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Review Article

The association between visual display terminal use and dry eye: a review

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ABSTRACT.

***Background*. Dry eye disease (DED) is a multifactorial disease of the tear film and ocular surface. It causes ocular symptoms, reduced quality of life and a considerable economic burden on society. Prolonged use of visual display terminals (VDTs) has been suggested as an important risk factor for DED.**

***Purpose*. This review aims to study the association between DED and VDT use with an emphasis on the prevalence of DED among VDT users and harmful daily duration of VDT use.**

***Methods*. A PubMed search was conducted and yielded 57 relevant articles based on a set of inclusion and exclusion criteria. The studies were subclassified according to study design.**

***Results*. The far majority of the studies showed an association between VDT use and DED or DED-related signs and symptoms. The prevalence of definite or probable DED in VDT and office workers ranged from 26% to 70%, with as few as 1–2 hr of VDT exposure per day being associated with DED.**

***Conclusion*. VDT use is strongly associated with DED. VDT-associated DED is prevalent, but the exact prevalence needs to be further elucidated using standardized DED diagnosis criteria. Furthermore, a safe lower limit of daily VDT use has yet to be established. More research is needed on the effect of digitalization and digital transformation, which are particularly high during the time of the COVID-19 pandemic.**

Key words: dry eye disease – daily VDT duration thresholds – prevalence – visual display terminal

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Introduction

Dry eye disease (DED) is a highly prevalent, multifactorial disorder of the tear film and ocular surface (cornea and conjunctiva; Craig et al. 2017). DED, which results from the loss of homeostasis of the tear film, causes ocular pain and discomfort in millions of individuals worldwide (Craig et al. 2017; Stapleton et al. 2017). The major symptoms of DED are ocular surface dryness, stinging, burning, pain and foreign body sensation (Wolffsohn et al. 2017). DED is one of the most common causes of ophthalmic visits (Stapleton et al. 2017), making it a substantial global health problem that impacts both DED patients and society as a whole. The annual loss of productivity in Japanese office workers due to DED was estimated to be worth 6160 USD per person afflicted (Uchino et al. 2014a,b). The total financial burden of DED in the United States has been estimated to be 55 billion USD annually (Yu et al. 2011). Productivity loss, cost of care and reduced quality of life represent the major components of the total cost of DED (Stapleton et al. 2017).

The healthy tear film covers the anterior surface of the cornea and conjunctiva and is responsible for protecting the ocular surface from the external environment (Dartt & Willcox 2013). The tear film is approximately 3 μm thick and is made up of two distinct layers: the outer lipid layer and the inner mucoaqueous layer (Willcox et al. 2017). The lipid layer is made up of meibum that is secreted from the meibomian glands (MG), while the mucoaqueous layer is mainly produced by the lacrimal gland and the conjunctival epithelial cells (Dartt & Willcox 2013; Deng et al. 2013; Swamynathan & Wells 2020). The lipid layer is evenly distributed during the blink and prevents tear fluid evaporation and desiccation of the ocular surface (Deng et al. 2013; Swamynathan & Wells 2020). Blinking also facilitates meibum delivery to the lipid layer by a milking action (Knop et al. 2011). The mucoaqueous layer is involved in water retention and lubrication and contributes to the metabolism and immunologic protection of the underlying avascular cornea (Gipson 2004; Dartt & Willcox 2013; Hori 2018). In patients with DED, the tear film is dysfunctional and the protective effects are reduced, leading to symptoms and signs of DED including damage to the cornea and conjunctiva (Bron et al. 2017; Craig et al. 2017).

DED is often classified into two non-mutually exclusive major aetiological groups: aqueous-deficiency dry eye (ADDE) and evaporative dry eye (EDE; Schaumberg et al. 2011; Bron et al. 2017; Craig et al. 2017). Briefly, ADDE is characterized by a deficiency of the aqueous component of the tear film, while EDE is marked by excessive evaporation from the ocular surface. In ADDE, the mucoaqueous layer input from the lacrimal gland is reduced. On the other hand, EDE commonly occurs from a defect of the lipid layer of the tear film (Bron et al. 2017). EDE affects most patients of the two groups and is usually the result of conditions that affect the eyelid, especially MG dysfunction (Schaumberg et al. 2011; Craig et al. 2017; Stapleton et al. 2017). Short break-up time dry eye (SBUDE) is a newly discovered form of EDE associated with symptoms and unstable tear film as measured by reduced tear film break-up time (TBUT), accompanied by other normal clinical objective findings (Tsubota 2018). It is found to occur frequently in office workers (Uchino et al. 2013; Bron et al. 2017).

Prolonged use of visual display terminals (VDTs) is linked to increased risk of EDE (Uchino et al. 2013; Bron et al. 2017; Mehra & Galor 2020). VDT use consistently decreases blink rate and increases the proportion of incomplete blinks, leading to increased exposure of the ocular surface to the environment and excess tear fluid evaporation (Tsubota 1998; Nielsen et al. 2008; Cardona et al. 2011; Wolkoff et al. 2012; Hirota et al. 2013; Chu et al. 2014; Argilés et al. 2015). The resulting loss of tear fluid can lead to hyperosmolarity, ocular surface damage, tear film instability and symptoms of dry eye (Stapleton et al. 2017). Hyperosmolarity and tear film instability are thought to be particularly important drivers of the vicious circle of DED (Bron et al. 2017; Fig. 1).

Computer use is acknowledged as a risk factor for DED and could play a major role in the burden of disease in the coming years (Stapleton et al. 2017; Mehra & Galor 2020). Estimates by the International Telecommunication Union show that the percentage of persons using the Internet approximately quadrupled from 2005 to 2019 (ITU 2020; Fig. 2). Similarly, the incidence of DED increased in the US population from 2008 to 2012. Although increasing recognition and improved diagnostics of DED could explain a part of this increase, other factors are also likely to be at play (Dana et al. 2019). Increased VDT use may account for some of the observed increase (Uchino et al. 2013; Stapleton et al. 2017) and will be reviewed herein.

A rapid increase in Internet use was seen in the first half of 2020 possibly due to the general restrictions caused by the COVID-19 pandemic. An estimated 63% of the world's population used the Internet in the fourth quarter of 2020 (IWS 2020; Fig. 2). Computer and general VDT use increased drastically in all age groups (Bahkir & Grandee 2020; GlobalWebIndex 2020; Griffith 2020; Jayadev et al. 2020; Koeze & Popper 2020; Sneader & Singhal 2021). A questionnaire-based survey from a university in Italy from June 2020 found that more than 24% of the students used VDT for more than 6 hr per day (hr/day), and over half of these students had pathological ocular surface disease index (OSDI) scores (Giannaccare et al. 2020).

Ageing is considered a strong risk factor for DED (Stapleton et al. 2017). As early adopters of VDTs are only now starting to reach retirement age, it is likely that the full long-term impact of VDT use has yet to occur due to the chronic nature of DED and the important role ageing plays in this condition. With the ongoing COVID-19

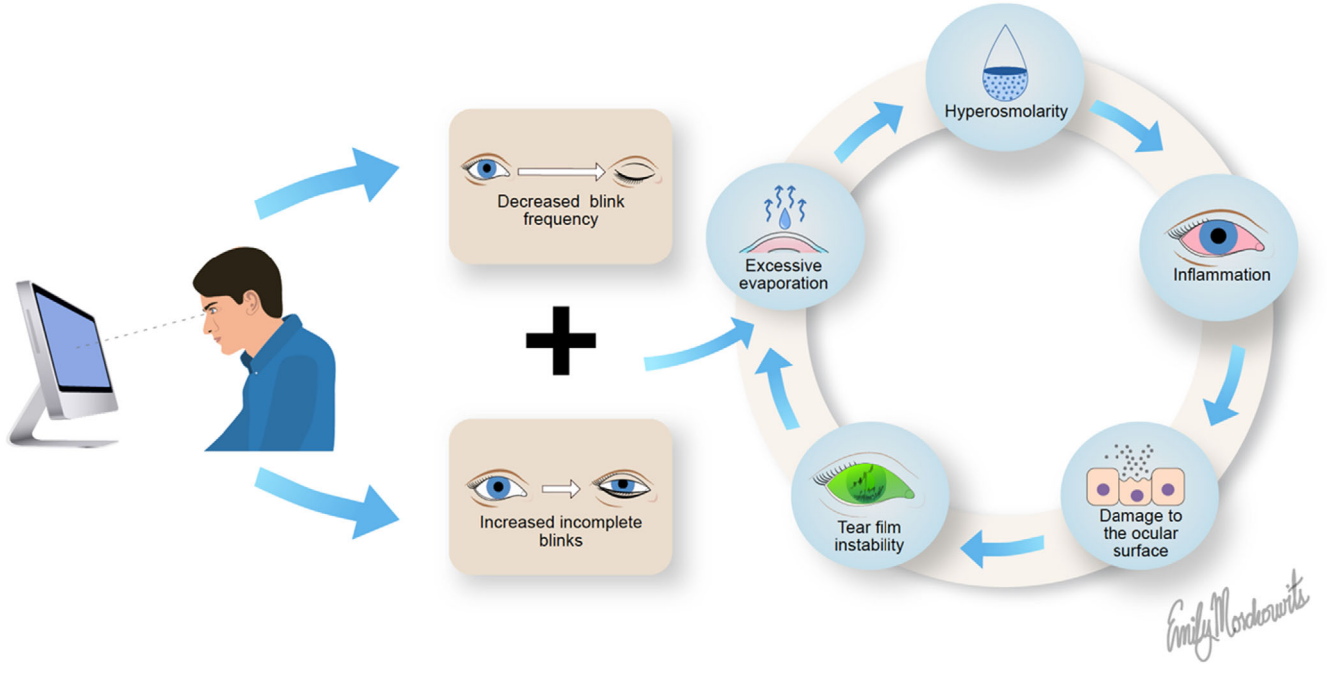

Fig. 1. The pathophysiology of VDT associated dry eye disease (DED). VDT use increases evaporation by reducing blink frequency and increasing the number of incomplete blinks and drives the vicious circle of DED.

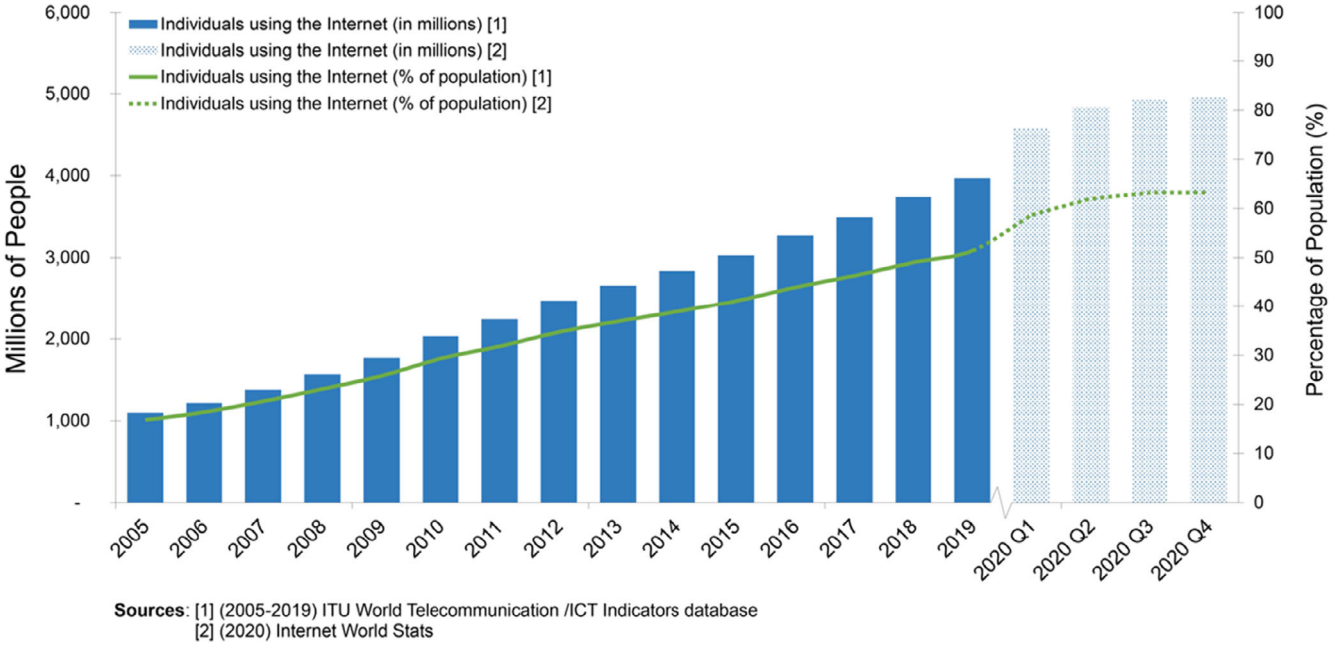

Fig. 2. Graph of Internet usage from 2005 to 2020. The global number of individuals using the Internet, total (left) and percentage (right).

pandemic making VDT use evermore ubiquitous, VDT-associated DED will likely increase in the future. It is thus necessary to further clarify the influence of VDT use on DED. The aim of this review is to critically evaluate the association between VDT use and DED with an emphasis on the prevalence of DED in VDT users and daily duration of VDT use.

Methods

Search strategy

A search was conducted on PubMed on the 3rd of May 2020 using the following search term: *(digital visual terminal* OR computer use OR screen use OR smartphone OR display OR visual display terminal* OR computer vision syndrome OR tablet OR phone OR screen time) AND (dry eye OR DED)*. Two authors (HF and KF) independently reviewed the articles. Discrepancies between the authors was settled through discussion with a third author (MSM). All published articles available in English were included in the initial search results. Case reports, letters to the editor and

review articles were excluded. The remaining full-text articles were then evaluated first by title and later by abstract to ensure relevance to topic. The full text was evaluated to ensure it met all of the following inclusion criteria: original, peer-reviewed study with available English full text that investigated: (1) the prevalence of dry eye in VDT users or (2) the daily duration of VDT use that is associated with changes in subjective or objective DED-related parameters. This process is shown in Fig. 3.

Quality assessment of included studies

The methodologic quality of the included studies was evaluated using five different quality assessment tools (NHLBI; Sterne et al. 2019). Four of five tools were developed by the US National Heart, Lung and Blood Institute (NHLBI). These included the NHLBI quality assessment tools for observational cohort and cross-sectional studies, case–control studies, before-after studies and case series studies. The fifth tool was the Cochrane Risk of Bias Tool 2.0 for randomized crossover trials (RCTs). The NHLBI quality assessment tools included between 9 and 14 questions on study design, methods and the resulting risk of bias. The Cochrane Risk of Bias Tool 2.0 for RCTs included six aspects: the randomization process, period and carryover effects, deviation from intended interventions, measurement of the outcome, missing outcome data and selection of the reported results, that each were rated as 'high risk', 'some concerns' or 'low risk' generating an overall risk of bias score.

Results

Overview of existing literature

The search term *(digital visual terminal* OR computer use OR screen use OR smartphone OR display OR visual display terminal* OR computer vision syndrome OR tablet OR phone OR screen time) AND (dry eye OR DED)* yielded 819 articles available in English. After excluding review articles, letters to the editor and case reports, the titles and abstracts of 782 articles were assessed for relevance to VDT and dry eye. For the remaining 147 articles, the full text was reviewed for relevance according to the inclusion criteria. A schematic of this process and the results after exclusion is shown in Fig. 4.

The final 57 articles included in this review were published between September 1995 (Hikichi et al. 1995) and April 2020 (Bilkhu et al. 2020) and conducted in 23 different countries: 11 in Japan (JP); 7 in Korea (KR); 5 in China (CN); 4 in Spain (ES), Turkey (TR) and USA (US); 3 in India (IN); 2 in Italy (IT), Portugal (PT) and Saudi Arabia (SA); 1 in Australia (AU), Brazil (BR), England (GB), Ghana (GH), Greece (GR), Jamaica (JM), Mexico (MX), Norway (NO), Poland (PL), Nepal (NP), Singapore (SG), Sri Lanka (LK) and Thailand (TH; Fig. 5).

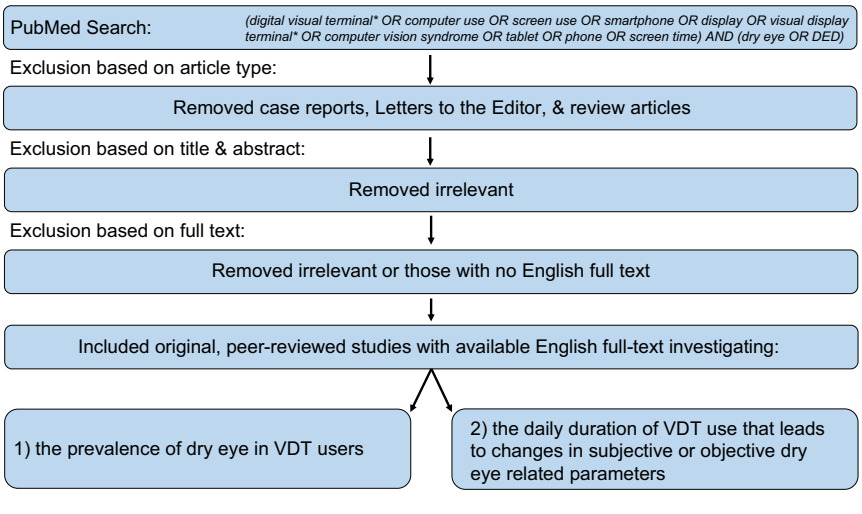

Fig. 3. Flow chart of the search strategy.

The final 57 studies were divided into four study designs that were analysed in these groups. Of the 57 studies, 15 studies had a follow-up period, while 42 did not follow subjects over time. Group 1: Of the 42 studies without follow-up, 26 relied on questionnaires alone for diagnosing dry eye or assess disease burden in relation to VDT use (Table 1). Group 2: The remaining 16 studies without follow-up used a combination of questionnaires and objective tests to assess dry eyes (Table 2). The 15 prospective studies with a follow-up period were either Group 3: observational (Table 3) or Group 4: interventional (Table 4). A summary of study characteristics and key findings of each group are presented in Tables 1–4.

Quality of included studies

The results of quality assessment of studies are summarized in Tables S1–S7. Fifty-two studies were assessed using the NHLBI quality assessment tools. Of the fifty-two studies, forty-three studies were assessed using the NHLBI quality assessment tool for observational cohort and cross-sectional studies (Tables S1–S3), three studies were evaluated using the tool for case–control studies (Table S4), five studies were assessed based on the tool for before-after studies (Table S5), and one study was assessed using the checklist for case series studies (Table S6). Five studies were evaluated using the Cochrane Risk of Bias Tool 2.0 for randomized crossover trials. For the studies that were assessed using the Cochrane Risk of Bias Tool 2.0 for randomized crossover trials, the overall risk of bias was graded as 'high' for two studies (Yee et al. 2007; Chu et al. 2011), while three studies had 'some concerns' (Antona et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020).

Overview of studies without follow-up

Group 1: Studies using questionnaires only
A wide range of types of individuals have been studied using questionnaires alone to diagnose DED (Shimmura et al. 1999; Uchino et al. 2008, 2011; Castro et al. 2018; Titiyal et al. 2018; Hyon et al. 2019a,b; Yamanishi et al. 2019; Hanyuda et al. 2020) or to describe dry eye symptoms (González-Méijome et al. 2007; Moschos et al.

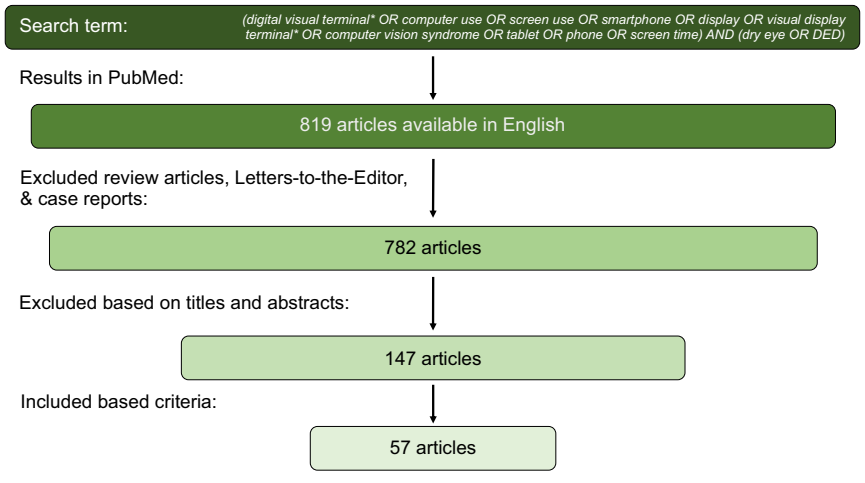

Fig. 4. Flow chart of results of search strategy.

2012; Portello et al. 2012; Logaraj et al. 2014; Garza-León et al. 2016; Porcar et al. 2016; Ranasinghe et al. 2016; Asiedu et al. 2017; Chałas et al. 2018; Kharel Sitaula & Khatri 2018; Mowatt et al. 2018; Cheng et al. 2019; Inomata et al. 2019; Köksoy Vayısoğlu et al. 2019; Al Tawil et al. 2020; Altalhi et al. 2020; Jeong et al. 2020; Table 1). These studies were conducted in 17 different countries over a time period of 21 years and included students (Logaraj et al. 2014; Garza-León et al. 2016; Asiedu et al. 2017; Kharel Sitaula & Khatri 2018; Mowatt et al. 2018; Hyon et al. 2019a,b; Al Tawil et al. 2020; Altalhi et al. 2020), office workers (Uchino et al. 2008; Portello et al. 2012; Ranasinghe et al. 2016; Cheng et al. 2019; Yamanishi et al. 2019), adults (Uchino et al. 2011; Castro et al. 2018; Inomata et al. 2019; Hanyuda et al. 2020), young adults (Shimmura et al. 1999; Moschos et al. 2012; Porcar et al. 2016), adolescents (Jeong et al. 2020), ophthalmic patients (Chałas et al. 2018; Titiyal et al. 2018), contact lens (CL) wearers (González-Méijome et al. 2007), lecturers (Köksoy Vayısoğlu et al. 2019) and paramedical workers (Hyon et al. 2019a,b). Sample sizes ranged from 87 (Moschos et al. 2012) to 102 582 (Hanyuda et al. 2020) participants, with a median sample size of 646, and a mean age of 32 years. Across all studies, the sexes were almost equally represented, with 49% males and 51% females in the total number of subjects included.

The questionnaire used most was the OSDI (Portello et al. 2012; Garza-León et al. 2016; Asiedu et al. 2017; Titiyal et al. 2018; Hyon et al. 2019a,b; Inomata et al. 2019; Köksoy Vayısoğlu et al. 2019), followed by the women's health study (WHS) questionnaire (Uchino et al. 2008, 2011; Castro et al. 2018; Yamanishi et al. 2019; Hanyuda et al. 2020) and the Hayes' symptom score (Moschos et al. 2012; Portello et al. 2012; Porcar et al. 2016). Five studies combined the OSDI with one (Portello et al. 2012; Asiedu et al. 2017; Köksoy Vayısoğlu et al. 2019) or two (Hyon et al. 2019a,b) other questionnaires. Visual analog scale (VAS; Hyon et al. 2019a,b), Standardized Patient Evaluation of Eye Dryness (SPEED; Asiedu et al. 2017) and the Interview and Examination Questionnaire (Chałas et al. 2018) were also applied. Several studies either used unspecified symptom scores (Shimmura et al. 1999; González-Méijome et al. 2007; Logaraj et al. 2014; Ranasinghe et al. 2016; Kharel Sitaula & Khatri 2018; Mowatt et al. 2018;

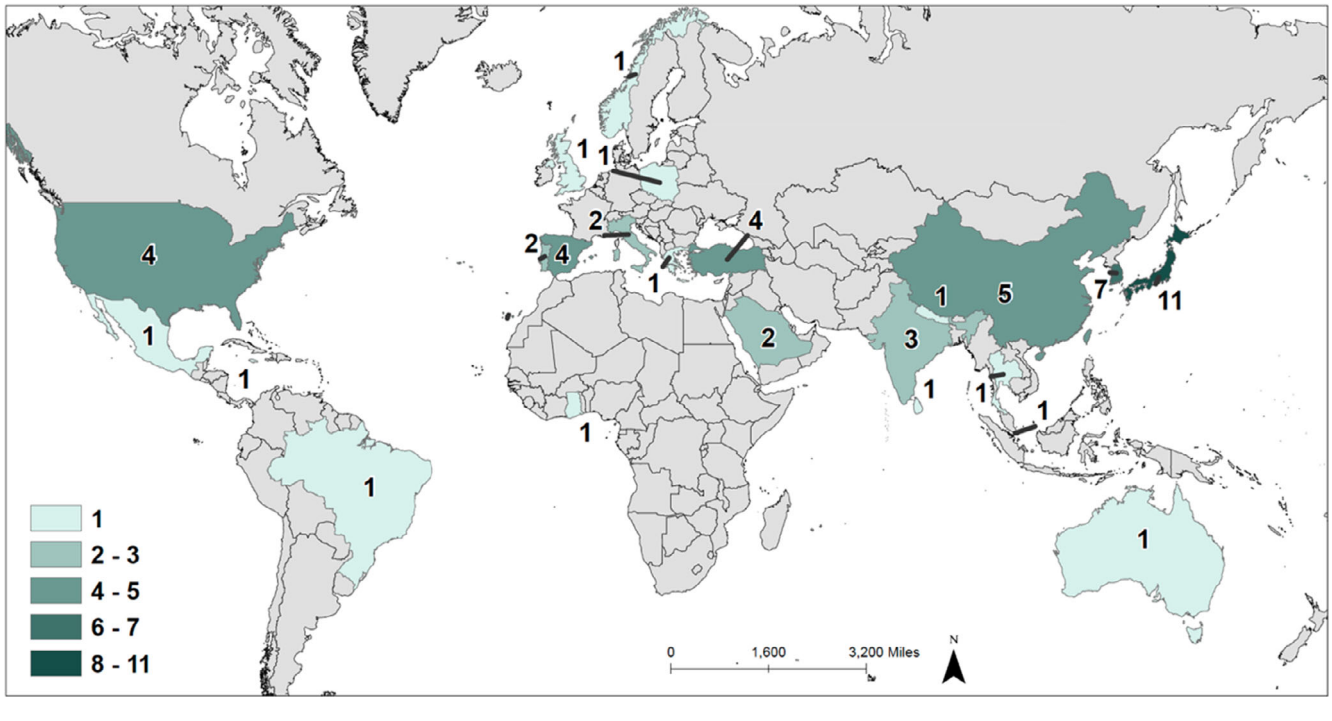

Fig. 5. Locations of included studies. The gradient represents the number of studies conducted in each country. Overlayed on grey ESRI basemap.

Table 1. Key characteristics and findings of single-visit studies utilizing questionnaires only.

Study	Sample	Mean age (SD)	Daily exposure	Questionnaires	Outcomes
Al Tawil et al. 2020, SA (Al Tawil et al. 2020)	713 students	N.D.	<5 hr/day, >5 hr/day	Symptom score	67% of business students and 34% of medical students reported eye dryness. VDT use >5 hr/day was associated with more ocular symptoms (OR 1.52; CI: 1.07–2.16). Ocular symptoms were influenced by position of device and screen brightness
Altalhi et al. 2020, SA (Altalhi et al. 2020)	334 students	20 (N.D.)	<6, >6 hr/day	Symptom score	48% reported eye dryness. VDT use >6 hr/day was not associated with an increase in symptoms of CVS compared to <6 hr/day ($p = 0.69$)
Asiedu et al. 2017, GH (Asiedu et al. 2017)	650 students	22 (3)	<1, >1 hr/day	SPEED, OSDI	Symptomatic dry eye was not associated with computer use >1 hr/day compared to <1 hr/day (OR 1.17; CI, 0.75–1.66; $p = 0.57$)
Cahlas et al. 2018, PL (Chałas et al. 2018)	642 ophthalmic and dental patients	51 (N.D.)	N.D.	The Interview and Examination Questionnaire	Prolonged VDT use was associated with eye dryness. 56% of computer users compared to 44% of non-computer users ($p < 0.001$) reported eye dryness
Cheng et al. 2019, CN (Cheng et al. 2019)	915 office workers	N.D.	<6, 6–11, >11 hr/day	Symptom score	41% reported eye dryness. 33% of those using VDT <6 hr/day compared to 53% of those using VDT >11 hr/day reported eye dryness (OR 2.22; CI: 1.17–4.20; $p < 0.05$). 41% of those using VDT 6–11 hr/day reported eye dryness, although this was not significantly different from VDT<6 hr/day (OR 1.42; CI: 0.84–2.39)
de Castro et al. 2018, BR (Castro et al. 2018)	3107 adults	41 (17)	<6 hr/day, >6 hr/day	WHS questionnaire	DED in 16% using computer >6 hr/day but 12% when <6 hr/day (OR 1.77; CI: 1.36–2.31)
Garza-León et al. 2016, MX (Garza-León et al. 2016)	823 students	21 (2)	N.D.	OSDI	70% had symptoms of OSD. Increased duration of computer use was associated with decreased OSDI scores (OR 0.82; CI: 0.72–0.93)
Hanyuda et al. 2020, JP (Hanyuda et al. 2020)	102 582 adults	58 (9)	<1, 1–<2, 2–<5, >5 hr/day	WHS questionnaire	22% of males and 37% of females using VDTs >5 hr/day had DED compared to 16% of males (OR 1.58; CI: 1.43–1.76) and 27% of females (OR 1.56; CI: 1.41–1.72) using VDTs <1 hr/day
Hyon et al. 2019a,b, KR (Hyon et al. 2019a,b)	232 paramedics	N.D.	7–8 hr/day	Symptom score, VAS, OSDI	Mean duration of computer use was 8 hr/day in the DED group and 7 hr/day in the non-DED group (OR 1.15; CI 1.01–1.3; $p = 0.029$)
Hyon et al. 2019a,b, KR (Hyon et al. 2019a,b)	188 students	28 (3)	6–8 hr/day	Symptom score, VAS, OSDI	Prevalence of DED was 27%. Mean duration of computer use was 8 hr/day in DED group and 6 hr/day in non-DED group (OR 1.15; CI: 1.05–1.27; $p = 0.004$). Smartphone use was not associated with DED ($p = 0.45$)
Inomata et al. 2019, JP (Inomata et al. 2019)	4454 adults	28 (13)	<4, 4–8, >8 hr/day	OSDI	VDT use >8 hr/day was associated with symptomatic DED, compared to <4 hr/day (OR 1.55; CI 1.25–1.91; $p < 0.001$)
Jeong et al. 2020, KR (Jeong et al. 2020)	2319 adolescents	N.D.	1–3 hr/day	Symptom score	The adolescents who spent most time on gaming had most dry eye symptoms (OR 3.8; CI 3.0–4.9)
Kharel Sitaula et al. 2018, NP (Kharel Sitaula & Khatri 2018)	236 students	21 (1)	<1 to >5 hr/day	Symptom score	93% of those using computer >2 hr/day, and 32% of those <2 hr/day, had one or more symptoms of

Table 1 (Continued)

Study	Sample	Mean age (SD)	Daily exposure	Questionnaires	Outcomes
					CVS ($p = 0.001$). Eye dryness was the second most frequent CVS symptom reported (13%)
Köksoy Vayisoğlu et al. 2019, TR (Köksoy Vayısoğlu et al. 2019)	254 lecturers	39 (9)	<8 hr/day, >8 hr/day	Symptom score, OSDI	53% had symptoms of DED. Increasing daily computer use was associated with worse OSDI score ($p = 0.009$). Smartphone use did not show the same association. No difference between those using computer >8 hr/day compared to <8 hr/day ($p = 0.21$)
Logaraj et al. 2014, IN (Logaraj et al. 2014)	416 students	N.D.	<4, 4–6, >6 hr/day	Symptom score	Engineering students used computer more than medical students ($p < 0.001$) and had a higher risk of eye dryness (OR 2.1; CI: 1.3–3.4; $p < 0.01$). Computer use >4 hr/day was associated with eye dryness (OR 1.79; CI: 1.09–2.95; $p = 0.02$). Fewer breaks linked to more eye dryness
Meijome et al. 2007, PT (González-Méijome et al. 2007)	213 CL and non-CL wearers	25 (5) and 24 (5)	0–3, 3–6, 6–9 hr/day	Symptom score	Non-CL wearers using computers 6–9 hr/day led to more symptoms. CL wearers using computer between 3 and 6 hr/day showed most symptoms. CL wearers generally had more symptoms
Moschos et al. 2012, GR (Moschos et al. 2012)	87 young adults	31 (8)	3 hr/day*	Hayes' symptom score	66% of participants reported eye dryness. Prolonged computer use was associated with more ocular symptoms ($p = 0.02$)
Mowatt et al. 2018, JM (Mowatt et al. 2018)	409 students	22 (2)	<2, 2–4, 4–6, >6 hr/day	Symptom score	10% reported eye dryness. Eye dryness was influenced by position of device, use of adjustable chairs and frequency of breaks, but not daily duration of computer use
Porcar et al. 2016, ES (Porcar et al. 2016)	116 young adults	25 (N.D.)	<2, 2–4, 4–6, 6–8, >8 hr/day	Hayes' symptom score	72% reported ocular symptoms. 9% had moderate eye dryness. VDT use >2 hr/day was associated with ocular symptoms compared to <2 hr/day ($p = 0.01$)
Portello et al. 2012, US (Portello et al. 2012)	520 office workers	39 (14)	6 hr/day*	OSDI, Hayes' symptom score	32% had eye dryness. Prolonged computer use linked to more ocular symptoms ($p < 0.001$)
Ranasinghe et al. 2016, LK (Ranasinghe et al. 2016)	2210 office workers	31 (8)	2–5, 6–9, >9 hr/day	Symptom score	31% reported eye dryness. Mean duration of computer use was 8 hr/day in CVS group, compared to 7 hr/day in non-CVS group ($p < 0.05$). Increased VDT use was associated with CVS (OR 1.10; CI: 1.07–1.14; $p < 0.001$)
Shimmura et al. 1999, JP (Shimmura et al. 1999)	598 young adults	35 (N.D.)	N.D.	Symptom score	33% believed that they had DED. VDT use, excluding television, was associated with ocular symptoms and self-diagnosed DED ($p = 0.058$)
Titiyal et al. 2018, IN (Titiyal et al. 2018)	15625 ophthalmic patients	N.D.	0–2, 2–4, >4 hr/day	OSDI	32% had DED. A desk job with computer use and increased duration of VDT use was linked to both DED and increased severity of DED ($p < 0.001$)
	2644 adults	N.D.	none, <2, 2–4, >4 hr/day	WHS questionnaire	

Table 1 (Continued)

Study	Sample	Mean age (SD)	Daily exposure	Questionnaires	Outcomes
Uchino et al. 2011, JP (Uchino et al. 2011)					VDT use ≥2 hr/day was associated with DED in women (OR 2.33; CI: 1.12–4.85), but not in men (OR 1.10; CI: 0.54–2.24)
Uchino et al. 2008, JP (Uchino et al. 2008)	3549 office workers	N.D.	<2, 2–4, >4 hr/day	WHS questionnaire	32% of office workers had DED. 31% of <2 hr/day compared to 41% >4 h/day had DED (OR 1.69; CI: 1.39–2.16). Eye dryness was not influenced by position of device or glare filter
Yamanishi et al. 2019, JP (Yamanishi et al. 2019)	1030 office workers	45 (N.D.)	7 hr/day*	WHS questionnaire	15% had diagnosed and 11% had undiagnosed DED. Mean VDT use was 7.5h/d in undiagnosed DED, 7 h/d in diagnosed and 6.5 hr/day in non-DED group. Prolonged VDT use was associated with undiagnosed (OR 1.12; CI: 1.04–1.21), but not diagnosed DED (OR 1.06; CI: 0.99–1.14)

CI = Confidence Interval, CL = Contact Lens, CVS = Computer Vision Syndrome, DED = Dry Eye Disease, N.D. = Not Described, OR = Odds Ratio, OSD = Ocular Surface Disease, OSDI = Ocular Surface Disease Index, SEEQ = Salisbury Eye Evaluation Questionnaire, SD = Standard Deviation, SPEED = Standardized Patient Evaluation of Eye Dryness, VAS = Visual Analog Scale, VDT = Visual Display Terminal, WHS = Women's Health Study questionnaire. Country of origin = BR – Brazil, CN – China, ES – Spain, GH – Ghana, GR – Greece, IN – India, JM – Jamaica, JP – Japan, KR – South Korea, LK – Sri Lanka, MX – Mexico, NP – Nepal, PL – Poland, PT – Portugal, SA – Saudi Arabia, TR – Turkey, US – United States.
* Mean daily duration of VDT use.

Cheng et al. 2019; Hyon et al. 2019a,b; Köksoy Vayısoğlu et al. 2019; Al Tawil et al. 2020; Altalhi et al. 2020; Jeong et al. 2020) or assessed dry eye symptoms based on questionnaires focussing on computer vision syndrome (CVS; Logaraj et al. 2014; Ranasinghe et al. 2016; Kharel Sitaula & Khatri 2018; Mowatt et al. 2018; Al Tawil et al. 2020; Altalhi et al. 2020).

The prevalence of dry eye symptoms or DED in office workers ranged from a minimum of 26% (Yamanishi et al. 2019) to a maximum of 41% (Cheng et al. 2019). Harmful daily VDT duration thresholds ranged from a minimum of 1–2 hr/day (Hanyuda et al. 2020) to a maximum of 8 hr/day (Inomata et al. 2019). Of students, 10% (Mowatt et al. 2018) to 67% (Al Tawil et al. 2020) reported eye dryness as a symptom. Of the 26 studies, four did not find a positive association between increased daily duration of VDT use and DED- or DED-related symptoms (Garza-León et al. 2016; Asiedu et al. 2017; Mowatt et al. 2018; Altalhi et al. 2020).

Group 2: Studies including objective measures

Sixteen studies without follow-up from seven different countries included the measurement of clinical parameters of dry eye when investigating the association between VDT use and DED or DED-related parameters (Table 2). These studies included a combined 15 661 participants, with sample sizes ranging from 77 (Julio et al. 2012) to 6657 (Li et al. 2015). Although varying between studies, the proportion of males and females in the total sample were 46% and 54%, respectively. The mean age of participants varied from 11 years (Moon et al. 2014) to 64 years (Viso et al. 2009). The mean average age was 37 years. The occupational groups studied were office workers (Nakamura et al. 2010; Kojima et al. 2011; Uchino et al. 2013), VDT workers (Bhargava et al. 2014; Wu et al. 2014; Kawashima et al. 2015) and students (Bhargava et al. 2014; Li et al. 2018). Ophthalmic patients (Hikichi et al. 1995; Li et al. 2015; Yang et al. 2015), adults (Viso et al. 2009; Julio et al. 2012; Rossi et al. 2019), young adults (Cortes et al. 2018), adolescents (Tichenor et al. 2019) and school children (Moon et al. 2014) were also studied.

Table 2. Summary of key characteristics and findings of single-visit studies with objective measures.

Study	Sample	Mean age (SD)	Daily VDT exposure	Symptoms	TBUT	OSS	MGA	Sch. I	TMH	Additional key takeaways
Bhargava et al. 2014, IN (Bhargava et al. 2014)	715 VDT workers and students	26 (4)	7 hr/day*	–[3]	–	N.D.	N.D.	–/O	N.D.	72% of computer users had moderate or severe symptoms of DED, compared to 9% of controls. Increased daily duration of computer use associated with worse TBUT, symptoms and CIC scores. GCD lower in computer workers. ($p < 0.001$ for all). Sch. I was worse in computer users than controls ($p < 0.001$), but was not associated with daily duration of computer use ($p = 0.36$)
Cortes et al. 2018, IT (Cortes et al. 2018)	120 young adults	47 (N.D.)	2 hr/day, >8 hr/day	–[2, 10]	O	O	N.D.	O	N.D.	59% in the group with computer use >8 hr/day had elevated OSDI values, compared to none in the 2 hr/day group
Hikichi et al. 1995, JP (Hikichi et al. 1995)	2127 ophthalmic patients	47 (N.D.)	N.D.	–[4]	†	–	N.D.	†	N.D.	23% of VDT users had DED, compared to 17% in the total study population ($p < 0.05$)
Julio et al. 2012, ES (Julio et al. 2012)	77 participants	41 (20)	<3, >3 hr/day	–[9]	N.D.	N.D.	N.D.	N.D.	N.D.	Computer use >3 hr/day was associated with increased tear osmolarity ($p < 0.01$)
Kawashima et al. 2015, JP (Kawashima et al. 2015)	369 VDT workers	44 (9)	6–6.5 hr/day	–[4]	†	–	N.D.	†	N.D.	4% had definite and 55% had probable DED. Prolonged computer use was associated with DED ($p = 0.015$). DED group had average daily computer use of 6.5 hr/day, and non-DED group 6 hr/day
Kojima et al. 2011, JP (Kojima et al. 2011)	171 office workers	36 (7)	<4, >4 hr/day	–[1]	O	O	N.D.	O	–	29% had definite DED and 41% had probable DED. Although not significantly different, 30% of those using computer >4 hr/day had DED compared to 28% of those <4 hr/day ($p = 0.62$)
Li et al. 2018, CN (Li et al. 2018)	901 students	20 (3)	<8 hr/day, >8 hr/day	–[1]	N.D.	–	N.D.	N.D.	N.D.	15% of those using VDTs >8 hr/day, had DED, compared to 9% of those <8 hr/day ($p = <0.01$). VDT use >8 hr/day was associated with increased CFS ($p = 0.02$), but not with change in corneal sensation ($p = 0.64$)
Li et al. 2015, CN (Li et al. 2015)	6657 ophthalmic patients	N.D.	<4 hr/day, >4 hr/day	–[1]	†	–	†	†	N.D.	Mean duration of VDT use >4 hr/day was found in 56% of those with DED
Moon et al. 2014, KR (Moon et al. 2014)	288 school children	11 (1)	2–2.5 hr/day	–[1]	–	–	N.D.	N.D.	N.D.	71% of children in DED group and 50% in non-DED group used smartphones (OR 2.5; CI: 1.06–5.88; $p = 0.036$). Daily smartphone use (OR 1.86; CI: 1.07–3.24; $p = 0.027$) and total daily VDT use (OR 1.82; CI: 1.26–2.63; $p = 0.001$) associated with DED. Daily computer use or television was not
Nakamura et al. 2010, JP	601 office workers	36 (10)	<2, 2–4, 4–6, 6–8, >8 hr/day	N.D.	O	N.D.	N.D.	–	N.D.	No association between computer use and lipid layer status (for >8 hr/day compared to <2 hr/day: OR 2.03; CI: 0.96–4.34). Sch. I

Table 2 (Continued)

Study	Sample	Mean age (SD)	Daily VDT exposure	Symptoms	TBUT	OSS	MGA	Sch. I	TMH	Additional key takeaways
(Nakamura et al. 2010)										score was worse with >8 hr/day of VDT use compared to <2 hr/day (OR 4.27; CI: 1.47–13.66)
Rossi et al. 2019, IT (Rossi et al. 2019)	194 adults	42 (13)	<4, >4 hr/day	– [6]	–	O	N.D.	N.D.	N.D.	68% of those using VDTs >4 hr/day, had definite or probable DED, compared to 56% of those <4 hr/day (OR 1.57; CI: 1.07–2.02; $p = 0.017$). Prolonged VDT use was associated with decreased TBUT ($p < 0.001$), but not with change in CFS ($p = 0.81$)
Tichenor et al. 2019, US (Tichenor et al. 2019)	225 adolescents	12 (N.D.)	4–8 hr/day	– [2, 7, 8]	O	O	O	N.D.	+	15% reported ocular discomfort. The older children used smartphones more and had a worse SPEED score compared to younger children. There was no correlation between VDT use and OSDI or SANDE
Uchino et al. 2013, JP (Uchino et al. 2013)	561 office workers	N.D.	<8 hr/day, >8 hr/day	– [4, 5]	–	–	O	O	N.D.	12% had definite DED and 54% had probable DED. 77% of those using computer >8 hr/day had probable or definite DED compared to 62% of those using computer <8 hr/day (OR 1.94; CI: 1.22–3.09; $p = 0.005$). 79% had TBUT <5 sec
Viso et al. 2009, ES (Viso et al. 2009)	654 adults	64 (14)	N.D.	O [1]	O	O/–	N.D.	O	N.D.	11% had DED. Computer use was associated with worse CFS (OR 2.69; CI 1.02–7.10), but not R/B (OR 1.26; CI: 0.56–2.84)
Wu et al. 2014, CN (Wu et al. 2014)	93 VDT workers with DED	31 (6)	<4 hr/day, >4 hr/day	– [2]	–	–	–	O	N.D.	41% of those who used computer >4 hr/day had apparent MG dropout (meiboscore ≥3), compared to 4% of those <4 hr/day
Yang et al. 2015, CN (Yang et al. 2015)	1908 DED patients and healthy subjects	56 (18)	<6 hr/day, >6 hr/day	– [2]	†	–	N.D.	†	N.D.	VDT use >6 hr/day associated with DED (OR 2.275; CI: 1.45–3.57; $p < 0.001$)

CFS = Corneal Fluorescein Staining, CI = Confidence Interval, CIC = Conjunctival Impression Cytology, CVSS17 = Computer Vision Symptom Scale 17, DEQ12 = Japanese Dry Eye Diagnostic Criteria, DEWS = Dry Eye Workshop, GCD = Goblet Cell Density, MG = Meibomian Gland, MGA = Meibomian Gland Assessment, N.D. = Not Described, OR = Odds Ratio, OSDI = Ocular Surface Disease Index, OSS = Ocular Surface Staining, R/B = Rose Bengal, SANDE = Symptom Assessment questionnaire iN Dry Eye, Sch. I = Schirmer I, SD = Standard Deviation, SEEQ = Salisbury Eye Evaluation Questionnaire, SPEED = Standardized Patient Evaluation of Eye Dryness, TBUT = Tear Break Up Time, TMH = Tear Meniscus Height, VAS = Visual Analog Scale, VDT = Visual Display Terminal.

O: No significant difference in parameter in relation to VDT use, –: Significant worsening in parameter associated with VDT use.

Country of origin: CN – China, ES – Spain, IN – India, IT – Italy, JP – Japan, KR – South Korea, US – United States.

[1] Symptom Score, [2]OSDI, [3]DESS, [4]DEQ12, [5]DEWS severity grading system, [6]CVSS17, [7]SPEED, [8]SANDE, [9]SEEQ, [10]VAS.

* Mean daily duration of VDT use.

[+] Significant improvement in parameter associated with VDT use.

[†] Measure not described in direct relation to VDT use.

Table 3. Summary of key characteristics and findings of observational studies with follow-up.

Study	Sample	Mean age (SD)	VDT, Duration	Symptoms	TBUT	OSS	Sch. I	TMH	Key takeaways
Akkaya et al. 2018, TR (Akkaya et al. 2018)	30 computer users, 30 controls	30 (4), 28 (5)	Computer, 8 versus 1 hr/day	O[1]	↓	N.D.	O	N.D.	TBUT but not Sch. I or OSDI significantly worsened in the VDT group compared to non-VDT group
Doguizi et al. 2019, TR (Doguizi et al. 2019)	53 computer users, 49 controls	39 (6), 38 (6)	Computer, >6 hr/day versus < 1 hr/day	–[1]	–	–	–	↓	38% in the computer group had DED, compared to 10% in the control group ($p = 0.001$). TMH decreased significantly in the VDT group, but not in the control group after a day of work. No difference in MG assessment between VDT users and non-VDT users
Yazici et al. 2015, TR (Yazici et al. 2015)	51 computer users, 26 controls	31 (6), 34 (6)	Computer, 7 versus 2 hr/day	↓[1]	↓	O	↓	N.D.	36% of VDT users had DED, compared to only 26% of controls, after one day of work. Tear osmolarity worsened in VDT group but not in the control group
Iyer et al. 2012, SG (Iyer et al. 2012)	35 DED patients	57 (11)	Computer, 2.2 hr/day*	+[2]	O	O	O	N.D.	The amount of computer use was negatively correlated with episodic blur vision, burning sensation and gritty sensation. Television use was associated with episodic blur vision

MG = Meibomian gland, N.A. = Not Applicable, N.D. = Not Described, OSS = Ocular Surface Staining, Sch. I = Schirmer I, SD = Standard Deviation, TBUT = Tear Break Up Time, TMH = Tear Meniscus Height.

[1] OSDI, [2]Symptom score. O: No change in variable in relation to VDT use, ↓: Significant worsening of variable with VDT use, ↑: Significant improvement of variable with VDT use, –: Significantly worse in VDT users compared to non-VDT users at baseline.

* Mean daily duration of VDT use.

+ VDT use associated with reduced symptoms. Country of origin: SG – Singapore, TR – Turkey.

The clinical parameters evaluated were TBUT (Hikichi et al. 1995; Viso et al. 2009; Nakamura et al. 2010; Kojima et al. 2011; Uchino et al. 2013; Bhargava et al. 2014; Moon et al. 2014; Wu et al. 2014; Kawashima et al. 2015; Li et al. 2015; Yang et al. 2015; Cortes et al. 2018; Rossi et al. 2019; Tichenor et al. 2019), Schirmer I (Sch. I) with topical anaesthesia (Hikichi et al. 1995; Viso et al. 2009; Nakamura et al. 2010; Kojima et al. 2011; Uchino et al. 2013; Bhargava et al. 2014; Wu et al. 2014; Kawashima et al. 2015; Li et al. 2015; Yang et al. 2015; Cortes et al. 2018), tear meniscus height (TMH; Kojima et al. 2011; Tichenor et al. 2019), lipid layer status (Nakamura et al. 2010) and tear osmolarity (Julio et al. 2012). Furthermore, MG assessment was included in four studies (Uchino et al. 2013; Wu et al. 2014; Li et al. 2015; Tichenor et al. 2019), but one (Li et al. 2015) did not report the outcome with regard to VDT use. Corneoconjunctival epithelial damage was evaluated with ocular surface staining (OSS; Hikichi et al. 1995; Viso et al. 2009; Kojima et al. 2011; Uchino et al. 2013; Moon et al. 2014; Wu et al. 2014; Kawashima et al. 2015; Li et al. 2015, 2018; Yang et al. 2015; Cortes et al. 2018; Rossi et al. 2019; Tichenor et al. 2019) or conjunctival impression cytology (Bhargava et al. 2014). Additionally, symptoms were addressed with a number of validated questionnaires: OSDI (Wu et al. 2014; Yang et al. 2015; Cortes et al. 2018; Li et al. 2018; Tichenor et al. 2019), Japanese Dry Eye Diagnostic Criteria (DEQ12; Hikichi et al. 1995; Uchino et al. 2013; Kawashima et al. 2015), Salisbury Eye Evaluation Questionnaire (SEEQ; Julio et al. 2012), VAS (Cortes et al. 2018), SPEED (Tichenor et al. 2019), Symptom Assessment questionnaire iN Dry Eye (SANDE; Tichenor et al. 2019), Dry Eye Scoring System (DESS; Bhargava et al. 2014), Dry Eye WorkShop (DEWS) severity grading system (Uchino et al. 2013) and Computer Vision Symptom Scale 17 (CVSS17; Rossi et al. 2019). Five studies used unspecified symptom scores (Viso et al. 2009; Kojima et al. 2011; Moon et al. 2014; Li et al. 2015, 2018).

Harmful daily VDT duration thresholds ranged from 2 hr/day (Moon et al. 2014) to 8 hr/day (Cortes et al. 2018). Fifteen studies investigated symptoms of dry eye in groups

Table 4. Summary of key characteristics and findings of experimental studies.

Study	Sample	Mean age (SD)	Protocol	Symptoms	TBUT	OSS	Sch. I	TMH	Key takeaways
Antona et al. 2018, ES (Antona et al. 2018)	54 healthy subjects	24 (3)	Smartphone or printed text. 20 min	↓[1]	N.D.	N.D.	N.D.	N.D.	Smartphone use increased all symptoms apart from headache more than printed text. Dim lighting further exacerbated total symptoms and ocular irritation, dryness and burning after smartphone use
Bilkhu et al. 2020, GB (Bilkhu et al. 2020)	40 healthy subjects	24 (5)	Tablet with/ without treatment. 30 min	↓[8]	↓	N.D.	N.D.	O	Tablet use decreased blink rate and increased incomplete blinks. Lipid layer status was unchanged and evaporation rates decreased. Humidity goggles improved symptoms and lipid layer status, but did not affect evaporation rates
Choi et al. 2018, KR (Choi et al. 2018)	80 healthy subjects	26 (3)	Smartphone or computer. 60 and 240 min	↓[2,6,7]	↓	O	O	O	Smartphone use induced more symptoms than computer use, especially ocular fatigue, burning and dryness. Oxidative stress markers and reactive oxygen species increased in the tear film and ocular surface after 240 min
Chu et al. 2011, US (Chu et al. 2011)	30 healthy subjects	24 (N.D.)	Computer or printed text. 20 min	↓[1]	N.D.	N.D.	N.D.	N.D.	Computer use worsened both total symptom burden and blurred vision separately more than printed text
Golebiowski et al. 2020, AU (Golebiowski et al. 2020)	12 healthy subjects	19 (N.D.)	Smartphone. 60 min	↓[3,4]	O	N.D.	N.D.	O	The incomplete blink rate increased after 20 min. Blink rate and lipid layer assessment were unchanged
Kim et al. 2017, KR (Kim et al. 2017)	59 healthy subjects	38 (10)	Tablet. 60 min	↓[7]	↓	N.D.	N.D.	N.D.	Tablet use triggered more ocular tiredness, soreness/achiness, irritation, watering and burning.
Prabhasawat et al. 2019, TH (Prabhasawat et al. 2019)	30 healthy subjects	32 (7)	E-book or printed text. 20 min	↓[5]	↓	O	N.D.	O	TBUT decreased in both groups, no difference between groups. Ocular burning and tearing were worse in e-book group than printed text
Thorud et al. 2012, NO (Thorud et al. 2012)	20 healthy subjects	22 (4)	Computer. 60 and 120 min	↓[2]	N.D.	N.D.	N.D.	N.D.	All symptoms except headache were exacerbated after 1 and 2 hr. Tiredness and blurred vision worsened from 1 to 2 hr
Yee et al. 2007, US (Yee et al. 2007)	40 VDT users	N.D.	Computer with/ without treatment. 30 min	↓[6,9]	↓/↑	O	N.D.	N.D.	At baseline, cumulative lifetime use, but not weekly computer use was associated with more ocular symptoms. TBUT worsened in subjects with dry eye symptoms, but improved in subjects without symptoms. MEGs improved ocular comfort and TBUT
Moon et al. 2016, KR (Moon et al. 2016)	916 children	10 (1)	Smartphone cessation. 4 weeks	↑[6]	↑	↑	N.D.	N.D.	Daily duration of smartphone and computer was higher in DED group at baseline. After intervention 0% filled the DED criteria used, compared to 7% at baseline
Vaz et al. 2019, PT (Vaz et al. 2019)	43 VDT users, 34 controls	34 (N.D.)	Behavioural intervention. 4 weeks	↑[10]/O[6]	↑	↑	↑	N.D.	Despite no change in OSDI, all objective parameters and the ocular fatigue score improved after 4 weeks of behavioural intervention

CVS-Q = Computer Vision Syndrome Questionnaire, MEGs = Micro Environment Glasses, N.D. = Not Described, OSDI = Ocular Surface Disease Index, PGE = Portuguese Group of Ergophthalmology questionnaire, SD = Standard Deviation, TBUT = Tear Break Up Time.

The dashed line represents the separation of studies using preventive measures only from studies using exacerbating interventions. Country of origin: AU – Australia, ES – Spain, GB – United Kingdom, KR – South Korea, NO – Norway, PT – Portugal, TH – Thailand, US – United States.

[1]: Hayes' Symptom score, [2]: VAS, [3]: ESQ, [4]: NRS, [5]: CVS-Q, [6]: OSDI, [7]: CVS score (Ames et al.), [8]: SANDE, [9]: Comfort score [10]: PGE questionnaire. O: No change in variable in relation to VDT use, ↓: Significant worsening of variable with intervention, ↑: Significant improvement of variable with intervention.

stratified by VDT use, and all but one (Viso et al. 2009) found an association between increasing VDT time and increasing dry eye symptoms. Five of the ten studies that measured TBUT reported worse scores in VDT users (Uchino et al. 2013; Bhargava et al. 2014; Moon et al. 2014; Wu et al. 2014; Rossi et al. 2019), while five studies did not find any difference (Viso et al. 2009; Nakamura et al. 2010; Kojima et al. 2011; Cortes et al. 2018; Tichenor et al. 2019). Four further studies used the 2006 Japanese dry eye diagnostic criteria (Tsubota et al. 2017), which does not differentiate between qualitative (TBUT) and quantitative (Sch. I) objective parameters when diagnosing patients (Hikichi et al. 1995; Kawashima et al. 2015; Li et al. 2015; Yang et al. 2015). Five out of seven studies reporting Sch. I found no difference between groups (Viso et al. 2009; Kojima et al. 2011; Uchino et al. 2013; Wu et al. 2014; Cortes et al. 2018), while the other two found worse scores in high VDT use groups compared to low VDT use groups (Nakamura et al. 2010; Bhargava et al. 2014). Nine studies reported a worsening in OSS score in high VDT use groups (Hikichi et al. 1995; Viso et al. 2009; Uchino et al. 2013; Moon et al. 2014; Wu et al. 2014; Kawashima et al. 2015; Li et al. 2015, 2018; Yang et al. 2015), while five reported no difference (Viso et al. 2009; Kojima et al. 2011; Cortes et al. 2018; Rossi et al. 2019; Tichenor et al. 2019). One of the three studies exploring the difference in MG assessment between high and low VDT users found a worse MG status in high VDT users (Wu et al. 2014), while the two other studies did not find any difference (Uchino et al. 2013; Tichenor et al. 2019). TMH worsened in one study (Kojima et al. 2011), but improved in another (Tichenor et al. 2019).

Studies with follow-up

Group 3: Observational studies with follow-up

As seen in Table 3, four observational studies with follow-up ranging from one (Yazici et al. 2015; Akkaya et al. 2018; Doguizi et al. 2019) to 2 days (Iyer et al. 2012) were included (Table 3). Three studies were conducted in Turkey (Yazici et al. 2015; Akkaya et al. 2018; Doguizi et al. 2019) and one in Singapore (Iyer et al. 2012). The sample sizes ranged from 35 (Iyer et al. 2012) to 102 (Doguizi et al. 2019), with a combined total of 274 participants. The female-to-male ratio was 168:106 with an average age of 39 years across studies. Three studies investigated dry eye symptoms (Yazici et al. 2015; Akkaya et al. 2018) and signs (Yazici et al. 2015; Akkaya et al. 2018; Doguizi et al. 2019) before and after work in VDT users and non-VDT users. The remaining study recorded the daily duration of VDT use in a cohort of DED patients in a usual rest and working day and measured outcomes one time only (Iyer et al. 2012). The questionnaires used were OSDI (Yazici et al. 2015; Akkaya et al. 2018; Doguizi et al. 2019) or an unspecified symptom score (Iyer et al. 2012). One study found a worsening of symptoms in VDT users, but not in non-VDT users, after a working day (Yazici et al. 2015), whereas another study did not find any change after work (Akkaya et al. 2018). However, both studies found a worsening in TBUT in VDT users, but not in non-VDT users (Yazici et al. 2015; Akkaya et al. 2018). OSS was unchanged after a day of work (Yazici et al. 2015). Sch. I worsened in VDT users in one (Yazici et al. 2015) out of the two studies (Yazici et al. 2015; Akkaya et al. 2018). In non-VDT users, however, Sch. I was unchanged after a day of work (Yazici et al. 2015; Akkaya et al. 2018). In another study, TMH was measured (as the only repeated objective measurement) and worsened after a working day in VDT users, but not in non-VDT users (Doguizi et al. 2019). At baseline, the same study found worse dry eye symptoms, TBUT, Sch. I and OSS in VDT users compared to non-VDT users, but no difference in MG assessment. The remaining study reported an inverse association between daily duration of VDT use and symptoms (Iyer et al. 2012). There was no association between TBUT, OSS or Sch. I and daily duration of VDT use (Iyer et al. 2012).

Group 4: Experimental studies

Eleven experimental studies were conducted in eight countries, with a combined sample size of 1358 study participants, as shown in Table 4. The sample sizes ranged from 12 (Golebiowski et al. 2020) to 916 participants (Moon et al. 2016), with a median of 40. Although the sex distribution in each study varied greatly, overall, 49% were males and 51% females. The average age of the participants ranged from 10 (Moon et al. 2016) to 38 years (Kim et al. 2017) with an overall mean age of 25 years across studies. Most participants were described as healthy subjects (Chu et al. 2011; Thorud et al. 2012; Kim et al. 2017; Antona et al. 2018; Choi et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020; Golebiowski et al. 2020). Two studies recruited regular VDT users (Yee et al. 2007; Vaz et al. 2019), while the subjects in another study were children with DED (Moon et al. 2016). Overall, ocular symptoms worsened with VDT use (Yee et al. 2007; Chu et al. 2011; Thorud et al. 2012; Kim et al. 2017; Antona et al. 2018; Choi et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020; Golebiowski et al. 2020) and improved with smart phone cessation (Moon et al. 2016) and preventive interventions including ergonomic advice and patient education (Vaz et al. 2019). Four out of eight studies measuring TBUT found a worsening after VDT use (Kim et al. 2017; Choi et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020), while one study did not find any change (Golebiowski et al. 2020). In addition, one study measured a worsened TBUT in VDT users with dry eye symptoms, but an improvement in VDT users without symptoms (Yee et al. 2007). The remaining two studies noted an improvement in TBUT in regular VDT users after preventive intervention (Moon et al. 2016; Vaz et al. 2019). Preventive measures also improved OSS in these two studies (Moon et al. 2016; Vaz et al. 2019). However, three other studies did not find a change in OSS after VDT use (Yee et al. 2007; Choi et al. 2018; Prabhasawat et al. 2019). Sch. I was measured in two studies; one found it unchanged after VDT use (Choi et al. 2018), and the other reported an improvement after preventive intervention (Vaz et al. 2019). All studies that investigated TMH did not reveal any change after VDT use (Choi et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020; Golebiowski et al. 2020).

Harmful threshold of VDT exposure

Twenty-four studies without follow-up investigated the association between DED- or DED-related parameters and daily VDT use duration thresholds. In addition, five single-visit studies reported DED- or DED-related symptoms for more than one daily VDT use duration threshold (Uchino et al. 2008; Logaraj et al. 2014; Titiyal et al. 2018; Cheng et al. 2019; Hanyuda et al. 2020). As shown in Fig. 6, all but two studies (Asiedu et al. 2017; Altalhi et al. 2020) revealed a higher prevalence of DED- or DED-related parameters with increasing daily use of VDT. One study found a positive association between daily computer use (on a continuous scale) and worse OSDI, but not a significant difference when looking at a threshold of 8 hr/day (Köksoy Vayısoğlu et al. 2019).

Discussion

The overall prevalence of probable or definite DED among VDT and office workers in the included studies ranged from 26% (Yamanishi et al. 2019) to 70% (Kojima et al. 2011) and is higher than the general estimates of the global prevalence of DED of 5–50% (Stapleton et al. 2017). This is particularly alarming as the average age of the subjects in the included trials was relatively low and DED increases with age (Stapleton et al. 2017). Furthermore, based on the included studies, it was not possible to determine any safe lower limit of VDT exposure that did not elevate the likelihood of having DED. As little as 1–2 hr/day of VDT use was associated with DED (Hanyuda et al. 2020). These findings implicate that a question about the amount of VDT use should be included in the anamnesis of every dry eye patient. The lowest threshold of 1–2 hr/day found in this review is in contrast to past findings. In a meta-analysis by Courtin et al., a threshold of 4 hr/day of VDT exposure was assumed safe (Courtin et al. 2016), and other studies have reported a threshold of 20 (Bergqvist & Knave 1994) to 25 hr/week (de Kluizenaar et al. 2016).

The high prevalence of DED observed can be due to prolonged VDT use and the subsequent pathophysiological processes, including increased tear evaporation and tear film instability, in most of the populations studied in this review. Of all of the 57 included studies, 52 reported a positive association between prolonged VDT use and DED or dry eye related signs and symptoms. Only five studies did not find a significant association between the two variables (Iyer et al. 2012; Garza-León et al. 2016; Asiedu et al. 2017; Mowatt et al. 2018; Altalhi et al. 2020). Interestingly, two of these five studies found an inverse relationship between VDT and DED-related parameters (Iyer et al. 2012; Garza-León et al. 2016), while the remaining three showed no significant effect either way. The results of these studies could have derived from the investigation of young and healthy students with intact protective tear films and compensatory mechanisms, in combination with frequent breaks and proper ergonomics (Garza-León et al. 2016; Asiedu et al. 2017; Mowatt et al. 2018; Altalhi et al. 2020), or the small sample size without sufficient power and short follow-up (Iyer et al. 2012). Another plausible explanation for a lack of or an inversed association in some of these studies is that DED patients with severe symptoms are not able to use VDT for long durations, thereby reducing VDT use and adjusting their daily activities (Yee et al. 2007; Iyer et al. 2012).

The observed high prevalence of DED with VDT use could, however, also be due to confounding factors such as CL wear, use of air conditioning and poor indoor climate including pollutants, allergens and low humidity (Bron et al. 2017; Idarraga et al. 2020; Mehra & Galor 2020). Moreover,

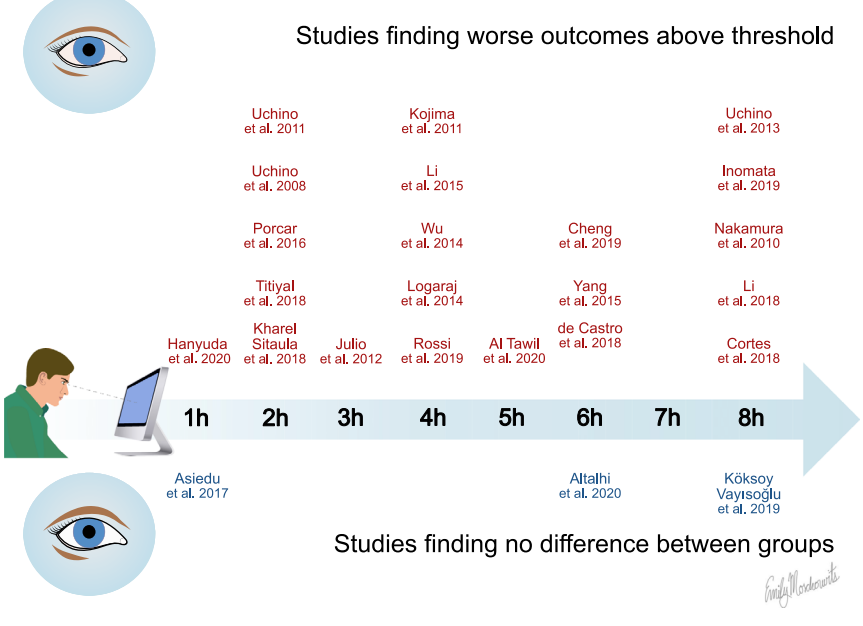

Fig. 6. Association between daily duration of VDT use and dry eye disease (DED) or DED-related signs and symptoms. Daily VDT use duration found to significantly increase the prevalence of reported eye dryness or DED in epidemiological studies. Hours of VDT exposure listed represents the lowest cut-off value investigated in the included study and the outcome of this analysis.

comorbidities can be important confounders as well (Kawashima et al. 2020; Mehra & Galor 2020). A recent large population-based study by Bazeer et al., that investigated the association between type of occupation and symptomatic DED, found a highly significant positive association between occupations relying on VDT use (such as customer service clerks and other administrative occupations) and symptomatic DED. This association, however, greatly disappeared after correction for 50 possible confounding factors including CL wear and systemic comorbidities (Bazeer et al. 2019). These findings suggest that it is important to adjust for the effect of CL use and other confounding comorbidities when studying the true relationship between VDT use and DED in analytical cross-sectional studies. Increased VDT use may be associated with CL wear and other comorbidities that come with an increased risk of DED such as connective tissue disease or chronic pain disorders.

Retrospective studies investigating exposures and risk factors using questionnaires alone are at risk of recall bias (Coughlin 1990; Vrijheid et al. 2006; Althubaiti 2016). Most of the studies in this review relied on questionnaires and were retrospective. Thus, participants could have reported an over- or underestimated daily duration of VDT use (Vrijheid et al. 2006; Althubaiti 2016).

Overall, the prevalence of DED in VDT users and the daily duration of VDT use that was assigned as harmful varied considerably between studies. Explanations for this substantial heterogeneity can be attributed to the different groups included (i.e. age, gender, and ethnicity), DED diagnostic criteria used (Stapleton et al. 2017; questionnaires only versus clinical parameters and questionnaires), type of questionnaire used, sample size and follow-up time. Japan and Korea accounted for 32% of the articles included in this review. It has been reported that Asian populations have DED at twice the rates of Caucasians (Stapleton et al. 2017). Several factors including genetics and lifestyle may explain this preponderance of DED. Previous reports state that lid anatomy of Asians likely contributes to an increased eyelid tension which may result in more incomplete blinks and lid wiper epitheliopathy, leading to the predisposition to EDE (Wang & Craig 2019). Furthermore, reports from the Organization for Economic Co-operation and Development (OECD) show that Korea and Japan have longer working hours compared to other countries (Ogura 2009). The combination of work culture and genetics should therefore also be taken into consideration as contributors to DED development.

Only 7 studies (Garza-León et al. 2016; Asiedu et al. 2017; Inomata et al. 2019; Köksoy Vayısoğlu et al. 2019; Rossi et al. 2019; Al Tawil et al. 2020; Bilkhu et al. 2020) presented a power-analysis and no studies followed VDT users for more than 1 month. Other sources of bias are shown in the quality assessment of studies (Tables S1–S7) and include factors such as the lack of randomization in interventional studies, not using proper masking, and only one time point of measurements of VDT use. Different study protocols were used in the prospective studies, ranging from studies exploring brief, 20 min exposure to VDT (Antona et al. 2018; Prabhasawat et al. 2019), to 4 weeks of follow-up after a behavioural intervention (Moon et al. 2016; Vaz et al. 2019). Several studies did not disclose which type of VDT was used or did not differentiate between devices in their analyses, potentially further contributing to the observed heterogeneity (Hikichi et al. 1995; Shimmura et al. 1999; Uchino et al. 2011; Li et al. 2015, 2018; Yang et al. 2015; Inomata et al. 2019; Rossi et al. 2019; Tichenor et al. 2019; Al Tawil et al. 2020; Hanyuda et al. 2020). This heterogeneity made direct comparison between studies more challenging, if not impossible. In addition, several studies did not report their cut-off values for 'prolonged VDT use', thus not providing any information on the threshold limit for harmful daily VDT use duration (Hikichi et al. 1995; Shimmura et al. 1999; Viso et al. 2009; Iyer et al. 2012; Portello et al. 2012; Bhargava et al. 2014; Moon et al. 2014; Kawashima et al. 2015; Chałas et al. 2018; Yamanishi et al. 2019). Several of the studies using questionnaires only investigated CVS or related ocular symptoms, not DED. Furthermore, some broader studies, investigating many potential risk factors of DED, only included VDT use as a small component of larger studies. Combined, all these factors contributed to the large range of the reported prevalence estimates and threshold values between studies and made the estimation of an overall prevalence of DED or DED-related parameters among VDT users not possible.

Inconsistent findings were reported by the few studies comparing the effect of computer use and smartphone use on DED (Moon et al. 2014; Hyon et al. 2019a,b; Köksoy Vayısoğlu et al. 2019). One study found an association between DED and daily smartphone use, but not computer use (Moon et al. 2014), whereas the two other studies found an association between DED and computer use, but not smartphone use (Hyon et al. 2019a,b; Köksoy Vayısoğlu et al. 2019). Factors related to the two types of VDTs that can explain the inconsistent findings include patterns of use (e.g. frequency, duration, task and environment), distance from screen, angle of gaze, screen size, luminance, glare and screen quality (Sheedy et al. 2005; Rosenfield et al. 2015; Jaiswal et al. 2019). Another factor which could have contributed to the inconsistent findings is age, as one study investigated elementary school children (Moon et al. 2014), whereas the two studies that had similar findings investigated university students (Hyon et al. 2019a,b) and lecturers (Köksoy Vayısoğlu et al. 2019). However, the remaining studies that looked at smartphone as the only type of VDT used reported worsening of symptoms and objective measures of DED (Antona et al. 2018; Choi et al. 2018; Golebiowski et al. 2020) and improvement if smartphone use ceased (Moon et al. 2016). Thus, there is insufficient evidence on the effects of smartphone use on the ocular surface and more studies are required to draw a conclusion.

Several studies proposed possible pathophysiological mechanisms tying VDT use to DED. One such hypothesis is that VDT use promotes instability of the tear film as a result of screen-induced increased tear film exposure, followed by increased evaporation (Fig. 1; Tsubota 1998; Nielsen et al. 2008; Cardona et al. 2011; Wolkoff et al. 2012; Hirota et al. 2013; Chu et al. 2014; Argilés et al. 2015; Stapleton et al. 2017). This is supported by

the findings of the included studies, where most studies reported a worsening in TBUT after prolonged VDT exposure as well as worse scores in VDT users compared to non-VDT users (Yee et al. 2007; Uchino et al. 2013; Bhargava et al. 2014; Moon et al. 2014; Wu et al. 2014; Yazici et al. 2015; Kim et al. 2017; Akkaya et al. 2018; Choi et al. 2018; Doguizi et al. 2019; Prabhasawat et al. 2019; Rossi et al. 2019; Bilkhu et al. 2020). In addition, two studies reported an improvement in TBUT after smartphone cessation and preventive intervention (Moon et al. 2016; Vaz et al. 2019). Of the studies that reported a worsening in TBUT, several studies (Yee et al. 2007; Kim et al. 2017; Akkaya et al. 2018; Choi et al. 2018; Prabhasawat et al. 2019; Bilkhu et al. 2020) found this as the only worsened objective parameter. A key initiating pathophysiological mechanism may be decreased blink frequency and increased incomplete blinking with VDT use (Hirota et al. 2013). This reduces the secretion and distribution of meibum to the lipid layer of the tear film on the ocular surface, lowering the stability of the tear film which finally causes a shorter TBUT and corneal nociceptive signalling (Fig. 1; Knop et al. 2011; Wu et al. 2014; Kaido et al. 2016). This is in line with the description of a newly proposed form of dry eye - SBUDE, where the only pathological findings are increased ocular symptoms and decreased TBUT scores (Tsubota 2018). OSS tends to be normal, but there is probably a low tear concentration of the protective large gel-forming mucin MUC5AC in patients with SBUDE (Dartt & Willcox 2013; Uchino et al. 2014a,b). It was proposed that SBUDE is common in office workers (Bron et al. 2017). Thus, future studies on DED and VDT use should take this new form of dry eye into account and adjust DED categorization accordingly (Tsubota et al. 2017).

There are no gold standard criteria for diagnosing DED (Wolffsohn et al. 2017), but standardized diagnostic criteria have been suggested in the literature (Tsubota et al. 2017; Wolffsohn et al. 2017). The DEWS II report suggests using symptoms combined with either abnormal TBUT, tear film osmolarity or OSS to diagnose DED, while the Asia Dry Eye Society (ADES) recommends using symptoms and decreased TBUT when diagnosing DED (Fig. 7). When assessing the prevalence of DED in VDT users, TBUT seems to be the most important objective parameter, and the simple diagnostic criteria presented by the ADES might be the most appropriate (Tsubota et al. 2017).

In light of the rapid increase in Internet and VDT use, further accelerated by the shift towards digitalization and increased use of virtual communication due to COVID-19 (Sneader & Singhal 2021), more research is needed on the association, treatment and prevention of DED in VDT users. DED has substantial health and financial impact on the lives of patients and on society. DED has repeatedly been found to reduce work productivity and increase days spent away from the office, thereby providing a substantial indirect financial loss (Stapleton et al. 2017; Sivakumar et al. 2021). Moreover, as VDT users appear to be affected with DED earlier in life, the cumulative effect of these financial burdens is further exacerbated. Due to the fact that the use of the Internet first became common in the late 90s, it is possible to speculate if the increase in Internet use in the last 20 years will continue into the future and lead to even higher DED incidence rates as the population ages.

Finding an exact threshold for acceptable VDT use would provide the opportunity to offer more accurate advice to the general public regarding VDT use and DED development. Future adequately powered, prospective, longitudinal studies with longer follow-up are necessary to clarify the association between VDT use and DED (Hill 1965). The type of VDT used needs to be specified and daily duration of exposure should be recorded using an app or dedicated computer programs to avoid recall bias and to better assess the role of breaks. Furthermore, the standardized criteria proposed by ADES or DEWS II (Fig. 6) should be consistently used in future studies aiming to investigate the prevalence of DED in VDT users. Masked, randomized, interventional studies allocating subjects to either smartphones or computers can be useful to uncover the effects of different VDT types on the ocular surface. Directly assessing blink rates and

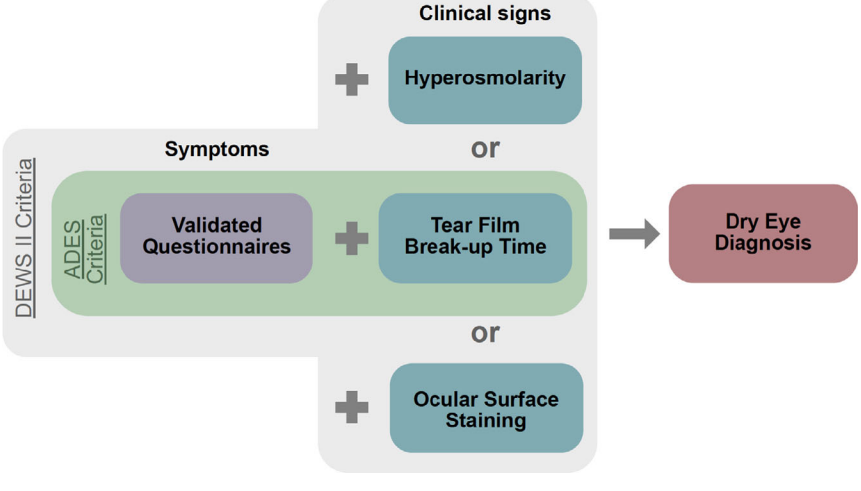

Fig. 7. Dry eye disease criteria as proposed by the Dry Eye Workshop (DEWS) II and Asia Dry Eye Society (ADES). According to DEWS II, the diagnosis is set on the basis of a combination of symptoms and one or more clinical signs (hyperosmolarity, tear film break-up time or ocular surface staining). ADES recommends only using symptoms and decreased tear film break-up time in the diagnosis of DED.

exposure to possible confounding factors, such as air conditioning, humidity and CL wear, will also provide useful insight. It is of importance to reveal the exact pathophysiological mechanisms of VDT-associated DED and find ways to treat and prevent this from happening. Finally, more research is needed on the short- and long-term impact of COVID-19 on VDT-associated DED.

This review has some limitations. Only PubMed was used to find relevant articles. Even though PubMed is an extensive search tool, databases such as Google Scholar could also have been used to find possibly more relevant articles. A second limitation is the search terms used, which could be too narrow or too broad, as well as the inclusion criteria. For example, 'computer vision syndrome' could also include participants reporting signs and symptoms not related to DED directly, such as neck and headache. Since DED is tightly linked to CVS, studies aiming to investigate the prevalence of CVS were also included in this review (Blehm et al. 2005; Wolffsohn et al. 2017).

Conclusion

The prevalence of definite or probable dry eye among VDT and office workers ranged from 26% to 70% in the included studies. Overall, VDT use was highly associated with DED- and DED-related signs and symptoms. To find a more accurate prevalence estimate of DED in VDT users, it is necessary that future studies use simple standardized DED diagnostic criteria, such as the ones proposed by ADES or the DEWS II criteria. No exact thresholds for safe daily duration of VDT use were found, with as little as 1–2 hr already being associated with DED. Future research should assess VDT users for sustained periods of time to establish the association between duration of VDT use and risk of DED. In addition, more effort to reveal the pathophysiological mechanisms responsible for VDT-associated DED is crucial to establish efficient treatment regimens and preventive measures. VDT-associated DED will present a major challenge going forward, with increased VDT use in all parts of life, at work, in education and daily life, especially now and after the COVID-19 pandemic.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Quality assessment of cross-sectional studies with questionnaires only based on the NHLBI checklist for observational cohort and cross-sectional studies (NHLBI).
Table S2 Quality assessment of cross-sectional studies with objective measures based on the NHLBI checklist for observational cohort and cross-sectional studies (NHLBI).
Table S3 Quality assessment of cohort study based on the NHLBI checklist for observational cohort and cross-sectional studies (NHLBI).
Table S4 Quality assessment of case-control studies based on the NHLBI checklist for case-control studies (NHLBI).
Table S5 Quality assessment of before-after studies based on the NHLBI checklist for before-after studies (NHLBI).
Table S6 Quality assessment of case series study based on the NHLBI checklist for case series studies (NHLBI).
Table S7 Quality assessment of interventional studies based on Cochrane Risk of Bias Tool 2.0 for randomized crossover trials (Sterne et al. 2019).