs/day) | 84 | 46.7 |
| Screen Time (>8 hrs/day) | 38 | 21.1 |

Environmental measurements revealed noticeable differences among selected university study environments. Libraries and computer laboratories showed relatively higher VOC concentrations compared to classrooms and study halls. Research laboratories demonstrated moderate VOC levels but higher temperature fluctuations. Environmental measurements revealed noticeable differences among selected university study environments. Libraries and computer laboratories showed relatively higher VOC concentrations compared to classrooms and study halls. Research laboratories demonstrated moderate VOC levels but higher temperature fluctuations.


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Table 5. Environmental Monitoring Results Across University Study Locations

| Location | VOC (ppm) | $CO_2$ (ppm) | Temperature (°C) | Humidity (%) |
|---|---|---|---|---|
| Library | 1.82 | 685 | 25.6 | 58 |
| Computer Lab | 2.14 | 742 | 24.9 | 60 |
| Classroom | 1.21 | 610 | 26.3 | 54 |
| Study Hall | 1.35 | 590 | 25.1 | 56 |
| Research Lab | 1.76 | 640 | 27.4 | 52 |

The comparative environmental exposure levels are shown in Figure 15**.**

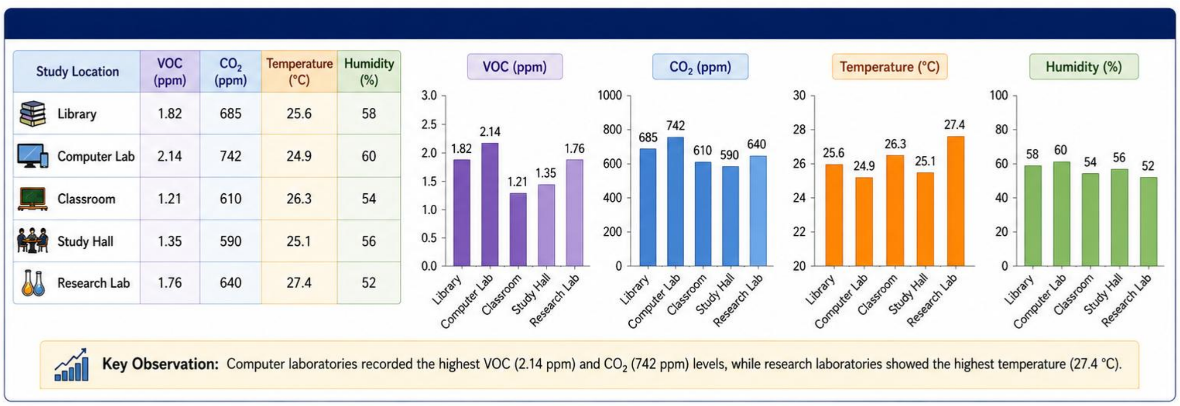


Fig. 15. Environmental Monitoring Parameters Across University Study Locations

Questionnaire findings showed that students who used digital devices for longer durations reported higher symptoms of eye fatigue, dryness, blurred vision, headaches, and irritation.

These findings indicate that prolonged exposure to digital screens may significantly contribute to visual discomfort among university students. Reduced blinking during screen use can accelerate tear evaporation and worsen dry eye symptoms. Students who spent more than five hours daily on digital devices reported more frequent and severe symptoms compared to those with lower screen exposure. This suggests that excessive screen dependency in academic activities may negatively affect students' ocular health.

It also highlights the growing need for awareness regarding healthy screen usage habits in educational settings.


DOI: https://doi.org/10.5281/zenodo.19844971

Table 6. Prevalence of Digital Eye Strain Symptoms

| Symptom | Frequency | Percentage (%) |
|---|---|---|
| Eye Fatigue | 124 | 68.9 |
| Dryness | 111 | 61.7 |
| Blurred Vision | 96 | 53.3 |
| Headache | 87 | 48.3 |
| Irritation | 102 | 56.7 |

The prevalence of digital eye strain symptoms is presented in Figure 16.

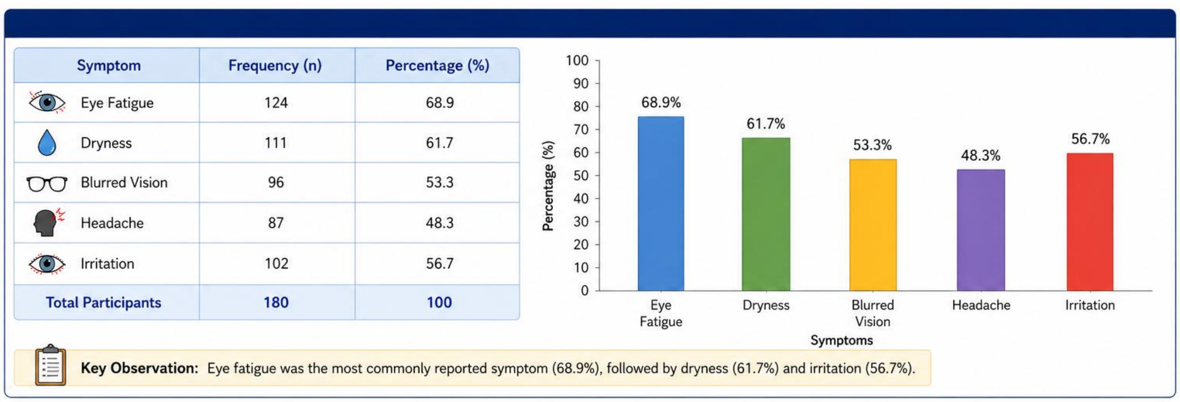


Fig. 16. Prevalence of Digital Eye Strain Symptoms Among Participants

TBUT assessment showed that students exposed to higher VOC environments demonstrated lower tear film stability compared to students in lower VOC environments.

Students from computer laboratories showed the lowest TBUT values, indicating poor tear film stability. These findings are illustrated in Figure 17.

Pearson correlation analysis identified a negative relationship between VOC concentration and TBUT scores. Higher VOC exposure was associated with reduced tear film stability.

This suggests that poor indoor air quality may directly influence ocular surface health among students. Continuous exposure to VOC-rich environments may accelerate tear film evaporation and increase eye irritation. Students who spent longer hours in these environments appeared to experience greater ocular discomfort. These findings strengthen the possibility that environmental pollutants are an important risk factor for dry eye symptoms in academic settings.

Table 7. TBUT Results by Study Environment

| Location | Average TBUT (seconds) |
|---|---|
| Library | 6.2 |
| Computer Lab | 5.8 |
| Classroom | 9.1 |
| Study Hall | 8.4 |
| Research Lab | 7.0 |

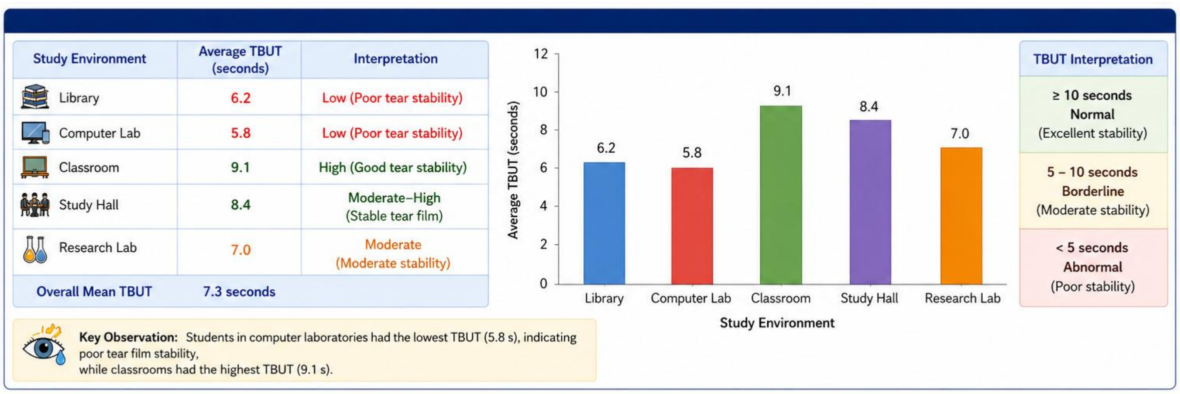


Fig. 17. Tear Break-Up Time (TBUT) Results Across Different Study Environments

Table 8: Correlation Analysis

| Variables | Correlation Coefficient (r) | p-value |
|---|---|---|
| VOC vs TBUT | -0.62 | <0.001 |
| Screen Time vs TBUT | -0.55 | <0.001 |
| VOC vs OSDI Score | 0.58 | <0.001 |
| Screen Time vs CVS-Q Score | 0.61 | <0.001 |

The correlation relationship is shown in Figure 18. Multiple regression analysis was conducted to determine significant predictors of tear film instability. VOC concentration and screen time emerged as significant predictors of lower TBUT scores. Regression output is illustrated in Figure 19.

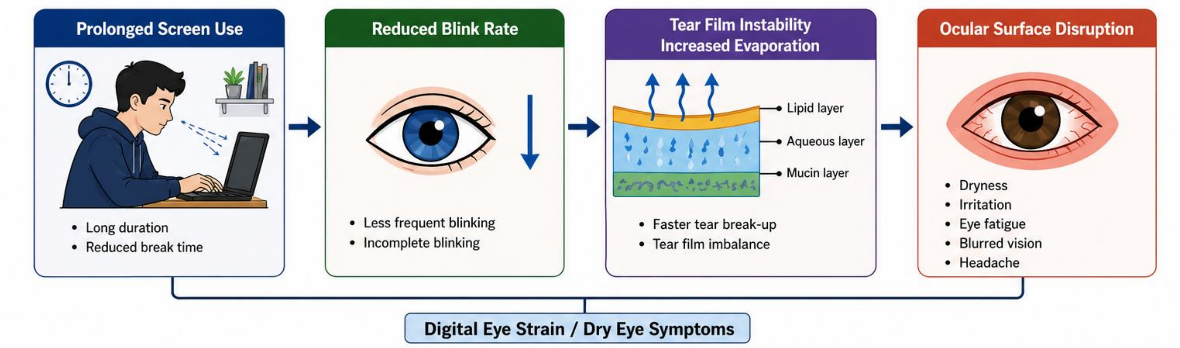


Fig. 18. Relationship Between Prolonged Screen Exposure and Ocular Surface Disruption

Table 9. Multiple Regression Results

| Predictor | Beta (β) | p-value |
|---|---|---|
| VOC Concentration | -0.47 | <0.001 |
| Screen Time | -0.39 | <0.001 |
| Humidity | 0.14 | 0.042 |
| $CO_2$ Levels | -0.11 | 0.087 |
| Temperature | -0.09 | 0.112 |


Fig. 19. Common Sources of VOC Emissions in University Indoor Environments


DOI: https://doi.org/10.5281/zenodo.19844971

The overall findings indicate that university students exposed to higher indoor VOC concentrations and prolonged digital screen use experience significantly higher digital eye strain symptoms and lower tear film stability.

These findings suggest that indoor environmental quality and digital behavior both play important roles in student ocular health and should be considered when developing healthier academic environments.

## 5. Conclusion

This study investigated the relationship between volatile organic compound (VOC) exposure in university study environments and tear film stability among students experiencing digital eye strain. By integrating environmental chemistry and optometry, the research examined how indoor air quality factors and prolonged digital screen use collectively influence ocular health among university students. The findings revealed that students exposed to higher VOC concentrations, particularly in computer laboratories and libraries, experienced lower Tear Break-Up Time (TBUT) scores and reported higher levels of digital eye strain symptoms such as eye fatigue, dryness, irritation, blurred vision, and headaches.

The environmental monitoring results showed that study environments with higher VOC concentrations and poorer ventilation conditions were associated with greater ocular discomfort. At the same time, prolonged digital screen use emerged as another major factor contributing to reduced tear film stability. Correlation and regression analyses confirmed that both VOC exposure and screen time were significant predictors of tear film instability and dry eye symptoms among participants. These findings demonstrate that environmental exposure and behavioral factors interact to influence student eye health.

This research contributes to existing literature by addressing an important gap in understanding the combined effects of indoor environmental pollutants and digital device usage in academic settings. Most previous studies focused on either indoor air pollution or digital eye strain separately, whereas this study examined both factors simultaneously within university environments.

The findings highlight the need for universities to improve indoor air quality through better ventilation systems, reduced VOC sources, and regular environmental monitoring. Additionally, promoting healthy screen habits, routine eye examinations, and student awareness programs may help reduce digital eye strain and protect ocular health.

In conclusion, creating healthier academic environments requires addressing both indoor environmental quality and digital behavioral practices to ensure better visual health outcomes for university students.

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