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Objective Assessment of Visual Workload in Video Display Terminal Workers Using a Non-Invasive Monitoring System

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Abstract

Background: *The risk assessment for video display terminal (VDT) operators in occupational settings often relies on indirect estimates, such as self-reported screen time, which may not accurately reflect the true visual workload. The objective is to assess visual workload in VDT workers by measuring active screen fixation time with a non-invasive monitoring system and to explore its relationship with ocular surface alterations and fatigue-related indicators.* **Methods:** *An observational cross-sectional study was conducted on 38 administrative workers employed at a hospital booking center. Active VDT screen fixation, as well as shift duration and time spent in front of the VDT screen, were objectively measured using a patented video-based monitoring system. Ophthalmological evaluation included the Ocular Surface Disease Index (OSDI®), tear break-up time (BUT), and slit-lamp examination. Other investigated markers included blink rate, the Percentage of Eyelid Closure over the Pupil over Time (PERCLOS), and the Fatigue Assessment Scale (FAS).* **Results:** *Active screen fixation accounted for approximately 60% of the total recorded working time. Ophthalmological assessment identified alterations of the ocular surface in a substantial proportion of workers, with pathological BUT values observed in nearly half (47%) of the study population. No statistically significant associations were found between objectively measured fixation time and ocular or fatigue-related outcomes. PERCLOS80 and blink rate values remained within physiological ranges across the work shift.* **Conclusions:** *Objective measurement of screen fixation provides a more accurate characterization of visual workload among VDT workers than indirect exposure estimates and may support occupational health surveillance and risk assessment in VDT-exposed workers.*

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1. Introduction

In the contemporary digital era, video display terminals (VDTs) are widely used across occupational settings. Digitalization has profoundly transformed work organization, particularly in administrative and service sectors, where screen-based activities are a major component of daily tasks [1]. While digital technologies improve efficiency and productivity, they also introduce potential visual and systemic health risks that require systematic evaluations by occupational health professionals, including ergonomists, prevention technicians, and physicians [1, 2]. Italian occupational safety and health legislation [2] classifies workers as VDT-exposed and at risk when VDT use is at least 20 hours per week, including physiological recovery breaks. This threshold, absent in Council Directive 90/270/EEC, which limits itself to "daily work on display screen equipment for an hour or more at a time", represents a more operational national implementation of the EU minimum framework, incorporating requirements for workstation analysis (Annex XXXIV), breaks (15 minutes every 2 hours), biennial health surveillance, and specific training. Council Directive 90/270/EEC, the fifth individual directive under Framework Directive 89/391/EEC, emphasizes general ergonomic standards for equipment (adjustable display, separate keyboard), environment (noise <55 dB, adequate lighting), and human-machine interface (eye level 15° below screen horizon), and mandates risk assessments for visual, musculoskeletal, and psychosocial hazards, with "appropriate" breaks and free eye tests. This European legislation, from which the Italian approach derives, underscores the need to replace self-reported estimates with objective methods to accurately assess effective exposure, as proposed in the present study, because in real-world conditions, workers frequently alternate screen use with other activities, making self-reported exposure prone to misclassification.

Prolonged VDT use has been linked to visual and ocular disorders, including computer vision syndrome and dry eye disease, as well as musculoskeletal complaints and mental fatigue [3-12]. These outcomes are influenced by actual visual engagement with the screen [13], which is rarely quantified objectively in occupational settings.

Computer vision syndrome (CVS) is a possible health consequence characterized by a wide range of visual and ocular symptoms, frequently associated with prolonged computer use. CVS affects 75% to 90% of computer users, with an estimated global prevalence of approximately 60 million people [14-20]. Common symptoms (visual fatigue, blurred vision, dry eyes, red eyes, and headaches) are often linked to ocular surface discomfort and are commonly reported in patients with dry eye disease. During prolonged screen fixation, VDT operators tend to reduce their blink rate and exhibit a higher proportion of incomplete blinks. This leads to increased tear film evaporation, tear film instability, and consequent ocular surface symptoms. This process can be self-perpetuating and worsen over the years, severely affecting quality of life and, as suggested by some studies, correlating with mental disorders such as depression, depending on the severity of symptoms [21-28].

The Percentage of Eyelid Closure Over the Pupil Time (PERCLOS) is one of the most promising and widely validated markers of fatigue, drowsiness, and reduced alertness without interrupting ongoing activities [29-31]. Studies have demonstrated its effectiveness in detecting fatigue among vehicle drivers [32], nuclear power plant operators [33], and air traffic controllers [34]. In addition, PERCLOS has been integrated into real-time monitoring technologies, often combined with other physiological and behavioral parameters to improve detection sensitivity and accuracy [31]. However, PERCLOS can be influenced by moderate sleepiness, environmental factors, or individual variations, as highlighted by some recent research [29, 31]. Researchers suggest combining PERCLOS with other metrics, such as blink rate or eye movements, and conducting more in-depth studies in real-world settings [32-33].

In earlier research [13], we validated a novel system that objectively measures active VDT interaction. It does so by collecting electrical impulses produced by mouse and keyboard use, along with visual fixation on the screen detected via a camera. This system enables analysis of various job tasks and outlines unique interaction profiles for different users and VDTs. Building on this approach, the present study aimed to objectively assess visual workload in

VDT workers by measuring active screen fixation time with a non-invasive monitoring system and to explore potential relationships with ocular effects and fatigue markers.

2. Methods

2.1. Instruments

VDT Visual Monitoring System (VMS). VDT Visual Monitoring System (VMS) prototype was developed by the Department of Information Engineering in collaboration with the Unit of Occupational Medicine and Industrial Hygiene of the University of Brescia. The system has been previously described and validated [35]. Briefly, it consists of a webcam positioned on the PC monitor in front of the operator and a laptop running dedicated software that processes camera signals and generates a report of specific events, including true screen fixation and face detection without active interaction, along with their respective durations. Below is a scheme (Figure 1) representing the workstation equipped with the VDT VMS, which has been described elsewhere [35].

Compared with previous versions, the updated prototype can detect true eye–screen fixation by improving identification of the worker's pupils and their relative spatial positions. The system requires an initial calibration phase during which the individual pupil position is recorded while the worker fixates the screen. When pupil centers align with calibration coordinates, a screen fixation event is recorded and the corresponding time counter is

Figure 1. Setting of the monitoring system.

updated. Deviations along the vertical or horizontal axis are recorded as face detection (worker at the workstation, in front of the screen) without fixation. Worker privacy is ensured because no facial images or screen content is stored.

PupilCore® by Pupil Labs®. The Pupil Core® system (Pupil Labs®, Berlin, Germany) consists of a lightweight, glasses-like frame without corrective lenses, housing three cameras: one outward-facing camera and two inward-facing infrared cameras oriented toward the eyes. In this study, the outward-facing camera was occluded to ensure privacy. The manufacturer's software was used to collect raw data on eyelid opening and blinking behavior. Data analysis focused on blink rate and PERCLOS. Specifically, eyelid closure of at least 80% (PERCLOS80) was considered a marker of drowsiness [36]. Raw data were exported and processed using Microsoft Excel® (Office 365).

2.2. Study Design

This observational cross-sectional study included 38 administrative workers (6 males, 32 females; mean age 36.7 ± SD 11.2 years) employed at the booking center of the University Hospital ASST Spedali Civili of Brescia, Italy. Table 1 summarizes the main demographic and clinical characteristics of the study population. The sample consisted predominantly of female workers (84%). Relevant clinical conditions that may affect ocular surface status were recorded, including allergies (37%), thyroid disorders (16%), and hypertension (13%). Contact lens use was reported by 24% of participants.

The duration of service in the current job position was 5.7 ± 3.8 years, with a range of 0.5 to 10.5 years. Tasks included interacting with service users, computerized data entry, and printing reservation documents, with alternating periods of screen fixation and face-to-face interaction.

All the evaluations performed in the study were included in occupational risk assessment and health surveillance that are mandatory by law; therefore, approval by the local Ethics Committee was not required, consistent with the criteria established by the Italian Ministry of Health Decree of 30

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Table 1. Demographic and clinical characteristics of the study population.

Parameters	Mean+SD (range)	No.	%
Gender, M/F		6/32	16/84
Age	36.7+11.2 (20-60)		
Work Seniority	6, 4 (1-11)		
BUT Values, Right; Left	8.7+2.5 (0.5-10); 8.1+2.9 (0.5-10)		
BUT Bilateral, Altered/Normal		18/20	47/53
Contact Lenses Use		9	24
Thyroid Disorders		6	16
Hypertension		5	13
Autoimmune Diseases		2	5
Allergies		14	37
Use of Antihistamines		7	18
Use of Antidepressants		2	5
Glaucoma		1	3
Eye Surgery		1	2.6

January 2023 for observational studies conducted in the context of occupational health monitoring. The study was conducted in accordance with the WMA Declaration of Helsinki and the General Data Protection Regulation (GDPR, Regulation EU 679/2016).

Participants followed a standardized protocol: (a) administration of the Fatigue Assessment Scale (FAS) [37-38]; (b) reading a standardized text (introductory chapter of *The Leopard* by Giuseppe Tomasi di Lampedusa) on a laptop for approximately 10 minutes while wearing the Pupil Core® device; (c) performance of routine work activities at a workstation equipped with the VDT VMS for the entire work shift, including breaks; (d) removal of the VDT VMS at the end of the shift; and (e) repetition of the reading task.

For interpreting the FAS questionnaire, the following criteria were used: scores below 22: absence of fatigue; scores between 22 and 34: mild to moderate fatigue; scores above 34: severe fatigue [37].

The shifts varied in length, depending on the internal organization, that guarantees the service from 6 a.m. to 9 p.m., with shifts lasting from 4 to 8 hours, including breaks.

All participants underwent comprehensive ophthalmological evaluation including medical history, Ocular Surface Disease Index (OSDI®) questionnaire, tear Non-Invasive Break-up Time (NI-BUT) measurement evaluated with HD Analyzer aberrometer (Visiometrics S.L., Terrassa, Spain), and slit-lamp examination. OSDI® scores were classified as normal (0–12), mild (13–22), moderate (23–32), or severe (33–100) dry eye disease. BUT values below 10 seconds were considered altered.

2.3. Statistical Analysis

VDT VMS data were processed using dedicated software and stored in a Microsoft Excel® database. Pupil Core® recordings were analyzed to extract blink rate and PERCLOS80 values. PERCLOS80 has been calculated in Microsoft Excel® from single-frame data processed by the PupilCore® software, which provided precise eyelid aperture percentages based on infrared camera captures.

Ophthalmological and occupational data were merged into a single dataset. Data were analyzed using IBM SPSS® Statistics (version 30.01; IBM SPSS Inc., Chicago, Illinois) and Stata® (version 19.1; Stata Corporation, College Station, Texas). Normality was assessed with the Kolmogorov-Smirnov test. Continuous variables were summarized as mean ± standard deviation or as median (range), depending on their distribution. Group comparisons were performed using parametric or non-parametric tests, based on the assessment of normality. Correlation analyses were conducted using Pearson's or Spearman's coefficients, as appropriate. When the assumptions for parametric analysis were met, Pearson's correlation was complemented by univariable linear regression models to further characterize the magnitude and direction of the association between exposure and outcome variables.

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3. Results

Table 2 resumes the descriptive statistics of the times recorded by the VDT VMS in workers stratified by gender. Males showed significantly higher exposure indices than females (p values ranging from p=0.0368 to p=0.0023).

Such job-related gender differences were not associated with any significant differences in the investigated markers of ocular effects, drowsiness, or fatigue.

Based on OSDI® questionnaire scores, 21 workers (55%) reported no symptoms consistent with dry eye disease. Mild dry eye disease (DED) was identified in 7 workers (18%), moderate DED in 3 workers (8%), and severe DED in 7 workers (18%). Tear break-up time (BUT) assessment showed normal values in 20 workers (53%), whereas altered BUT values (<10 sec. in at least one eye) were observed in 18 workers (47%).

The OSDI® questionnaire scores were significantly correlated with screen fixation time (Spearman's rho = 0.34, p = 0.0349) but not with shift duration or workers' time at the workstation.

Figure 2 illustrates the significant positive relationship between shift duration and employees' time at the workstation (Linear regression analysis: Y = 0.562X; $R^2 = 0.92$, $p < 0.001$).

Figure 3 illustrates the significant relationship between employees' time at the workstation and the duration of active VDT screen fixation (Linear regression analysis: Y = 0.342X; $R^2 = 0.86$, $p < 0.001$).

Figure 4 shows the relationship between the time workers spent in front of the VDT screen and active screen fixation, with an even stronger correlation observed (Linear regression analysis: Y=0.611X; $R^2=0.94$, $p < 0.001$).

The blink rate at the end of the shift showed an increase of about 34% (mean of 17 ± 12.3 blinks/min), as compared to the values recorded at the beginning of the work shift (mean of 13.1 ± 8.3 blinks/min), approaching statistical significance (p = 0.051). PERCLOS80 values did not show significant variations throughout the shift (mean values of 10.7 ± 16.3% *vs* 10.8 ± 15.0% before and at the end of the shift, respectively), indicating mild drowsiness without significant variation over the shift. Such results were in agreement with the FAS questionnaire, whose results indicated absence of fatigue in most of the workers (n=23, 60%), mild to moderate fatigue in 14 workers (37%), and severe fatigue in 1 worker (3%) only.

In correlation analysis, the PERCLOS80 values before and at the end of the shift showed significant relationships with the blink values at the corresponding times (Spearman's rho of 0.67 and 0.72 before and after the shift, respectively, p <0.001).

In the analysis of workers grouped by comorbidities, subjects with thyroid dysfunction did not show significant differences in eye blinking, PERCLOS80

Table 2. Distribution of measures recorded by the VDT VMS in workers stratified by gender.

		Percentiles			
Parameters	**Min.**	**25**	**50**	**75**	**Max.**
Males, N = 6					
Shift Duration, sec.	22911	26366.50	29486***	31491	31708
Face Detection Time, sec.	12448	14422.75	14817**	18964.25	23000
Screen Fixation Time, sec.	2387	9245	11201*	12350	16743
Females, N = 32					
Shift Duration, sec.	11899	13617.50	18681	24483	31516
Face Detection Time, sec.	2620	7726.50	10482.50	15001	19032
Screen Fixation Time, sec.	1589	4325.25	6306.50	8179.50	15882

**p=0.0368; **p=0.0208; ***p=0.0023*

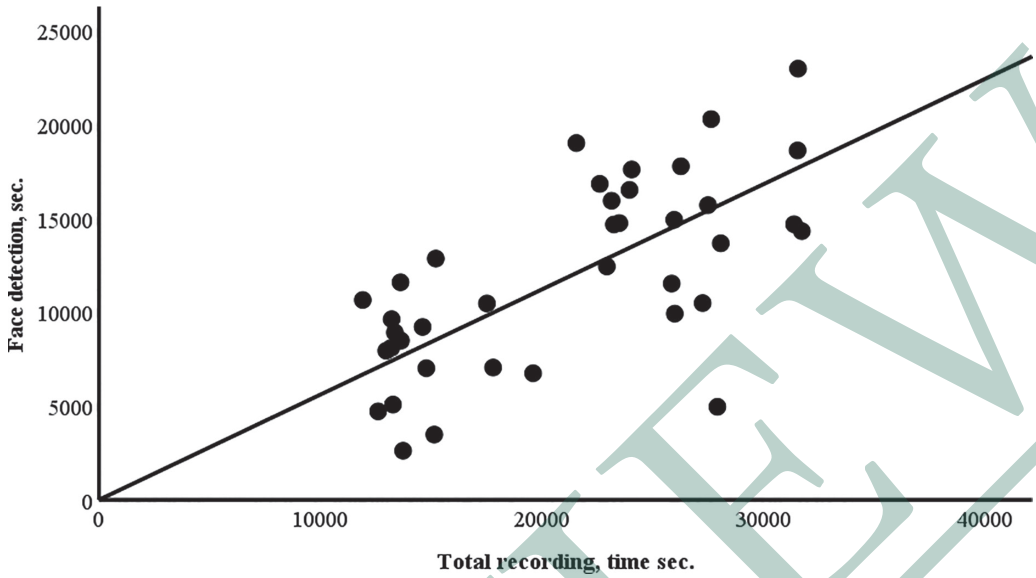

Figure 2. Relationship between shift duration and the time employees spend in front of the VDT screen, as recorded by the VDT Visual Monitoring System.

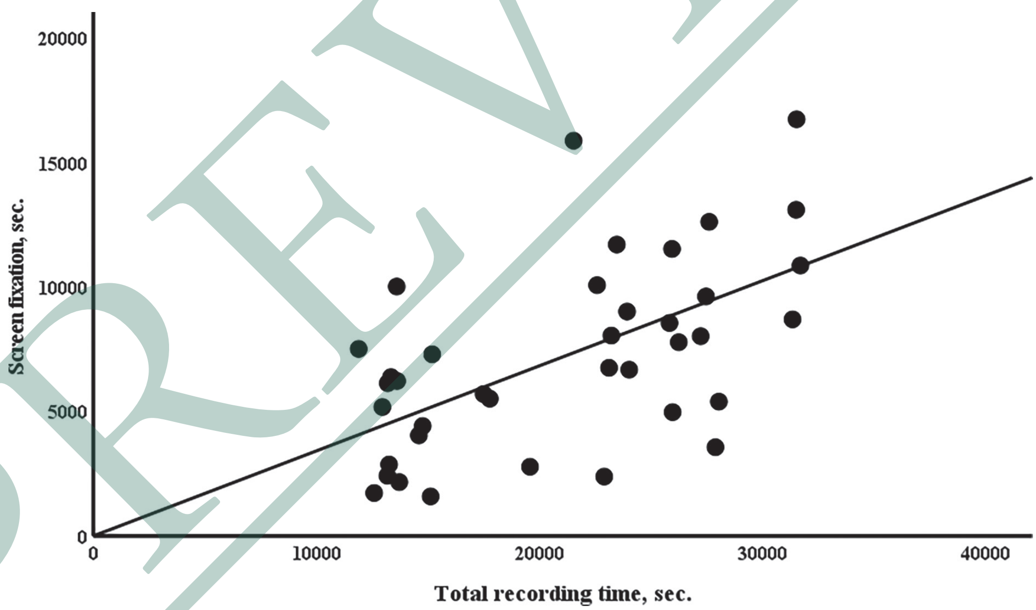

Figure 3. Relationship between shift duration and screen fixation time, as recorded by the VDT Visual Monitoring System.

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or FAS results. On the other hand, hypertensive subjects showed significantly (p=0.01) higher end-of-shift values of blinks/min (median values of 23.9 *vs.* 15.1), PERCLOS80 (median values of 19.6 *vs.* 3.9) and FAS questionnaire score, limited to physical fatigue (median values of 14 vs. 11).

4. Discussion

The present study explored the feasibility of objectively assessing visual workload among video display terminal (VDT) workers by measuring true screen fixation time with a novel, non-invasive monitoring

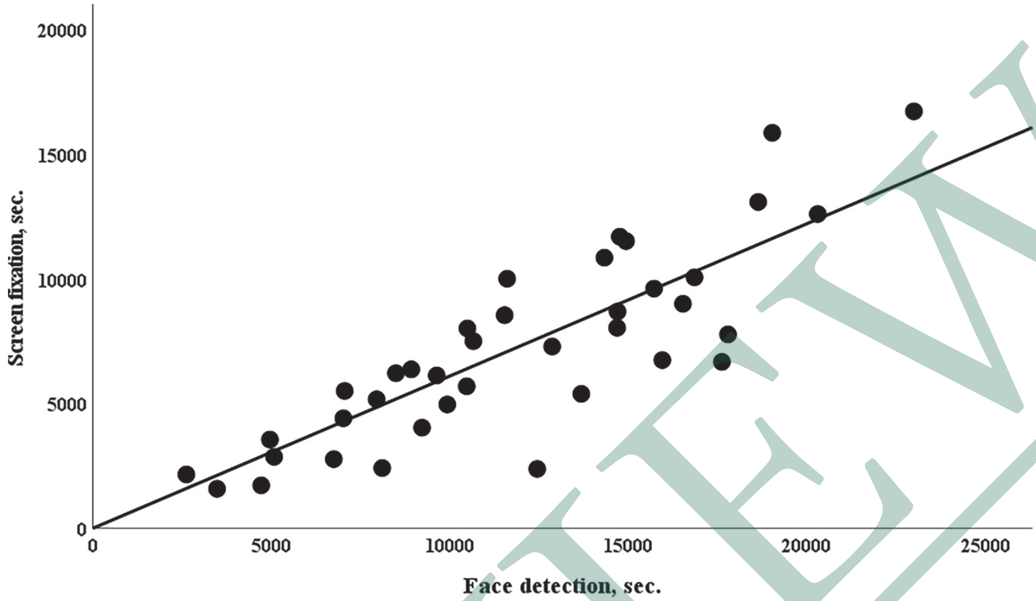

Figure 4. Relationship between face detection time and screen fixation time, as recorded by the VDT Visual Monitoring System.

system. By integrating objective exposure metrics with ophthalmological evaluation and fatigue-related indicators, this study provides an interdisciplinary contribution to occupational health research.

The primary finding of this study is the confirmation of the VDT Visual Monitoring System (VMS) as a reliable and well-tolerated tool for quantifying active screen fixation during routine administrative work. The job characteristics of our worker sample, a mix of VDT work and front-office tasks, make it challenging to evaluate the system's ability to discriminate between simply staying in front of the VDT screen and actual screen fixation. The results demonstrate that these metrics differed significantly, with total recording times (i.e., the whole work shift, about 8 h and 19 min, on average) higher than the time spent simply at the workstation in front of the screen (about 4 h and 11 min, on average), which in turn was higher than the time of active screen fixation (about 3 h and 11 min, on average). These differences are particularly relevant in real-world occupational settings, where VDT use is often discontinuous and difficult to quantify accurately through self-reported estimates. In terms of worker ocular and mental strain, the true VDT screen fixation time is the most relevant parameter to consider. According to Italian law, the investigated worker group would be classified as at risk considering both the shift duration and the time spent at the VDT workstation. However, our results indicate that the true dangerous fixation time is lower than 4 hours, which is the cut-off for VDT risk. The instrument's accuracy in discriminating between mere presence at the VDT workstation and actual visual engagement with the display through fixation is demonstrated by the lower regression coefficient of screen fixation time vs. face detection when both are considered vs. total recording time, and by the highest R^2 obtained in the relationship between screen fixation and face detection times. These results confirm our previously obtained ones [35].

From an ophthalmological perspective, a substantial proportion of workers exhibited signs of ocular surface alteration. Approximately half of the study population had pathological tear break-up time values, and OSDI® scores indicated varying degrees of dry eye disease. These findings are consistent with previous reports documenting an increased prevalence of dry eye symptoms among VDT-exposed workers [39].

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Interestingly, a significant correlation was found between the OSDI® scores and the extent of screen VDT fixation, but not with shift duration or the time the employee was in front of the VDT screen while performing other tasks at the workstation. This confirms the specificity of the fixation time collected by the VDT VSM. Although no statistically significant associations were identified between fixation time and BUT, this could be attributable to the limited sample size and the cross-sectional nature of the study. The lack of a significant association between objectively measured screen fixation time and BUT needs further consideration. While acute VDT exposure during a single shift reduces blink rates and leads to incomplete blinks, resulting in evaporative stress and transient tear film instability, the observed ocular surface alterations may primarily reflect chronic/cumulative effects of prolonged VDT use. Chronic exposure has been linked to persistent meibomian gland dysfunction (MGD) and compositional changes in the tear film lipid layer, promoting ongoing instability independent of daily fixation duration. Indeed, previous studies among VDT workers report discrepancies between OSDI (subjective symptoms) and objective signs such as BUT, attributable to a multifactorial etiology, including individual susceptibility, environmental factors (e.g., low humidity), and comorbidities. OSDI scores, which correlated with fixation time (Spearman's $\rho=0.34$, $p=0.05$), may capture symptomatic burden from both acute visual strain and chronic tear film alterations, whereas single measure BUT primarily reflects instantaneous stability. Longitudinal studies with repeated ophthalmological assessments could elucidate whether acute workloads exacerbate pre-existing chronic tear-film derangements, thereby informing targeted interventions in occupational settings.

Fatigue assessment using the Pupil Core® system did not reveal significant differences in PERCLOS80 values between the start and end of the work shift. Blink rate remained within physiological ranges and showed only a modest, significant increase over the shift. These findings suggest that the administrative tasks performed by the study population may not have been sufficiently demanding to induce measurable visual or cognitive fatigue within a single work shift. Alternatively, PERCLOS80 may be less sensitive to low-to-moderate levels of visual strain in office-based occupations.

The results of the FAS questionnaire further support this interpretation, with most participants reporting no or only mild fatigue. The concordance between subjective questionnaire data and objective PERCLOS80 measurements strengthens the internal consistency of the findings, although both approaches may lack sensitivity in detecting subtle or early fatigue-related effects.

A key strength of this study is the integration of occupational medicine, ophthalmology, and digital monitoring technologies. The objective quantification of visual exposure marks a significant advance over traditional assessment methods that rely on indirect estimates. The non-invasive nature of the VMS prototype and its minimal interference with routine work activities further enhance its potential applicability in occupational risk assessment and preventive strategies.

Several limitations must be acknowledged. The variability in shift duration and timing may have introduced heterogeneity in exposure conditions. In addition, the public-facing nature of the work tasks inherently involves unpredictable interruptions, which may affect both fixation patterns and fatigue measures. While this variability reflects real-world working conditions, it complicates exposure standardization. The relatively small sample size limits statistical power and precludes definitive conclusions regarding exposure–response relationships.

From a practical standpoint, the VDT Visual Monitoring System (VMS) offers actionable implications for occupational physicians under Italian Legislative Decree 81/2008. Integration of VMS data into the risk assessment document (DVR) enables precise quantification of active screen fixation, surpassing self-reported estimates and supporting tailored health surveillance protocols. Physicians could leverage real-time VMS reports to identify workers exceeding fixation thresholds (e.g., >60% shift time), prioritizing biennial ophthalmological exams (art. 176) and ergonomic interventions, such as mandatory 15-min breaks every 2 hours or workstation adjustments. In fitness-for-work judgments, VMS profiles may inform suitability restrictions,

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correlating fixation duration with OSDI scores to detect early visual strain. Future deployment in multi-shift settings, combined with wearable metrics (e.g., blink rate), would enhance DVR updates, preventive training, and compliance verification, ultimately reducing VDT-related morbidity in administrative cohorts.

Future research should aim to include larger study populations and repeated measurements across multiple workdays to improve exposure characterization and statistical robustness. The application of the VDT VMS in different occupational settings and its integration with ergonomic and musculoskeletal assessments may further elucidate the relationship between visual workload and work-related health outcomes.

5. Conclusion

The VDT VMS proved to be an effective tool for objectively quantifying true eye (and mental) engagement among VDT-exposed employees. Although ophthalmological assessments revealed a notable prevalence of ocular surface alterations, no clear exposure–response relationship was identified, likely due to the study's small sample size. Nonetheless, the proposed approach offers a promising framework for more accurate, evidence-based assessment of VDT-related visual workload in occupational contexts to support health protection.

Institutional Review Board Statement: Consistent with the criteria established by the Italian Ministry of Health Decree of 30 January 2023 for observational studies conducted in the context of occupational health monitoring, formal approval by an Ethics Committee was not required. All participants provided written informed consent prior to enrollment. The study was conducted in accordance with the WMA Declaration of Helsinki and the General Data Protection Regulation (GDPR, Regulation EU 679/2016).

Declaration of Interest: The authors declare no conflict of interest.

Author Contribution Statement: Conceptualization, G.D.P, E.M, D.R. V.R. and F.S.; Methodology, E.S., G.D.P. and V.R..; Software, S.D. and M.F.; Validation, E.S., V.F., V.R. and G.D.P.; Formal analysis, G.D.P.; Investigation, E.M., D.R., G.B. and N.V.; Resources, V.F. and G.D.P.; Data curation, S.D. and C.T.; Writing—original draft, E.M., D.R. and G.D.P.:; Writing—review & editing, G.D.P, E.M. and D.R..; Supervision, E.S., V.F., V.R. and G.D.P.; Project administration, G.D.P. All authors have read and agreed to the published version of the manuscript.

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