Blink Rate and Incomplete Blinks in Six Different Controlled Hard-Copy and Electronic Reading Conditions

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Purpose. To evaluate spontaneous eye blink rate (SEBR) and percentage of incomplete blinks in different hard-copy and visual display terminal (VDT) reading conditions, compared with baseline conditions.

Methods. A sample of 50 participants (29 females, age range, 18–74 years) were recruited for this study. All participants had good ocular health and reported no symptoms of dry eye (OSDI score < 15). Face video recordings were captured while participants observed in silence a landscape picture at 2 m (baseline) and during six different, 6-minute controlled reading experimental conditions. Texts were presented in electronic (tablet and computer display at 100% and 330% zoom levels) and hard-copy (text in book position in silence and aloud and text pasted on the computer display) formats. Video analysis was subsequently conducted to assess blink parameters.

Results. All reading conditions resulted in a decrease in SEBR when compared with baseline conditions (all $P < 0.001$), with the least negative impact corresponding to reading in a 330% expanded display. The percentage of incomplete blinks was found to increase when reading was conducted on an electronic platform, in contrast to hard-copy text.

Conclusions. The high cognitive demands associated with a reading task led to a reduction in SEBR, irrespective of type of reading platform. However, only electronic reading resulted in an increase in the percentage of incomplete blinks, which may account for the symptoms experienced by VDT users.

Keywords: blinking amplitude, saccades, spontaneous eye blink rate, reading task

Objetivos. Evaluar la frecuencia espontánea de parpadeo (FEP) y el porcentaje de parpadeos incompletos en diferentes condiciones de lectura, incluyendo texto en papel y en terminales de visualización de datos (TVD), en comparación con condiciones *baseline*.

Métodos. Una muestra de 50 participantes (29 mujeres, edades entre 18 y 74 años) fue reclutada. Todos los participantes tenían buena salud ocular y no presentaban síntomas de ojo seco (OSDI < 15). Se capturaron vídeos mientras los participantes observaban en silencio una imagen situada a 2 metros (*baseline*), y en seis diferentes condiciones controladas de lectura (durante 6 minutos). Los textos se presentaron en formato electrónico (tableta, pantalla con un nivel de zoom de 100% y de 330%) y papel (libro en silencio y en voz alta y texto pegado encima de la pantalla). Posteriormente, se analizaron los vídeos para evaluar los parámetros del parpadeo.

Resultados. Todas las condiciones de lectura provocaron una disminución de la FEP al compararlas con el *baseline* (todas las $P < 0.001$), siendo el impacto menos negativo en el caso de la pantalla expandida a 330%. El porcentaje de parpadeos incompletos aumentó durante la lectura electrónica, en comparación con papel.

Conclusiones. La demanda cognitiva asociada a la lectura origina una disminución en FEP en todas las plataformas de lectura. Sin embargo, sólo la lectura electrónica ocasiona un aumento del porcentaje de parpadeo incompleto, lo que puede explicar los síntomas de sequedad ocular en usuarios de TVD.

It may be argued that reading text presented in hard-copy or electronic formats is one of the most common cognitive demanding near-vision tasks. Researchers from different disciplines agree that the choice of reading platform, however, is not trivial.[1–5] For example, while dry eye is a frequently reported symptom amongst visual display terminal (VDT) users,[1–4] reading in paper format has not been traditionally associated with complaints of dry eye.

Visual fatigue among VDT users was first documented by Hultgren and Knave in 1974,[6] with symptoms increasing toward the end of the day.[7] Several factors may account for the differences in visual fatigue among reading platforms. First, ocular exposure, which results in tear film evaporation,[8] is influenced by actual screen position, and is more relevant for desktop computers.[9] It may be noted that ergonomic recommendations for these devices suggest that the center of the display should be placed slightly lower than the horizontal line of sight. In contrast, laptop users have been observed to place their devices in a variety of positions,[10] usually opting for a lower position, compared with desktop computer users. As for tablets, e-books, and other handheld devices such as smartphones, they are usually viewed in inferior gaze, similar to traditional printed reading material, and at a shorter distance, although user preferences also may vary.[10,11] Although ergonomic recommendations aim at reducing postural related symptoms arising from prolonged computer use, as far as we know, they do not consider the relationship between display position and ocular surface exposure.

Second, subtle differences between hard-copy and electronic formats have been observed in spontaneous eye blink rate (SEBR) and blink amplitude (complete or incomplete). Changes in SEBR have been documented to be modulated by fine motor controls, speech centers, emotional states, cognitive demands, and attention,[8,9,12–14] although previous research has also revealed a possible influence of other, device-related factors on SEBR. Thus, Benedetto and colleagues[15] compared a liquid crystal display (LCD) tablet, an electronic ink reader (E-ink) and a paper book, describing an overall subjective preference for the paper book, with the LCD tablet presenting the worst results in terms of visual fatigue and reduction in SEBR, which the authors attributed to the higher level of luminance emitted by the LCD device. On the contrary, Chu et al.,[16] while also reporting higher levels of discomfort (in terms of blurred vision) when viewing a text on the computer screen, did not uncover any difference in SEBR between both conditions.[17] Interestingly, however, they described a higher percentage of incomplete blinks during computer use, which may have accounted for ocular discomfort. Other authors have also documented that incomplete blinking, rather than an actual decrease in SEBR, is the main contributory factor of dry eye symptoms, further supporting the role of blink amplitude in visual fatigue.[18]

Lastly, reading involves horizontal saccade eye movements, followed by fixations. To maintain stable and continuous vision, saccades are accompanied by a certain degree of visual suppression,[19] the depth of which depends on the actual amplitude of the saccade.[20] Thus, for small amplitude saccades, such as those involved in reading, visual suppression is effective in stabilizing vision. However, visual suppression in saccades with amplitude larger than 33° is less effective, often requiring a coupled eye blink, with its corresponding suppression, to maintain visual stability.[21] It may be hypothesized that reading larger text presented in a panoramic display may result in an increase of the percentage of large amplitude horizontal saccades which, in turn, may introduce changes in SEBR.

The aim of the present study was to explore SEBR and blink amplitude from video recordings of a sample of nondry eye subjects while they were reading the same text in six different reading configurations including three hard-copy (A4 text pasted on a desktop display; A4 text in normal lower gaze reading position in silent reading; A4 text in normal lower gaze reading position reading aloud) and three electronic (text at a 100% zoom level presented on a panoramic desktop display [PC100]; text at a 330% zoom level presented on a panoramic desktop display [PC330]; text displayed on a tablet in normal lower gaze reading position and in silent reading) formats. Results were compared with those obtained while subjects were observing in silence a landscape picture on the median plane at 2 m. In addition, given the documented—albeit still controversial—influence of age and sex on SEBR, which some authors have associated with the higher prevalence of dry eye in the elderly population and in females,[22–26] the relationship between these predictor variables and blink parameters was investigated.

Methods

Participants

Fifty participants (29 females) with ages ranging from 18 to 74 years (mean ± SD of 34.1 ± 16.4 years) were recruited for this study. All participants were in good general and ocular health, had no known neurologic disorders or took any medications that could affect blinking and were neither diagnosed nor reported any symptoms of dry eye (Ocular Surface Disease Index [OSDI] score < 15).[27] All participants had binocular corrected distance and near visual acuity ≥ 1 (decimal). Exclusion criteria were binocular vision imbalance of more than 4 prism diopters of esophoria or 10 prism diopters of exophoria at near (Von Graefe technique, with a 6Δ base-up dissociating prism in front of the right eye and a 12Δ base-in measuring prism in front of the left eye), near point of convergence cutoff of 5 cm for break and 7 cm for recovery with accommodative target, presence of any heterotropia, decreased accommodation amplitude, defined as >2.00 diopters (D) below the lowest expected amplitude based on the Hofstetter's formula of $15 - 1/4$ age (push-up technique),[28] amblyopia, oculomotor abnormalities, and self-reported dyslexia or other forms of reading disability.

All participants provided written informed consent after the nature of the study was explained to them, although they were not explicitly informed that blinking would be monitored until after completion of the reading sessions to avoid possible contamination of the results.[29] The study was conducted in accordance with the tenets of the Declaration of Helsinki of 1975 (as revised in Tokyo in 2004) and received the approval of an Institutional Review Board (Universitat Politècnica de Catalunya).

Baseline and Reading Conditions

Seven different experimental configurations were tested (baseline and six reading conditions). Table 1 presents a summary of the main characteristics of each experimental setting. During baseline (3 minutes), subjects were instructed to observe in silence a high-contrast landscape picture pasted on the wall at 2 m and eye level. All the other experimental settings (6 minutes) required subjects to read a text in various conditions, either in hard-copy or electronic format, in silence or aloud.

A collection of short easy reading stories by a famous Catalan author (Quim Monzó) was used as reading material and all texts were presented in the same typeface (Arial), font size (9), line spacing (1.15), and approximate number of words per page. The same reading stories were presented either in Catalan or Spanish according to the mother tongue of the participants. Electronic reading took place on a panoramic 24-inch, 16:9 liquid crystal display (TFT-LCD) set to a resolution of 1920×1080 pixels, 32-bit color configuration, contrast ratio 700:1, and 75 Hz refresh rate, or on a 9.7-inch, 4:3 display tablet (Energy i10 Quad SuperHD, Energy Sistem Soyntec S.A., Alicante, Spain) at a resolution of 2048×1536 pixels. The same display was employed to present the text at 330% magnification. This magnification value was set by adjusting the zoom level slider of the word processor software until the lines of the text fitted completely the whole width of the display. It must be noted that whereas hard-copy A4 size (297×210 mm) is very similar to the electronic page size when

TABLE 1. Summary of the Experimental Configurations for Baseline and Reading Conditions

Experimental Configuration	Description	Time, min	Observation distance, cm	Luminance, cd/m²
Baseline	Observing in silence a landscape picture pasted on the wall at 2 m and at eye level	3	200	130
Tablet	Reading in silence a text presented on a tablet placed on a bookrest (45° reading angle)	6	40	120
PC100	Reading in silence a text presented on a display at 100% magnification	6	60	210
PC330	Reading in silence a text presented on panoramic display at 330% magnification	6	60	210
Text (pasted over display)	Reading in silence an A4 text pasted over a switched off display	6	60	140
Text (book position)	Reading in silence an A4 text placed on a bookrest (45° reading angle)	6	40	150
Text aloud (book position)	Reading aloud an A4 text placed on a bookrest (45° reading angle)	6	40	150

displayed at 100% scale (PC100), the actual screen size of the tablet is slightly smaller (239 × 179 mm).

The level of luminance emitted by each display (computer and tablet) was measured with a light meter (Gossen Mavolux 5032; Gossen Foto- und Lichtmesstechnik GmbH, Nürnberg, Germany) with the luminance attachment and adjusted to allow comparison among themselves and with the hard-copy text format (Table 1). Small differences in luminance were allowed to guarantee correct visualization of the text.

Room temperature and humidity were maintained at 20°C (±2°C) and 40% (±10%), respectively, by adjusting and as displayed in the air conditioning settings. Background illumination was between 750 and 800 lx, and provided by diffuse lighting to avoid unwanted screen reflections.

Procedure

Following a complete visual and ocular examination according to the inclusion and exclusion criteria, each participant completed the sequence of experimental conditions in a different random order to account for the potential effect of fatigue on the results. Block randomization was employed to assign a different order of experimental conditions to each participant. Baseline and reading sessions took place in the same day between 10 AM and 2 PM and all measurements were completed in approximately 40 minutes.

Subjects were instructed to scroll down using the middle wheel of a mouse or to flip pages by lightly tapping the edge of the screen (tablet) or by physically turning the page (hard-copy text). Subjects marked the last word they were able to read in each session and continued reading from the same word in the following session. Subjects were allowed time to familiarize themselves with the corresponding reading device before each reading session. All participants were instructed, if necessary, to use their spectacles instead of their contact lenses on the day of the study.

FIGURE 1. Screen capture of the video recordings obtained from the same participant in each of the seven experimental configurations. (**a**) Silent observation of a landscape picture at 2 m. (**b**) text (book position). (**c**) Tablet. (**d**) Text aloud (book position). (**e**) Text pasted over display. (**f**) PC330. (**g**) PC100.

Video Recording and Analysis

During baseline and reading sessions, video captures of the eyes of the participants were obtained with either an HD camera (Canon Legria HF M307; Canon España S.A., Alcobendas, Madrid, Spain), which supported 3.3-MP image capture at a resolution of 1920 × 1080 and frame rate of 60 frames per second (fps), or a webcam (LifeCam HD-3000; Microsoft, Pozuelo de Alarcón, Madrid, Spain), with a resolution of 1280 × 720 and frame rate of 30 fps. Cameras were placed next to the hard-copy text and tablet and tilted upwards or affixed to the top of the computer screen to ensure that in all conditions the eye movements of the participants could be recorded in good quality while not intruding with the task at hand (Fig. 1). All video captures were saved onto an external hard drive for subsequent analysis.

A real-time analysis of the video captures was conducted by two external independent examiners, unaware of the reading conditions associated to each video, although complete masking was not possible as line of gaze and convergence were markers of observation distance. Complete blinks were counted when none of the cornea was visible on blink

FIGURE 2. Screen capture of the video recordings obtained from the same participant at the moment of a complete (**a1**, **a2**) and an incomplete blink (**b1**, **b2**). (**a1**, **b1**) Text (book position). (**a2**, **b2**) PC330.

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TABLE 2. Spontaneous Eye Blink Rate and Percentage of Incomplete Blinks for Each Experimental Condition

Experimental Configuration	SEBR, blinks/min, Median (interquartile)	Incomplete Blinks, %, Median (interquartile)
Baseline	15.5 (16)	14.5 (29.5)
Tablet	6 (11)	14.5 (28.5)
PC100	6.5 (11)	9 (20)
PC330	11.5 (11)	13.5 (25.8)
Text, pasted over display	7 (12)	0 (16.3)
Text, book position	5 (10)	5 (22.8)
Text aloud, book position	4 (9)	0 (14.5)
Friedman test	$\chi^2 = 75.71$ ($P < 0.001$)	$\chi^2 = 28.46$ ($P < 0.001$)

Results are presented as median and interquartile range. The outcome of the Friedman analysis of statistical significance is shown as χ^2 and P.

completion (Fig. 2).[17] Otherwise, blinks were counted as incomplete. Minor twitches or lid tremors were ignored.

An ad hoc blink counting application (freely available in the public domain at http://www.blinkcounter.oo.upc.edu) was developed to facilitate video analysis. A horizontal grating with 60 small squares denoted 1 minute of video recording. Each square corresponded to 1 second and the software allowed marking more than one blink per square if necessary. The occurrence of complete or incomplete blinks was marked by pressing the corresponding predefined keyboard keys—that is, examiners revised each 1-minute segment of video recording in real time while this software was running in the background. Once a minute of video recording was reviewed, the application provided data on the total number of blinks and on the percentage of incomplete blinks.

For analysis purposes, the first minutes of all video captures were discarded, that is, baseline was assessed from the start of minute 2 to the end of minute 3 and reading sessions from the start of minute 2 to the end of minute 6.[30] Videos were examined independently by each examiner and only in case of discrepancies with their individual results were they subjected to further joint frame-by-frame analysis to inspect particular blinking events. Both examiners attended a training session before the start of the analysis to define criteria regarding blink amplitude and to familiarize themselves with the video assessment procedure.

Data Analysis

Statistical analysis of the data was performed with statistical software (SPSS software 19.0 for Windows; IBM Corp., Armonk, NY, USA). All data were examined for normality with

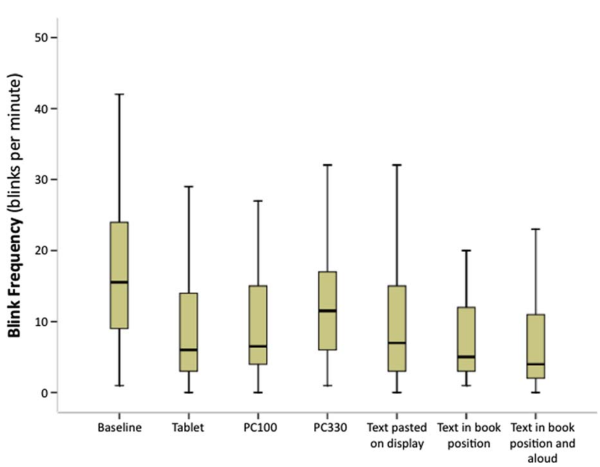

FIGURE 3. Box plot diagram of SEBR (in blinks per minute) for each experimental condition.

the Kolmogorov-Smirnov test, which as previously reported on blink parameters,[9] uncovered several instances of nonnormal distribution. Accordingly, descriptive statistics of the study variables are presented in terms of median and interquartile range values. The Friedman test was used to investigate the statistical significance of the differences in SEBR and in percentage of incomplete blinks between the experimental conditions and the Wilcoxon test for paired samples was employed for pair-wise analysis. In addition, the Mann-Whitney test was used to assess the differences in the study variables between males and females and the Spearman rho correlation test to explore the influence of age on blink parameters. In all cases, the significance level was established at 95% ($P < 0.05$). Given the exploratory nature of the present research, no Bonferroni correction was applied to control family-wise type I error to avoid missing a possible effect worthy of further investigation.[31] (Please note that with seven experimental conditions and 21 multiple comparisons, the cutoff for statistical significance would correspond to an adjusted P value < 0.002).

RESULTS

Table 2 displays a summary of the results of SEBR and percentage of incomplete blinks for each of the experimental conditions. When submitted to a group Friedman analysis, statistically significant differences were found in both blink parameters among the seven conditions (also shown in Table 2). Therefore, a post hoc pairwise analysis was conducted with the Wilcoxon test for paired samples to determine the origin of these differences.

Regarding SEBR, all reading conditions were found to lead to a reduction of blinking frequency, when compared with the baseline measurement (all $P < 0.001$; Fig. 3). Statistically significant differences were also found between reading aloud and the other reading in silence conditions (all $P < 0.05$), with participants experimenting a further reduction in SEBR when reading aloud. In addition, reading in an expanded display at 330% was found to increase SEBR, when compared with all the other reading conditions (both text and electronic formats; all $P < 0.05$). Other interesting statistically significant differences in SEBR were encountered between the following pairs of conditions: hard-copy text in book position and tablet ($Z = -2.077$; $P = 0.038$) and hard-copy text in book position and hard-copy text pasted on a computer display ($Z = -2.304$; $P = 0.021$).

The same analysis for the percentage of incomplete blinks revealed several statistically significant differences between hard-copy text and electronic text, with electronic reading leading to an increase in the percentage of incomplete blinks (Fig. 4). These findings were particularly relevant when comparing reading in an expanded display at 330% with hard-copy text in book position ($Z = -3.082$; $P = 0.002$), hard-

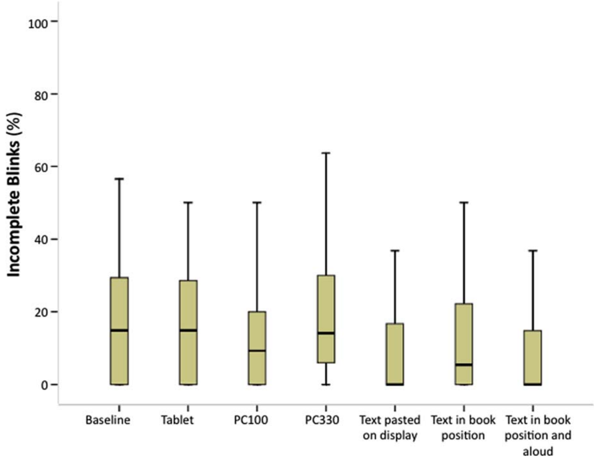

FIGURE 4. Box plot diagram of percentage of incomplete blinks for each experimental condition.

copy text pasted on a computer display ($Z = -3.783$; $P < 0.001$) and reading aloud a hard-copy text in book position ($Z = -2.988$; $P = 0.003$). In addition, reading in an expanded display was also found to lead to a larger percentage of incomplete blinks than reading in a 100% display ($Z = -2.040$; $P = 0.041$).

A weak, statistically significant positive correlation was revealed between age and SEBR ($\rho = 0.310$; $P = 0.021$) in baseline conditions. Age and OSDI scores were not correlated ($\rho = 0.079$; $P = 0.585$). The Mann-Whitney test for unrelated samples disclosed statistically significant differences in SEBR between males and females in almost all experimental conditions (Table 3). Interestingly, although none of the participants had an OSDI score over 15 (cutoff for dry eye used as an exclusion criterion), mean OSDI score for males and females was 8.3 and 12.7, respectively. However, this difference was not statistically significant.

Discussion

The aim of the present study was to assess several blink-related parameters while participants read texts in hard-copy and electronic format under controlled conditions, compared with a baseline situation of silent observation of a target at 2 m. Previous efforts have been directed at investigating differences in SEBR and percentage of incomplete eye blinks between texts presented in hard-copy format and on various types of displays,[4,8,9,13–18] although, to the best of our knowledge, these studies were in general limited to a single device.

Spontaneous blink rate in baseline conditions (median of 15.5 blinks per minute; interquartile range of 16 blinks per minute) was similar or slightly higher than the results reported in previous studies. For example, Doughty[32] calculated an average of 14.5 ± 3.3 blinks per minute in primary gaze, based on the findings of 22 previous studies. It must be noted that, in contrast with other authors, our criteria did not exclude participants with SEBR higher than 21 blinks per minute in baseline conditions, previously labeled as "frequent blinkers."[33,34] This might have resulted in a higher median SEBR and in a larger intersubject variability than previously described, as well as in an increased probability of type II error. In addition, measurements in baseline conditions were restricted to 2 minutes, instead of the recommended 5 minutes,[9] as it was observed that some of the participants failed to remain interested in the fixation target after 3 minutes. This may be acknowledged as a limitation of the present research.

TABLE 3. Spontaneous Eye Blink Rate in Males and Females

Experimental Configuration	SEBR, blinks/min, Median (interquartile) Male	SEBR, blinks/min, Median (interquartile) Female	Z	P
Baseline	9 (12)	20 (16)	−2.932	0.003
Tablet	4 (6)	8 (14)	−1.498	0.134
PC100	5 (8)	10 (13)	−2.377	0.017
PC330	7 (8)	16 (13)	−2.392	0.017
Text (pasted over display)	3 (5)	10 (15)	−3.446	0.001
Text (book position)	4 (3)	8 (14)	−2.343	0.019
Text aloud (book position)	2 (7)	6 (10)	−1.979	0.048

Results are presented as median and interquartile range. The outcome of the Mann-Whitney analysis of statistical significance is shown as Z and P.

In agreement with other studies, all reading conditions, both in hard-copy and electronic format, led to a similar reduction in SEBR when compared with baseline conditions.[17,35] These findings may be explained by the attentional and cognitive demands associated with the reading task, which have been found to influence the central "pacemaker" mechanism governing SEBR. Tablet and computer at 100% zoom level resulted in a similar compromise in SEBR, with median values of 6 and 6.5 blinks per minute, respectively. Interestingly, however, this reduction was not as manifest when participants read text presented on an expanded display at 330%. The inclusion of an experimental condition requiring participants to read text in expanded format aimed at testing the hypothesis that SEBR would improve in a situation involving an increase in the percentage of large amplitude saccades (larger than 33°), many of which have been found to be associated with blinks (to reinforce visual suppression).[21] Nevertheless, it may be noted that, as far as we know, the association of blinking and large amplitude saccades has not been previously documented in the context of large format reading material or platforms.

Previous researchers have reported that the ocular discomfort experienced by computer users may be associated with an increase in the percentage of incomplete blinks, rather than with an actual reduction in SEBR.[17,18] Therefore, the advantage offered by the expanded display in terms of SEBR may not result in an actual reduction in ocular discomfort, particularly when considering the percentage of incomplete blinks observed with this reading condition. In effect, in contrast with hard-copy reading, reading in electronic format led to an increase in the percentage of incomplete blinks. In addition, this difference was particularly significant when comparing the expanded 330% display (13.5% of incomplete blinks) and the tablet (14.5% of incomplete blinks) with all hard-copy texts (from 0 to 5% of incomplete blinks), as well as with electronic reading at 100% (9% of incomplete blinks). These findings are in agreement with a recent investigation,[17] although the difference in incomplete blinks between electronic and hard-copy texts has not been explored in detail in the literature. Nevertheless, it may be argued that the contribution of incomplete blinking may be critical to explain the dry eye symptoms reported by VDT users and not by readers in traditional formats,[8,18,36] although it may be noted that one of our participants exhibited 100% incomplete blinks in both tablet and reading aloud conditions. The specific influence of VDT on incomplete blinks remains unexplained and may not only be attributed to differences in the actual position of the reading source. Indeed, incomplete blinks were found when participants read on a VDT display at 100%, but were less

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frequent when the same participants read a hard-copy text pasted on the switched off display under approximately the same, previously defined conditions (illumination, luminance, distance, font type and size, etc.).

Regarding age, OSDI scores and SEBR our findings were inconsistent. Thus, although a weak statistically significant correlation was found between SEBR and age ($\rho = 0.310$; $P = 0.021$), with elder participants presenting larger SEBR scores, there was a lack of correlation between OSDI scores and age ($\rho = 0.079$; $P = 0.585$). The influence of age in SEBR has been described in the literature,[22,23] and has been attributed to the associated increase in dry eye in the elderly population. The age distribution of the present study sample was skewed toward younger participants without dry eye symptoms (OSDI < 15). Therefore, even though it may be speculated that with a wider age range, a stronger correlation between SEBR and age might have been found, further research is needed to clarify this issue.

On the other hand, females were found to blink more frequently than men in all but one of the experimental conditions, and to report larger OSDI scores (median values of 12.7 for females and 8.3 for males, although $P > 0.05$). Controversial evidence exists in the literature about blink parameter differences between males and females,[24–26] with some authors describing a possible link between SEBR sex differences and hormone-related factors such as use of estro-progestinics or phase of the ovarian cycle, both of which may affect blinking on the one hand and tear production on the other. The present findings give support to the existence of sex differences, although further research with two groups of OSDI-matched males and females is required to investigate whether these differences have an ocular surface or central origin.

It must be noted that we based our estimation of the required sample size on the meta-analysis conducted by Doughty,[9] in which reading resulted in a SEBR of 7.9 ± 3.3 blinks per minute. With an α level of 0.05 and an 80% power to detect a difference between reading conditions of at least one standard deviation, a sample size of 16 was deemed necessary. In addition, recent work by Chu et al.[17] on blink amplitude in computer screen versus hard copy disclosed a change in the percentage of incomplete blinks from 7.02% (SD: 7.96%) to 4.33% (SD: 6.27%), respectively. The required sample size to replicate these findings (i.e., to detect changes in the percentage of incomplete blinks between different electronic and hard copy conditions) was found to be 80. Therefore, it may not be ruled out that, regarding blink amplitude, the present statistical analysis based on a sample of 50 participants was underpowered to detect differences.

In conclusion, the present findings—in which significant differences were disclosed in several blink parameters among electronic and hard-copy reading conditions—highlight the need to explore the percentage of incomplete blinks in addition to the commonly assessed SEBR. In effect, statistically significant differences were found between hard-copy and electronic reading in the percentage of incomplete blinks, a finding that warrants further research in this direction. In a constantly changing society in which handheld devices are not only ubiquitous but usually accessed under less than optimal viewing conditions (distance, font size, luminance), the evaluation of blink parameters in real-life situations and across platforms may be particularly relevant to assist in the design of strategies aimed at improving the ocular comfort and health of VDT users.

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