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Use of digital displays and ocular surface alterations: A review

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ABSTRACT

Digital display use has been accepted to be implicated as a contributing factor for dry eye disease (DED). Abnormal blinking during computer operation, including a reduced blink rate and an incomplete eyelid closure, increased palpebral fissure as consequence of high visualization angles, and meibomian gland dysfunction associated to long-term display use, are behind the increased prevalence of dry eye signs and symptoms found in digital display users. Previous research reveals significant reductions in tear volume and stability, alterations in tear film composition, including increased osmolarity, inflammatory cytokines, oxidative stress markers and reduced mucin secretion, eyelid abnormalities and ocular surface damage, encompassing corneal and conjunctival staining and bulbar redness, as a direct consequence of digital display use. In this regard, individual differences in the way that the various digital displays are typically set up and used may account for differences in their effects on induced dryness signs and symptoms. Furthermore, factors such as the use of contact lenses or inappropriate working environments, usually accompanying the use of displays, may significantly increase the prevalence and the severity of induced dry eye. Other factors, such as old age and female gender are also relevant in the appearance of associated alterations. Finally, clinicians should adopt a treatment strategy based on a multidirectional approach, with various treatments being applied in conjunction.

1. Introduction

The use of digital displays is ubiquitous and has become a common and essential practice in our everyday life. In 1995 there were 16 million internet users in the world (0.4% of the population), while nowadays they ascend to 4208 million (55.1% of the population) [1]. Numbers tend to peak amongst young people, with 91% of Europeans between 16 and 29 years of age using the internet [2]. New forms of digital displays, such as laptops, smartphones, tablets or even e-readers, have emerged, and the use of digital electronic screens is no longer restricted to desktop computers.

This tremendous change in work and life conditions experienced over the last decades has been accompanied by an increase in health-related complaints associated with the use of digital displays, which have been collectively termed "computer vision syndrome" (CVS) [3]. Dry eye-related symptoms, including eye burning, irritation, ocular dryness, tearing, tired eyes, foreign body sensation, and eye discomfort make one of the main groups of CVS symptomatology [4], and are often encountered in otherwise healthy patients [5].

In this regard, studies indicate a significantly higher dry eye symptom score in digital display users as compared to controls [6]. Many studies have also advised the relationship between the use of digital displays and tear film and ocular surface abnormalities [7–9]. For example, fluorescein break-up time (FBUT), non-invasive break-up time (NIBUT), and tear meniscus height (TMH) have all shown to be significantly lower among display users and to decrease with device use [7–9]. Similarly, oxidative stress markers in the tear film [7], inflammatory mediators [8] and tear osmolarity [9], have shown to be altered in computer users. Consequently, digital display use has been implicated as a contributing factor to dry eye disease (DED).

Obeying to a recent meta-analysis, the overall prevalence of DED in computer users is probably around 49.5%, and ranges from 9.5% to 87.5% [10]. This prevalence appears to be higher than the one observed in the general population, which, as indicated by the Tear Film and Ocular Surface (TFOS) Dry Eye Workshop (DEWS) II epidemiology report, is found to range between 5 and 50% at various ages [11].

The following review intends to summarize the current understanding regarding the effects of digital display use on the ocular surface

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and tear film, and their causal mechanisms. Additionally, it will disclose potential risk factors and possible treatments to be considered by the clinician.

2. Symptom inducing factors

2.1. Blinking abnormalities

2.1.1. Reduced blink rate

Blinking is essential for maintaining ocular surface integrity, tear film stability and clarity of vision. Blinking keeps the eye surface humid and hydrated, favours the drainage of tears, helps in the expression of lipids from the meibomian glands and spreads tear lipids through the precorneal film [12–14]. Therefore, a reduced blink rate will contribute to the disruption of the tear film and a reduction of its quality and quantity, along with an increase in corneal stress, leading to dry eye symptoms [15].

Particularly, a reduced blink rate is consistently reported during computer operation [16–20]. For example, Tsubota and Nakamori [18] evaluated the rate of blinking in 104 office workers and found that mean blink rate was 22 blinks/min while relaxed, decreased to 10 blinks/min while reading a book and was only of 7 blinks/min while viewing text on a computer screen. Similarly, Patel et al. [19] found a substantial reduction in mean blink rate between before computer use (18.4 blinks/min) and during operation (3.6 blinks/min).

In many of these studies, however, test conditions were not kept constant and varied not only in the form of presentation but also in task format. It has been shown that blink rate is decreased by factors such as poor visual image, like reduced contrast and decreased font size [21], or increased cognitive and visual task demand [22,23], which may consequently arise from the need of a longer fixation duration to increase the time to acquire visual information [22,24]. It has been suggested that the poorer image quality of electronic screens, compared to printed material, might be responsible for the change in blink rate [25]. Eyelid squinting has been shown as capable of improving visual acuity and decrease retinal illumination in glare conditions [26]. Sheedy et al. [27] noted that voluntary squinting significantly reduced blink rate by an average of 50% or more, with greater levels of squinting causing more substantial reduction. Therefore, conditions of poorer image quality of electronic text and possible glare from the device screen may have been the cause under the adversely affected blink rate noted in studies [24].

In this context, Chu et al. [28] compared the blink rate of 25 subjects, who performed a continuous 20-min reading task from either a desktop computer screen or a print hard copy page, with text matched for size and contrast along with similar luminance and viewing angle. The authors concluded that there was no reduction of blink rate during computer operation compared to hard copy and that previous differences were more likely to be provoked by changes in cognitive demand. One year later, Rosenfield et al. [29] confirmed this hypothesis and proposed that, given the technological improvements in digital displays over the past years, dry eye symptoms which users keep experiencing nowadays, may be more likely produced by factors such as incomplete blinks or greater corneal exposure, than a decline in blink rate.

Nakamura et al. [30] carried out an animal study with rats. Authors evaluated whether reduced blinking while focusing at a digital display screen had a direct deleterious impact on the lacrimal gland function. The study concluded that not only was there an excessive evaporative loss of tears during computer use, provoked by abnormal blinking, but also a possible hypofunction of the lacrimal gland, which lead to a reduced tear secretion in chronic display users. Kamoi et al. [31] found no infiltration of immune cells in the lacrimal glands of digital display users and suggested that dry eye associated with digital displays was more likely to be due to a disorder in tear secretion, rather than an alteration in the production of tears. However, sample volumes were limited and the study population was not adjusted for age or gender. In line with this study, Su et al. [32] found that the prevalence of tear secretion dysfunction, evaluated through Schirmer test, was approximately 40% in a sample of office workers, and that dysfunction increased with time of employment.

When it comes to hand-held devices specifically, research is still limited. Choi et al. [7] and Argilés et al. [33] hypothesized that reading from smaller screens possibly worsened spontaneous blink rate, as they require lower saccade amplitude and no requirement of combined blinking, which in turn may lead to increased dryness symptoms. Notwithstanding this hypothesis, Benedetto et al. [34] found a significantly lower blink rate when reading for 1 h from a tablet device compared to printed text, despite a similar setup, including distance, page and font size, and number of words per page. Therefore, smaller screens may influence blink rate, but they may not account for all the difference obtained when compared to hard copy text.

2.1.2. Incomplete blinking

Although reduced blink rate may not be so relevant today, with current digital displays patients continue to experience dry eye signs and symptoms with their use. According to recent research, incomplete blinking may be a more pertinent issue [24,28,29]. Partial blinking alters the distribution of mucin over the ocular surface, causes poor maintenance of lipid layer integrity and reduces tear film thickness in the inferior cornea, which is, therefore, more prone to tear evaporation and break-up problems [35]. In addition to this, blinking abnormalities affect the drainage of tears, leading to low tear clearance from the ocular surface, and the accumulation of inflammatory mediators in the conjunctival sac [36].

Portello et al. [24] found a significant positive correlation between total symptom score and the percentage of incomplete blinks while reading from a desktop computer. Besides, several authors have found a higher proportion of incomplete blinks when reading on an electronic platform compared to hard copy text [30,37].

Considering hand-held devices, Golebiowski et al. [38] obtained an increase of incomplete blinks during smartphone visualization: 6 versus 15 incomplete blinks at 1-min and 15-min display use, respectively. Similarly, a higher proportion of incomplete blinks while reading from a tablet (14.5%) compared to printed text (5%) has been also observed [33].

Harrison et al. [39] pointed out that incomplete blinks may occur so as to not interrupt concentration. This links with McMonnies suggestion [35] that partial blinking may represent an attempt to inhibit spontaneous blinking during visually demanding tasks. Cardona et al. [22] observed a negative influence of cognitive demand on blink amplitude while playing a computer game. Nevertheless, higher symptomatology and percentage of incomplete blinks during computer operation (7.02%) compared to reading from a hard copy page (4.33%) have still been noted with matched visual demand [28]. it is relevant to mention that most studies comparing different visualization devices or formats were not masked (i.e. subjects were aware with which device were they performing the task). Therefore, subjective responses to questionnaires may have been influenced by format preference or bias based on prior experiences or preconceptions.

Alterations in the composition and distribution of tears and the derived break-up problems arisen after abnormal blinking, associated with digital display use, will further alter the subject's natural behaviour of blinking by decreasing the maximum blink interval (i.e. number of seconds the eyes can stay open without blinking) [40] and by producing a compensatory blinking, after cessation of the active display task [41]. Nielsen et al. [41] reported a compensatory burst of blinks during the shifts from periods of high visual and cognitive demand to periods of low visual and cognitive demand, in digital display users carrying two different tasks on a digital display in a simulated office environment. Authors attributed this phenomenon to compensation for the oppression of blink frequency and complete eyelid closure during the more demanding task, e.g., a wetting process, which could be viewed as a

Table 1
Summary of significant effects of digital display use on blinking.

Reference (Year)	Sample	Task	Duration and distance	Main findings
Patel et al. [19] (1991)	N = 16 17–31 years	Playing computer game vs conversation	10 min, not provided	•Lower BR with computer.
Tsubota et al. [18] (1993)	N = 104 20–69 years	Relaxed conditions vs reading book vs viewing text on computer	Not provided	•Lower BR with computer vs reading and relaxed. •Lower BR with reading vs relaxed.
Freudenthaler et al. [16] (2003)	N = 51 18–53 years	Computer use (arrangement of words in alphabetical order) vs conversation	10 min, 40 cm	•Lower BR with computer.
Schlote et al. [20] (2004)	N = 30 18–67 years. Patients with DED	Computer use (arrangement of words in alphabetical order and reading) vs conversation	30 min, 40 cm	•Lower BR with computer.
Himebaugh et al. [23] (2009)	N = 32 22–73 years Normal patients and with DED	Looking straight ahead vs watching movie vs playing video game vs identifying changing letters on computer	3 min, not provided	•Lower BR when playing computer game and identifying changing letters on computer (high-concentration tasks). •No differences in BA amongst tasks. •No differences in BR or BA amongst DED and control.
Chu et al. [37] (2010)	N = 24	Reading aloud from computer vs reading aloud from printed text. Matched text characteristics.	20 min, 50 cm	•No significant difference in BR between tasks.
Cardona et al. [22] (2011)	N = 25 21–28 years	Viewing distance target (baseline) vs playing slow-paced computer game vs playing fast-paced computer game	20 min, 50 cm	•Lower BR with computer. •Lower BR with fast-paced game vs slow-paced game. •Lower BA with computer. •Higher % incomplete blinks with computer.
Chu et al. [28] (2014)	N = 25 22–28 years	Reading aloud from computer vs reading aloud from print. Matched text characteristics.	20 min, 50 cm	•No significant difference in BR between tasks. •Higher % incomplete blinks with computer.
Rosenfield et al. [29] (2015)	N = 16 16–17 years	Reading aloud from a tablet vs reading aloud from print/high cognitive demand task vs low cognitive demand task. Matched text characteristics	10 min, 30 cm	•No change in BR produced by form of presentation. •Lower BR with high-cognitive demand in tablet and print. •Lower BR with high-cognitive demand and tablet.
Argilés et al. [33] (2015)	N = 50 18–74 years	Viewing distance target (baseline) vs reading on tablet (book position) vs reading on computer vs reading printed text (pasted on computer) vs reading printed text (book position)	6 min, 40–60 cm	•Lower BR in tablet, computer and printed text vs viewing distant target. •Higher BR with tablet vs printed text (down gaze). •Lower BR with printed text (book position) vs printed text (pasted on computer). •Higher % incomplete blinks with tablet and computer vs printed text.
Golebiowski et al. [38] (2019)	N = 12 18–23 years	Reading from smartphone	60 min, 30–34 cm	•Increase in n° incomplete blinks/minute over time. •No significant change in BR over time.

BA, Blink Amplitude; BR, Blink Rate; DED, Dry Eye Disease.

marker of ocular surface disturbance. Table 1 summarizes the literature relevant to the impact of digital displays on blinking.

2.2. *Gaze angle*

A pertinent issue of dry eye associated with digital displays is the specific gaze angle adopted when viewing these devices. Greater gaze angles result on a wider palpebral fissure which, in turn, leads to increased instability of the tear film, as a result of the thinning of the mucin and lipid layers [42], and to an increased ocular surface area being exposed to the effects of tear film evaporation and desiccation [43]. In this regard, computer screens, mainly desktop displays, are usually held at higher gaze angles compared to hard copy text.

Tsubota and Nakamori [44], obtained an average exposed ocular surface area of 1.2 cm^2 when reading a book, and of 2.3 cm^2 when working at a computer. Years later, these authors studied the effects of exposed surface area on tear dynamics and confirmed that tear evaporation increased proportionally with ocular surface area, not only per eye but also per area unit, being 3.4 and 2.5 times greater when looking up and ahead than when looking down [43]. In line with this, Ranasinghe et al. [45] found that the angle of gaze to the monitor was significantly higher in computer workers with CVS and severe CVS than in those without CVS and mild CVS, respectively. The study, however, did not include ophthalmic examinations and the symptoms reported were self-reported.

Unlike computers, hand-held devices are typically held at closer distances and below eye level. Therefore, it is expected that individual differences in the way that the various digital displays are typically set up and used, may account for differences in their effects on induced dryness signs and symptoms. Nielsen et al. [41] investigated how ocular surface area was affected by a high versus low-monitor position. Authors obtained a significant decrease in ocular surface area when lowering the

gaze angle by 25°.

A relationship between gaze angle and blink frequency during computer use is suspected. Lower blink rate has been associated when reading printed text in downgaze [33,46]. Nielsen et al. [41] found that lowering the gaze angle of the monitor by 25° decreased blink frequency significantly. Consequently, the effect of lower blink rate while viewing digital displays in downgaze is difficult to predict. It is hypothesized that the reduction in blink rate may be a direct consequence of the reduction in exposed ocular surface area [47]. Thus, it has bee pointed out that, a low position of the monitor may still be preferable despite the decreased blink frequency [41]. The extent to which this decrease in blink frequency matches the decrease in exposed ocular surface area is still unknown.

These pending investigations are of particular relevance nowadays in an era in which the use of digital electronic screens is no longer restricted to desktop computers. Such a huge variety of displays, ways of use and potentially influencing factors lead to device-dependent results, making conclusions hard to extrapolate. Researchers should attempt to control and define experimental conditions fully to allow as much accurate comparison of results as possible amongst studies.

2.3. Meibomian gland dysfunction

Proper blinking plays an important role in maintaining lipid layer through meibomian gland lipid expression [48]. Delivery of the oils conforming the lipid layer of the tear film occurs in part by the expression of small aliquots from the meibomian glands with each blink [49]. Abnormal blinking may alter meibomian gland secretion, leading in the long run to chronic changes in the gland, which may eventually cause inflammation, gland obstruction and a further reduction of the outflow of meibum [50]. Consequently, according to Blehm et al. [15], blinking abnormalities, such as reduced blink rate and incomplete eye closure, associated with digital display use may lead to a high incidence of meibomian gland dysfunction (MGD) in computer users.

Wang et al. [51], for instance, found that participants who exhibited incomplete blinking had greater levels of meibomian gland dropout, along with poorer tear film lipid layer thickness, tear film stability and expressed meibum quality, which predisposed to the development of evaporative dry eye. Wu et al. [52] explored meibomian gland function in a group of long (>4 h per day) and short (<4 h per day) time digital display workers. Results revealed a positive correlation of lid margin abnormalities, meibomian gland dropout and altered meibum expression with display working time.

Finally, lid margin abnormalities associated with MGD can additionally result in inefficient tear film spreading, which may further contribute to dry eye signs and symptoms in digital display users.

Overall, MGD associated with display use may sum up to abnormal blinking, and boost tear instability and evaporation, ultimately leading to an increase in inflammatory cytokines, osmolarity and reduced mucin secretion [8,53,54], which may further exacerbate dryness by initiating the closed-loop of inflammatory vicious circle of DED [55]. Digital display-induced ocular surface inflammation, meibomian gland dysfunction and DED, along with the consequent chemical and mechanical stimulation of the cornea, will simultaneously lead to an increase in conjunctival redness, particularly prevalent in digital display users [56,57].

3. Tear film and ocular surface

3.1. Tear volume

Several studies have indicated a reduction in tear film volume after digital display use [7–9,22,30,32]. On the one hand, Yazici et al. [9] evaluated changes in Schirmer test results in young computer users, at the end of a 9-h working day. Authors' results revealed a significant decrease in tear volume with computer use, with an approximate 9% reduction in Schirmer at the end of the day. Similarly, a decreased TMH has been found after playing a computer game for only 20 min [22]. Considering the effects of long-term computer use, a large-scale epidemiological study involving 1025 digital display users found a significantly decreased Schirmer score for those using the computer more than 2 h per day, or for more than 4 years [30].

Concerning hand-held devices, no difference in TMH has been found after 60-min reading from a smartphone [38]. Maducdoc et al. [58] and Prabhasawat et al. [59] found no differences in tear volume (Schirmer test and TMH, respectively) after reading from a tablet, compared to reading on paper. In both studies, however, sample size was relatively small and populations lacked heterogeneity. In this regard, hand-held devices might induce a lower reduction in tear volume compared to computers. Recently, Talens-Estarelles et al. [60] compared the effects of 15-min reading on four different digital displays (laptop computer, tablet, e-reader and smartphone), with matched text and display characteristics, on several tear film and ocular surface parameters, under controlled environmental conditions. Authors obtained a significantly lower TMH with the computer compared to the tablet, e-reader and smartphone, although no differences were obtained in Schirmer I test. Nevertheless, no differences in Schirmer or TMH between 4 h smartphone and computer use have been obtained [7]. The lack of studies involving handheld devices, along with the differences in experimental conditions and settings, may account for these discrepancies.

Overall, computer use seems to lead to reduced tear volume. On the contrary, hand-held devices may influence tear film volume to a lower extent, although for now, studies are scarce and conflicting, and further research is still required.

3.2. Tear stability

Reduced tear stability in computer users is commonly acknowledged [6,9,22,52,61]. Uchino et al. [6] investigated tear function in 672 office workers and found an average FBUT of 4 s (s), with 78.6% of participants having a FBUT shorter than 5 s. Nevertheless, a break of only 1 h was allowed in display usage prior to clinical examinations and no information on subjects' medications or other confounding factors for DED was collected.

Tear stability has shown to decrease with the duration of computer use [9,52,61]. A considerably shorter FBUT has been found in patients using the computer for more than 4 h per day (4.92 s), in comparison to those with less than 4 h of daily use (6.71 s) [52]. Hirota et al. [61] found a decrease in mean NIBUT after 30 min playing a computer game compared to baseline. Despite this, a few studies to date have found no correlation between hours spent at the computer and tear stability [30,62].

Reduced tear stability has been obtained even after a few minutes of computer visualization [22,60,61]. Cardona et al. [22], for instance, obtained a significant decrease in FBUT and NIBUT after as little as 20-min computer playing, for both a fast- and slow-paced gameplay. Authors, who additionally evaluated tear volume, suggested that tear film stability may be more influenced by dynamic visual tasks than volume [22].

When it comes to hand-held devices an overall trend to reduced tear stability with display use can also be seen [7,59,63,64]. Choi et al. [7] found a significantly reduced non-invasive keratograph break-up time (NIKBUT) and FBUT at 4 h of smartphone use, compared to those at baseline. Moon et al. [63] found that FBUT improved significantly in a sample of 916 children after cessation of smartphone use over 4 weeks. Similarly, Kim et al. [64] obtained a decrease in FBUT after 1 h of tablet watching (either watching a movie or playing a computer game), and Prabhasawat et al. [59] found reduced FBUT and NIBUT values after reading from a tablet for as little as 20 min. Nonetheless, no difference in NIBUT or tear lipid layer thickness has been found after 60 min reading from a smartphone [38]. Likewise, no differences in NIKBUT amongst displays were obtained after 15 min of reading on a computer, tablet,

Table 2
Summary of significant effects of digital display use on tear film and ocular surface parameters.

Reference (Year)	Sample	Task	Duration and distance	Tear volume	Tear stability	Tear composition	Ocular surface
Patel et al. [19] (1991)	N = 16 17–31 years	Playing a computer game	10 min, not provided	–	• No change in NIBUT.	–	–
Su et al. [32] (2006)	N = 319 24.2 ± 3.8 years	Ocular examination of operators working with LCDs.	13.6 ± 5.7 months of employment, not provided	40.1% prevalence of tear secretion dysfunction (Schirmer test score ≤ 5 mm).	–	–	–
Fenga et al. [62] (2008)	N = 70 31–56 years	Computer workers with and without MGD	3.9 ± 1.7 h/day, not provided	• Lower Schirmer in workers with MGD.	• No differences in FBUT between workers with and without MGD.	–	• Higher conjunctival signs in workers with MGD. • No differences in corneal staining between workers with and without MGD.
Nakamura et al. [30] (2010)	N = 1025 35.6 ± 10.1 years	Survey in office workers using computer	5.1 ± 2.7 h/day of computer/8.2 ± 5.7 computer working years, not provided.	• Lower Schirmer with working years (≥4 years) and computer daily using time (≥2 h).	• No effect of duration of computer use on FBUT.	–	–
Cardona et al. [22] (2011)	N = 25 21–28 years	Viewing distance target (baseline) vs playing slow-paced computer game vs playing fast-paced computer game.	20 min, 50 cm	• Lower TMH with computer. • No differences in phenol red test amongst tasks.	• Shorter FBUT and NIBUT with computer. • Shorter FBUT and NIBUT with fast game vs slow game. • Lower LLT with computer.	–	–
Kojima et al. [70] (2011)	N = 171 28–73 years	Short-term computer workers vs long-term computer workers	≤4 h/day (short-term)/> 4 h/day (long-term), not provided	• Lower TMH in long-term computer workers. • No differences in Schirmer between groups.	• No differences in FBUT between groups.	–	• No differences in corneal or conjunctival staining between groups.
Hirota et al. [61] (2013)	N = 11 19–32 years	Playing a computer game	60 min, 40 cm	–	• Reduced NIBUT after 30 and 60 min.	–	–
Yazici et al. [9] (2014)	N = 77 20–50 years	Computer users vs non-computer users.	6.9 ± 2.7 h (working day), not provided	• Reduced Schirmer in computer users after working day.	• Reduced FBUT in computer users after working day.	• Increased osmolarity in computer users after working day.	–
Wu et al. [52] (2014)	N = 53 20–52 years	Short-term computer workers vs long-term computer workers	≤4 h/day (short-term)/> 4 h/day (long-term), not provided	• No difference in Schirmer between groups.	• Shorter FBUT in long-term workers. • Lower meibum expression in long-term workers.	–	• Higher corneal staining in long-term workers. • Higher lid margin abnormality in long-term workers.
Uchino et al. [53] (2014)	N = 96 22–60 years	Short vs intermediate vs long-term computer workers	<5 h/day (short)/5–7 h/day (intermediate)/> 7 h/day (long), not provided	–	–	• Reduced MUC5AC concentration in long-term computer workers.	–
Ribelles et al. [8] (2015)	N = 148 40–65 years	Computer users vs non-computer users	–	• Lower Schirmer in computer users.	–	• Higher IL-1β and IL6 levels in older patients and in computer users.	–
Maducdoc et al. [58] (2017)	N = 44 21–31 years	Reading from tablet vs reading from print	60 min, 37.9 ± 5.1 cm (print)/38.1 ± 5.6 cm (tablet)	• No changes in Schirmer after reading from tablet or print. • No differences in Schirmer between tasks.	–	–	–
Kim et al. [64] (2017)	N = 59 22–64 years	Watching movie or playing game on tablet	60 min, 40 cm	–	• Reduced FBUT after tablet use.	–	–
Choi et al. [7] (2018)	N = 80 21–26 years	Playing a game with smartphone vs	4 h, not provided	• No changes in Schirmer and TMH	• Reduced FBUT after 4 h smartphone use.	• Increased HEL concentration after 4 h smartphone	

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Table 2 (*continued*)

Reference (Year)	Sample	Task	Duration and distance	Tear volume	Tear stability	Tear composition	Ocular surface
		playing a game with computer		after smartphone or computer use	• Reduced NIKBUT after 1 h and 4 h smartphone use.	use. • Increased ROS levels after 1 h and 4 h smartphone and computer use.	
Golebiowski et al. [38] (2019)	N = 12 18–23 years	Reading from smartphone	60 min, 30–34 cm	• No changes in TMH.	• No changes in lipid layer appearance. • No changes in NIBUT.	–	–
Prabhasawat et al. [59] (2019)	N = 30 24–55 years	Reading from tablet vs reading from print	20 min, 30 cm	• No changes in TMH after reading from tablet or print. • No differences in TMH between tasks	• Reduced FBUT and NIBUT after reading from tablet or print. • No differences in FBUT and NIBUT between tasks.	–	• No changes in corneal and conjunctival staining after reading from tablet or print. • No differences in corneal and conjunctival staining between tasks.
Doguizi et al. [68] (2019)	N = 102 38.9 ± 5.5 years in computer users/37.8 ± 5.8 years in control.	Vocational computer users (>6 h/day) vs control (<1 h/day)	–	• Lower Schirmer in computer users. • Reduced TMH and TMA in computer users.	• Shorter FBUT in computer users.	–	• Higher staining score in computer users. • No differences in MGD score between computer users and control.
Talens-Estarelles et al. [60] (2020)	N = 31 21.26 ± 1.73	Viewing distance target (baseline) vs reading from computer vs tablet vs e-reader vs smartphone	15 min 60 cm and 10° angle for computer, 45 cm and 25° angle for tablet and e-reader, 30 cm and 45° angle for smartphone	• Lower TMH with computer compared to other devices and baseline. • Lower Schirmer with computer compared to baseline.	• Lower NIKBUT with computer compared to baseline. • No differences in NIKBUT amongst displays.	• Higher osmolarity with computer compared to smartphone.	• Higher bulbar redness with computer compared to smartphone.

BUT, Fluorescein Break-Up Time; h/day, hours per day; HEL, Hexanoyl Lysine; IL, Interleukins; LCD, Liquid Crystal Display;; LLT, Lipid Layer Thickness; MGD, Meibomian Gland Dysfunction; MUC5AC, Tear Mucin 5AC; NIBUT, Non-Invasive Break-Up Time; NIKBUT Non-Invasive Keratograph Break-Up Time; TMA, Tear Meniscus Area; TMH, Tear Meniscus Height; ROS, Reactive Oxygen Species.

e-reader or smartphone [60].

3.3. Tear composition

The use of digital displays has additionally been associated with alterations in tear film composition [7–9,53,54]. Osmolarity is considered the most reliable marker of DED severity, acting as a global indicator of ocular surface impairment and inflammation [65]. Significantly increased osmolarity was obtained in a group of 51 computer users at the end of a 9-h working day [9]. Additionally, osmolarity was negatively correlated with the duration of computer use and with FBUT and Schirmer scores. Authors pointed out that the decreased volume and increased evaporation of tears, as a result of computer use, were behind the increment of tear osmolarity [9]. Likewise, Fenga et al. [54] reported an inverse correlation of tear osmolarity with FBUT, and a direct correlation with corneal stain, ocular surface dysfunction and MGD in 64 computer workers.

Ribelles et al. [8] found a significantly higher level of interleukins-1β and −6 in computer users as compared to non-computer users, which reflected a relevant inflammatory background in patients using this display. As expected, these pro-inflammatory mediators correlated with clinical DED parameters.

Chronic inflammation and raised tear osmolarity produce damage on the ocular surface, including loss of goblet cells in the conjunctiva or stem cells in the limbus [66]. Mucins dissolved in tears are produced by goblet cells and play an important role in epithelial surface protection, by increasing epithelium wettability and helping to retain fluids on it [67]. Uchino et al. [53] found that mean MUC5AC mucin concentration was lower in computer users working for longer hours (>7 h), compared to shorter (<5 h), and that MUC5AC concentration was lower in symptomatic participants than in asymptomatic.

Oxidative stress is considered as a possible inciting factor in the generation of ocular surface inflammation. Choi et al. [7] measured oxidative stress markers in the tear film of 80 volunteers, before and after smartphone or computer use. Authors obtained an increase in hexanoyl lysine concentration after 4 h of smartphone use, compared with baseline and 1-h use. Additionally, authors assessed oxidative stress by measuring reactive oxygen species (ROS) in the conjunctival epithelium and found an increase of ROS production after using the smartphone and the computer. Scientists concluded that smartphone use was capable of inducing oxidative stress response and cellular apoptosis at the ocular surface [7].

3.4. Ocular surface staining

Vital staining may be used to indicate corneo-conjunctival epithelial damage. An increased prevalence of corneal staining was obtained in a large sample of young office workers, who used the computer for an average of 7.9 h a day [6]. Another study found significantly greater corneal staining scores in a group of computer workers compared to the control [68]. However, sample size in this study was relatively small and further research is needed to back up these findings. Also, significantly higher corneal staining has been found with increasing hours of daily computer use [52]. In this regard, a significant association between the

degree of incomplete blinking and the grade of corneal staining has been demonstrated [39,69]. Consequently, ocular surface staining may arise from tear thinning and reduced goblet cell mucin in the exposed area, leading to exposure keratopathy [35].

Several investigations have revealed no effect of digital display use on ocular surface staining [9,59,62,70–72]. Kojima et al. [70], for instance, found no difference in vital staining (fluorescein and rose bengal) scores between subjects working with the computer for less than 4 h per day and those working for longer periods. Likewise, no differences in corneal and conjunctival staining scores were found after reading for 20 min from a tablet or printed paper [59]. However, since only young and middle-aged subjects participated in these studies, results may not apply for older-aged individuals.

Concerning the above, ocular surface staining has been suggested as lacking discriminatory power, and to act as a sign of severe disease rather than of mild-to-moderate disorder [73,74]. According to literature, staining may be absent in up to 40–50% of mild to moderate DED patients [65,75]. This reasoning may explain results discrepancies amongst studies.

3.5. Conjunctival redness

As aforementioned, conjunctival redness may arise as a consequence of induced ocular surface inflammation, meibomian gland dysfunction and DED after digital display use [56]. Also, conjunctival redness has shown to occur as a response to chemical and mechanical stimulation of the cornea [57], which may further explain the increased prevalence of eye redness in patients with CVS-related dry eye.

Choi et al. [76], for example, found an increase in conjunctival bulbar redness after as little as 15-min display reading as well as a significant effect of task duration on this parameter. Still, these findings pertain to specific experimental conditions and thus it is necessary to examine the effects of digital displays under other experimental circumstances and tasks. Tauste et al. [77] found that bulbar redness was the most prevalent abnormality of the ocular surface in office workers, ahead of corneal staining, and that the risk for conjunctival limbal redness was higher for those who used the computer more than 4 h per day. Regarding hand-held devices, longer daily smartphone use and higher lifetime smartphone exposure, have been associated with a higher likelihood of having signs of redness [78]. Recently, a significantly higher bulbar redness has been obtained after reading from a computer for 15 min compared to a smartphone, under controlled conditions and matched text and display characteristics [60]. Table 2 summarizes the literature relevant to the impact of digital displays on the tear film and ocular surface.

Interestingly, in recent years several mobile phone applications (apps) have been developed to manage dry eye, which may seem ironic. According to a recent study, which analyzed the market for patient-oriented mobile phone apps in ophthalmology, dry eye was the most frequently downloaded and best-rated subspeciality out of a total of 7 [79]. Nevertheless, scientific research regarding dry eye apps is still very scarce, and clinicians and patients should bear in mind that most of these apps lack supported research and have not been properly validated before being launched.

Uchino et al. [80] evaluated a dry eye mobile app for the screening of DED in a group of 100 subjects. Authors backed the utility of the app as an easy way of DED screening. However, despite their novel research, no consideration of how the use of the display may have had influenced blinking, and hence the possible outcomes of the measurements, was made. Likewise, authors did not mention the physical properties of the device or how the device was used by the participants, which both have shown to influence the impact of display use on the ocular surface and tear film (see later).

Inomata et al. [81] used a mobile phone app to assess the characteristics and risk factors associated with diagnosed and undiagnosed dry eye in a sample of 4454 users. Dry eye symptoms were collected using dry eye questionnaires such as OSDI, after participants answered an extensive list of questions on demographics, medical history and lifestyle. Given that the use of digital displays can impact tear film after a few minutes of visualization, dry eye symptomatology results may have been influenced by prolonged exposure to the device. Overall, researchers should pay close attention to how digital displays may affect the ocular surface of users when considering the development of dry eye screening apps, especially if several measurements are being taken consecutively.

4. Visual function

DED leads to tear film instability and hyperosmolarity, inflammation of the ocular surface and, ultimately, visual disturbance [82], that has shown to significantly impact patients quality of life [83]. The tear film makes the first surface that light meets before entering the eye, and given the large step of refractive index between the air and the tears, the precorneal tear film has the greatest dioptric power of any optical interface of the eye [84]. Consequently, alterations in the composition, distribution and homogeneity of the tear film may potentially lead to notable changes of the visual function [85]. Several studies have reported a reduction in visual acuity (VA) [86] and contrast sensitivity [87], and an increase in glare disability in patients with DED [87].

Additionally, the tear film undergoes disruptions following a blink, leading to its break-up [84]. After a blink, the progressive irregularity in the thickness of the tear film over the ocular surface worsens its optical quality more and more. When the tear film breaks-up the cornea is exposed. Unlike the tear film, the cornea has a natural irregular surface caused by the presence of numerous microvilli. Hence in the absence of the tear film, the quality of the image formed is poor. Goto et al. [88], for instance, found that VA was significantly reduced from 1.18 to 0.336 in normal patients after they gazed for 10–20 s without blinking. Likewise, contrast sensitivity and high-order optical aberrations have also shown to significantly decrease and increase, respectively, when blinking is suppressed [89].

Visual disturbances, such as blur or glare, are common visual symptoms in digital display users. According to a survey involving 520 New York office workers, up to 36% reported having blurred vision while viewing the computer and 24.1% declared suffering sensitivity to bright lights during computer use [4]. In all cases, the symptom score increased with the number of hours of computer use. Considering the aforementioned, it is expected that at least part of these symptoms are attributed to alterations in the tear film associated with digital display use. In this line, DED induced or aggravated by the use of digital displays will further alter the properties of the tear film and lead to a further worsening of the visual function during display usage.

Despite this, it is relevant to bear in mind that alterations of the visual function during display use tend to be mostly associated to alterations in the mechanism of accommodation and vergence, which are beyond the scope of this review. Portello et al. [4] found that blurred vision while viewing the computer was mostly correlated with accommodation rather than dry eye (0.38 for dry eye vs 0.72 for accommodation), while sensitivity to bright lights was mostly correlated with dry eye (0.62 for dry eye vs 0.32 for accommodation).

Overall, there is a lack of research on the effects of digital displays on visual function and acuity. Further research to understand the effects of digital technology on vision across all ages is crucial so as to set guidelines for technology usage.

5. Risk factors

5.1. Contact lenses

Contact lens (CL) wear is recognized as one of the main risk factors for DED [11]. According to the literature, DED appears to be up to 4 times more prevalent in CL wearers [90–92]. CL use has been associated

Table 3
Summary of significant effects of contact lens use on tear film, ocular surface and blinking in digital display users.

Reference (Year)	Sample	Purpose	Main findings
González-Méijome et al. [100] (2007)	N = 334 18–61 years	Evaluation of dryness symptoms in CL and non-CL wearers using computers.	•Higher scratchiness in CL wearers. •Higher prevalence of reported symptoms at the end of the day in CL wearers. •Higher scratchiness in female vs male CL-wearers. •Higher burning sensation with longer computer work in CL wearers. •Increase in scratchiness symptoms in CL wearers with air conditioning and heating units exposure.
Uchino et al. [103] (2008)	N = 4393 22–60 years	Determine the prevalence of DED risk factors in computer workers.	•Higher prevalence of DED in CL wearers computer workers. •Higher prevalence of severe DED symptoms in CL wearers computer workers.
Jansen et al. [105] (2010)	N = 15 18–30 years	Examine blink parameters and tear stability while listening to music or playing a computer game with and without CLs.	•Lower BR and BA with computer vs listening to music without CLs. •Lower BA with computer vs listening to music with CLs. •No change in BR between tasks with CLs. •Higher AB when using the computer with CLs. •Higher % of blinks preceded by AB when using the computer with CLs. •Increased ocular irritation with CLs.
Kojima et al. [70] (2011)	N = 171 28–73 years	Evaluation of the effects of CL wear on ocular surface and tear film.	•Lower TMH in CL wearers. •Higher dry eye symptomatology and severity in CL wearers. •Higher symptom aggravation from exposure to air conditioners in CL wearers. •No differences in FBUT, Schirmer and staining between CL and non-CL wearers.
Ranasinghe et al. [45] (2016)	N = 2210 18–60 years	Description of prevalence of CVS associated factors	•Higher prevalence of DED in CL vs non-CL wearers. •Use of CLs second most significant risk factor for CVS.
Tauste et al. [101] (2016)	N = 426 47.3 ± 8.9 years	Analysis of the relationship between CVS and CL use in computer workers.	•Higher CVS prevalence in CL wearers. •Higher risk of CVS in CL wearers using the computer >6 h/day. •Trend to higher CVS prevalence in SH and CH CL wearers vs RGP CL wearers.
Tauste et al. [77] (2018)	N = 236 26–67 years	Study of differences in ocular surface and tear film of CL vs non-CL wearers computer workers.	•Higher risk of ocular surface abnormalities in CL vs non-CL wearers. •Higher prevalence and/or risk of ocular surface abnormalities with CH and SH CLs vs RGP CLs (CH > SH > RGP). •No differences in prevalence or risks of FBUT and Schirmer abnormalities between CL and non-CL wearers. •Higher risk of redness in CL wearers with >4 h/day computer exposure.

AB, Area of Tear Film Break-up; BA, Blink Amplitude; BR, Blink Rate; CH, Conventional Hydrogel; CL, Contact Lens; CVS, Computer Vision Syndrome; DED, Dry Eye Disease; FBUT, Fluorescein Break-UP Time; h/day, hours per day; RGP, Rigid Gas Permeable; SH, Silicone Hydrogel; TMH, Tear Meniscus Height.

with a higher prevalence of severe DED symptoms [93]. The use of CLs leads to a thinner and irregular lipid layer with deficient tear spreading and wettability [94], tear film instability [95], increased tear evaporation and osmolarity [67], lower basal tear turnover rate [95], decreased tear volume [96,97] and reduced levels of the mucin MUC5AC [98]. Furthermore, meibomian glands can also be affected by CL use [99].

Several studies indicate an increase in the prevalence of dryness symptoms in CL computer workers [45,70,77,100–104]. Gonzalez-Meijome et al. [100], for instance, found that soft CL wearers who worked with digital displays for longer periods were more likely to develop symptoms such as eye burning and scratchiness than non-CL wearers. The combination of long-term digital display work and CL wear has been found to synergistically exacerbated dry eye symptoms.

Tauste et al. [101] found that workers who wore CL and used the computer for more than 6 h per day were more likely to suffer CVS than non-CL wearers, working at the computer for the same amount of time. Authors found a trend towards a greater problem in conventional hydrogel, and especially in silicone hydrogel, CL wearers compared with rigid gas permeable users. These results were attributed to possible ineffective cleaning of the monthly replaced hydrogel and silicone hydrogel lenses with multipurpose lens care solutions, which lead to superficial deposits, and to the high elastic modulus and hydrophobic surfaces, with a tendency to accumulate lipid deposits, of the silicone hydrogel lenses. However, given the limitation in sample size, this study should be considered as a starting point for further investigations with larger samples.

Years later the same authors carried out a similar experiment, and analyzed the differences in ocular surface appearance of CL and non-CL digital display workers, with different lens materials [77]. Results revealed that digital display workers who wore CLs were more likely to suffer bulbar, limbal and lid redness and lid roughness. Also, conventional hydrogel wearers had the highest prevalence of ocular surface abnormalities, while rigid gas permeable wearers had the lowest. Authors attributed these findings in part to the lower permeability of conventional hydrogel lenses, as opposed to the higher permeability of silicone hydrogel lenses, which limits the passage of oxygen to the cornea and favours corneal and conjunctival vascular response [77]. Once more, sample size was limited and particularly insufficient for the rigid gas permeable lenses group.

Concerning tear function, a reduced TMH has been obtained in long-term VDT workers CL users, in comparison to short-term VDT workers who did not wear CLs [70]. Nevertheless, no differences between groups were found in Schirmer, FBUT and fluorescein or rose bengal staining. Likewise, no differences in Schirmer, FBUT and fluorescein staining have been found between CL and non-CL wearers computer workers, although there could be a possible underestimation in FBUT and Schirmer in this study as a result of the study design [77].

CLs wear has been shown to increase blink rate, even in fully adapted wearers [105]. Although one of the most pertinent issues associated with digital display use is a reduced rate of blinking, it must be kept in mind that CL wearers may be up to 12 times more likely than emmetropes to report dry eye symptoms [106]. Conversely, as in the general population, blink amplitude does show a decrease in CL wearers using digital displays [105]. Partial blinking leads to tear film evaporation and break-up problems and to the precipitation of deposits on the lens surface [35], which in turn decreases lens wettability and leads to further symptoms of dryness and discomfort [107]. Table 3 summarizes the literature relevant to the impact of CL use on the tear film, ocular surface and blinking in digital display users.

5.2. Age and gender

Age is categorized as a consistent risk factor for DED [11]. The recent meta-analyses carried out by the TFOS DEWS confirmed that symptomatic disease and signs of DED increase with age [11]. Ranasinghe et al. [45] evaluated the prevalence of CVS in a group of 250 computer office workers and found that the prevalence of CVS significantly increased with increasing age of the computer user. These results are particularly relevant considering that internet adoption among seniors has risen steadily over the last decades [108].

Digital display usage is particularly high amongst young people. Rahman et al. [109], found that younger age (less than 27 years) had higher odds for CVS than older age (more than 33 years), and attributed these findings to the negative correlation found between age and duration of computer usage. Kim et al. [78] studied the association between smartphone use and ocular health in a group of 715 adolescents, with a mean age of 15 years, and found that the lifetime exposure to smartphones increased the risk of ocular symptoms including dryness. Authors advised that special caution should be taken by adolescents, given their increased time of exposure to digital displays. Nevertheless, the questionnaire used to assess symptomatology in this study was self-administered and not validated, thus the validity of the obtained data could be low.

Moving to younger age groups, digital display use in children has shown to be strongly associated with pediatric DED [63,110]. For instance, a decrease in FBUT and an increase in modified OSDI have been obtained with longer daily smartphone use in children aged 7–12 years [63]. This study additionally found that the odds of having DED were 13 times higher in children who used the smartphone for more than 3 h a day [63].

Female gender is widely accepted as a risk factor for the development of DED [11]. Differences in DED rates between women and men, however, tend to become significant only with increasing age [11]. Schaumberg et al. [111], observed that women were, on average, 6 years younger when diagnosed with DED compared with men. In their study, women also reported a significantly greater impact of DED on working with a computer [111]. Recent research has revealed an abnormally low Schirmer test and reduced spontaneous blink frequency in older women (53–65 years) working with computers, compared to younger (40–52 years) [8]. Increased levels in interleukins-1β and −6 were also found with computer use and age [8].

5.3. Environmental conditions

Studies reveal a strong association between low relative humidity environments and prevalence of DED [112]. Tear evaporation rate, lipid layer thickness, ocular comfort, and tear film stability and production have shown to be adversely affected by low relative humidity [113,114]. Low relative humidity exposure of the ocular surface may cause conjunctival goblet cells cornification, and alter the delivery of mucins which make up the tear film [115]. High horizontal or downward air velocity, by the use of ventilation fans or air conditioning settings, can also increase tear film evaporation leading to exposure keratitis and epithelial damage [116].

Moreover, elevated room temperature has been found to adversely affect tear film quality [117]. Mendell et al. [118] found that lowering room temperature by 1 °C (within 22–26 °C) decreased dry eye symptoms by 19%. Cold thermoreceptors in the cornea regulate the basal flow of tears [119]. Consequently, warmer office environments will reduce basal tear secretion. Lower temperatures stimulate thermo-sensitive cold fibres in the cornea which will initiate reflex blinking [120]. Hence, higher temperatures will lower blink frequency and promote dryness. Also, increased temperatures have been associated with a less stable tear film lipid layer [121].

Besides this, airborne chemicals produced by building materials and products are capable of producing eye irritation and oxidative stress [122]. However, recent measurements in office environments show concentration levels are not high enough to cause dry eye irritation-related symptoms [123].

Finally, improper lighting conditions, with unequal luminance between the digital display and its background, glare from windows or overhead lights and reflections from the display screen, can cause discomfort and disability glare [124]. Glare and reflections from the screen reduce contrast leading to poorer image quality [125]. This is particularly relevant, as degraded visual image of electronic screens has been associated with reduce blink rate [25]. At the same time, glare may additionally produce the contraction of the orbicularis oculi muscle so as to decrease retinal illumination and improve vision [26], leading to squinting and consequently reducing blink frequency further. [27].

6. Potential treatments

Artificial tears form one of the main strategies of management of dry eye associated with digital display use. According to several authors, lubricating eye drops may be effective on counteracting the issue of dry eyes in digital display users [5,15,126–128]. High viscosity drops (elastoviscous solution) have shown to regularize the interblink interval and relief ocular symptoms during work with digital displays more effectively than regular balanced salt solutions [126]. Moreover, treatment with artificial tears has also shown to be capable of reducing symptoms of dryness in regular computer users CL wearers, although symptoms may not be fully eliminated [127].

Another treatment option includes dietary supplementation with omega-3 fatty acids [129–131]. In a randomized, double-blind study of 478 symptomatic regular computer users, the supplementation of two 180 mg capsules of omega-3 fatty acids daily for two months, significantly alleviated dry eye symptoms, decreased tear evaporation rate and improved Nelson grade (cellular morphology and goblet cell density) in patients with CVS-related dry eye [129]. Nevertheless, part of these studies did not include a placebo group which would have been suitable.

Given the impact of digital display use on blinking, blink training may be a helpful treatment strategy in symptomatic digital display users. Portello and Roselfield [132]. found that increasing blink rate during computer reading by means of a metronome, to produce a blink every 4 s, did not reduce symptoms significantly. According to recent findings, incomplete blinking may be a more pertinent issue than blink rate in display users [28,29]. It should be noted, however, that subjects in both of these studies were required to read aloud and this may have represented a subtle stimulus to blinks. Overall, blink exercises focused on increasing the completeness of blinks during display visualization are expected to be more appropriate, although they may hinder task performance [22,39,132].

Screen filters, such as anti-glare filters, act as neutral density filters which can be useful for reducing screen reflections and improving contrast [125,133]. The better image quality on the display screen and the reduced glare can decrease squinting [26], and alter blinking to a lesser extent [134]. Other filters, such as mesh or polarizing filters may also be appropriate [125]. According to recent studies, the use of screen filters is associated with reduced incidence of dry eyes in digital display

Table 4
Treatment strategies for the management of dry eye associated to digital display use.

Treatment strategy	References	Potential benefits and results
Artificial tears	(5,15,126–128)	•Regularization of the IBI. •Reduction of dry eye symptoms. •Better results with high viscosity eyedrops.
Omega-3 fatty acids supplementation	(129–131)	•Alleviation of dry eye symptoms. •Reduction of tear fil evaporation rate. •Improvement of cellular morphology and goblet cell density.
Blink training	(24,28,29)	•Lack of available literature. •Training of BA expected to be more beneficial than BR.
Anti-reflection screen filters	(45,125,134,135)	•Increase of BR and BA. •Reduction of dry eye symptoms. •Reduction of DED incidence.
Blue-blocking filters	(136–139)	•Possible reduction of dry eye symptoms. •No consensus. •No difference with neutral density filters. •Lack of available literature.
Ergonomic practices o *Optimum text legibility and quality.* o *Appropriate lighting and screen positioning.* o *Lower monitor height.*	(5, 21–25,41-44, 125,134,141)	•Increase of BR and BA. •Improvement of tear film stability. •Reduction of exposed ocular surface area. •Reduction of tear film evaporation. •Reduction of dry eye symptoms.
Regular breaks	(5,15,108,135,141)	•Reduction of tear film abnormalities. •Reduction of dry eye symptoms.
Work environments o *Appropriate room temperature and humidity.* o *Avoidance of direct air to the eyes.*	(117,118,120,121,142,143)	•Increase of BR. •Improvement of tear film stability. •Reduction of tear film evaporation. •Reduction of ocular surface desiccation. •Reduction of dry eye symptoms.

BA, Blink Amplitude; BR, Blink Rate; DED, Dry Eye Disease; IBI, Inter-Blink Interval.

users [45,135].

Also, blue light emitted by digital displays has been suggested as contributing factor for CVS [136]. Nonetheless, up to date there is no consensus on the effectiveness of blue-filtering lenses for the treatment of symptoms during digital display use [137–139]. Cheng et al. [137] showed no improvement in Schirmer test values in a group of dry eye and non-dry eye patients after wearing low, medium and high-density blue light filters. Dry eye patients reported more comfort with all filters, although no difference was found in the normal group. However, the study did not include a control condition, and so a placebo effect cannot be ruled out. Lin et al. [138] found that wearing high-blocking spectacles produced fewer feelings of itchy eyes in patients compared to no-blocking and low-blocking spectacles. Nevertheless, the study sample was considerably small and despite the efforts of the researchers, complete masking was impossible to ensure (i.e. subjects could suspect which glasses were they wearing). Palavets and Rosenfield [139] recently found that a filter which eliminated 99% of the emitted blue light from a tablet computer was not more effective than an equivalent neutral density filter at reducing CVS symptoms, including dryness. Overall, there is limited evidence to support the proposal that blue light emitted by digital displays is capable of producing eyestrain.

Finally, ergonomic considerations while using digital displays are important for the management of CVS-related dry eye [5,140]. On the one hand, adequate blinking may be suppressed to maximize the acquisition of information in visually demanding tasks. Therefore, good text legibility, including contrast, text size, line spacing, etc. will reduce cognitive and visual task demand and hence improve blinking, leading to lower dry eye signs and symptoms [21–25,44]. Likewise, appropriate lighting, achieved with a uniform distribution of luminance in the visual field [125], and careful positioning of the display, avoiding screen reflections and glare from the window or overhead lights, will elude squinting [26] and possible blinking abnormalities [134]. Specifically, regarding illumination, authors recommend the brightness of the screen to match the immediate surround so as to avoid glare from the surrounding or the display [125,135]. Furthermore, lowering the monitor will reduce ocular surface exposure [41] and tear film evaporation [43], and improve tear film stability [42].

Also, as previously addressed, longer periods of display visualization have been associated with higher tear film abnormalities and dryness signs and symptoms [7,9,30,52,53,61,63,68,77,101]. Therefore, regular breaks during digital display use are generally considered as a good management strategy [5,15,108,135,141]. Last, adequate work environments with appropriate room temperature (20–22 °C), ambient humidity, and no direct horizontal or upper air from ventilation fans, will help maintain a normal eye blink frequency and minimize alterations of the tear film [142,143].

CVS represents in most cases a reversible condition which tends to improve with the sole interruption of display visualization. Recent research revealed a significant improvement in both subjective symptoms and objective signs (punctate epithelial erosion, FBUT) of dry eye in a large sample of children after cessation of smartphone use for 4 weeks [63]. Remarkably, the DED rate in the DED group of this study decreased from 100% to 0% after smartphone cessation, although the actual prevalence of DED in this study may have been affected by using adult-targeted diagnostic criteria. Despite these results, it should be noted that long-term digital display use is considered a predisposing factor to DED, which in its most severe condition can lead to permanent damage to the ocular surface. Table 4 summarizes the main treatment strategies for the management of CVS-related dry eye.

7. Conclusions

Abnormal blinking, including a reduced blink rate and incomplete eyelid closure, during computer operation, is considered one of the main mechanisms of CVS-related dry eye. Possible glare from the device screen and poor image quality of electronic text are probably behind the change in blink rate found in display users. Nevertheless, given the current technological improvements, incomplete blinking, resulting from increased cognitive and task demand, may be a more pertinent issue today. Other dry eye-inducing factors include the higher gaze angle at which computers are usually held and MGD prompted by abnormal blinking in long-term display users.

Accordingly, studies indicate a reduction in tear volume, a noticeable decrease in tear stability and alterations in tear film composition, including increased osmolarity levels, inflammatory cytokines, oxidative stress markers and reduced mucin secretion. Conjunctival redness is frequently found in display users, whereas vital staining of the ocular surface may be present as a sign of mild-to-moderate disorder. Lower tear film and ocular surface impact may occur after hand-held device use compared to computer, although further research is required. Dryness

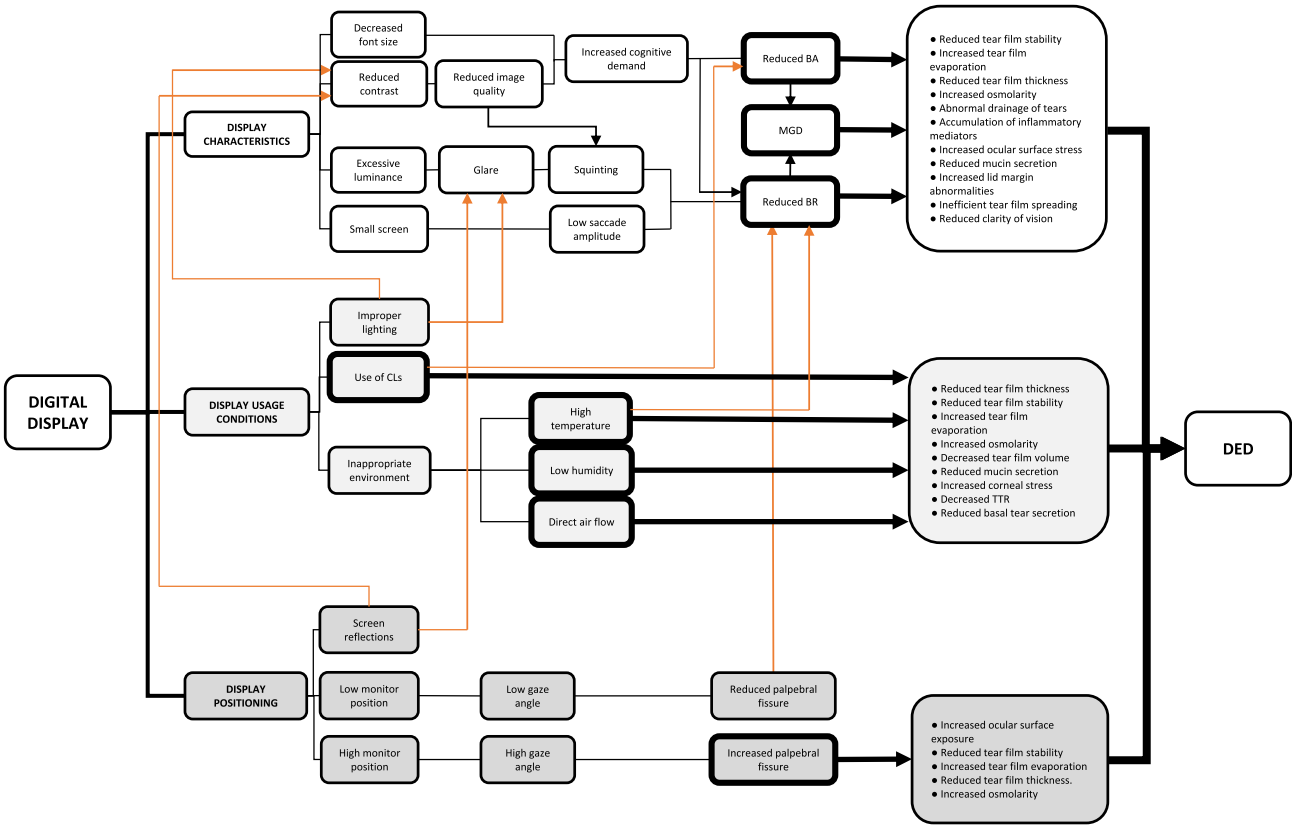

Fig. 1. From digital displays to dry eye disease. Summary diagram of the factors and mechanisms of digital display use leading to ocular surface alterations and dry eye disease. Orange arrows correspond to interactions between dry eye inducing factors of different classification group. Black bold arrows indicate ultimate factors responsible of tear film and ocular surface abnormalities. BA, Blink Amplitude; BR, Blink Rate; CLs, Contact Lenses; DED, Dry Eye Disease; MGD, Meibomian Gland Disfunction; TTR, Tear Turnover Rate. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

signs and symptoms are globally accepted to be dose-dependent and to increase with longer duration of display use. Risk factors such as CL use, increasing age, female gender, improper lighting, and high-temperature and low humidity environmental conditions may significantly increase the prevalence and the severity of CVS-related dry eye. Fig. 1 represents the complete process by which digital displays and associated factors give rise to ocular surface alterations, ultimately producing DED.

Finally, the treatment strategy should follow a multidirectional approach, with various treatments being applied jointly. These may include the use of high-viscosity lubricating eyedrops, omega-3 fatty acids dietary supplementation, blink exercises focused on increasing blink amplitude, the use of screen filters, improving the work environment, optimizing display position and taking regular breaks.

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Declaration of competing interest

None.

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