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Effect of virtual reality headset wear on the tear film: A randomised crossover study

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ABSTRACT

Purpose: To compare the effects of virtual reality headset wear and conventional desktop computer display use on ocular surface and tear film parameters.

Methods: Twenty computer operators were enrolled in a prospective, investigator-masked, randomised crossover study. On separate days, participants were randomised to 40 min of continuous virtual reality headset wear or conventional desktop computer display use. Outer eyelid and corneal temperatures, tear film lipid layer grade, and non-invasive tear film breakup time were measured at baseline and immediately following the 40-minute exposure period.

Results: Virtual reality headset wear resulted in increases in outer eyelid (mean difference +0.5 ± 0.6 °C; $p < 0.001$) and corneal temperatures (mean difference, +0.4 ± 0.6 °C; $p = 0.004$), relative to conventional desktop computer display use. These increases were associated with significant improvements in tear film lipid layer grade (median difference, +1 grade; interquartile range, 0 to +2 grades; $p < 0.001$) and non-invasive tear film breakup time (mean difference, +7.2 ± 12.4 s; $p = 0.02$).

Conclusions: Clinically significant improvements in lipid layer thickness and tear film stability were observed with virtual reality headset wear, despite producing only modest increases in ocular temperatures relative to conventional desktop computer display use. These findings would suggest that virtual reality headset wear demonstrates potential for dry eye relief for computer operators in the modern workplace environment.

1. Introduction

The modern workplace can be a hostile environment, especially for a dry eye sufferer [1–3]. Provoked by increasing amounts of computer use, headache and dry eye are among the two most commonly experienced symptoms in the modern office environment [4]. Computer screens are becoming an increasingly necessary part of many jobs, and extended periods of computer use for more than four hours are associated with an increase in the prevalence of dry eye symptoms [5,6], as well as a range of other ocular asthenopia features, including difficulty maintaining visual focus and fatigue [7]. Although the underlying mechanisms are not yet fully understood [8], blinking frequency can decrease by more than 50% with computer use [9], preventing restoration of the protective tear film lipid layer [10], with a resultant increase in aqueous tear evaporation [11].

Air-conditioned and centrally-heated offices tend to have lower relative humidity and elevated airflow velocity [12], and workers in these environments are more than twice as likely to experience dry eye symptoms [13]. The increasing mean age of the workforce [14], coupled with the recognised positive association between ageing and dry eye severity [15], would suggest that the prevalence of dry eye symptoms in the workplace environment is likely to continue to grow [16].

Dry eye disease has a measurable impact on workplace productivity which affects the economy [17]. In the United States, it is estimated that approximately US$783 per patient is spent on managing the condition each year, and when productivity loss and other associated costs are considered, the total expenditure is estimated to be $11,302 per patient [18]. On a more humanitarian level, dry eye symptoms are associated with poorer levels of emotional well-being and quality of life [19,20], and have negative impacts on the ability to perform tasks of daily living, such as driving, reading, or watching television [21]. Employee wellness is increasingly recognised as a fundamental concept of the modern workplace [22], yet dry eye disease and its impact on employees seems often to be overlooked.

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Many interventions have been developed for the management of dry eye disease [23], however, few of these target workplace factors which might exacerbate the signs and symptoms of dry eye. Artificial tear supplementation remains the mainstay of treatment for aqueous deficient dry eye disease [23], although it is often applied as a means of achieving symptomatic relief [24], addressing the downstream consequence of the pathophysiological cascade of dry eye disease [25], rather than its source, and thus limiting potential therapeutic efficacy [26]. For evaporative dry eye disease secondary to meibomian gland dysfunction [27], treatment options including warm compress application [28], eyelid hygiene regimens [29], physical meibum expression techniques [30], topical lipid supplementation [31,32], intense pulsed light therapy [33], and thermal pulsation technology [34] have been shown to improve tear film stability. While patient-applied therapies remain more widely adopted than more costly in-office treatments, they require regular application, sometimes frequently, thus risking disruption to workplace activities, and often failing to mitigate the ongoing exposure to provocative stimuli in the modern office environment.

Moisture goggles have been reported to alleviate dry eye symptoms by creating a warm and humid periocular microenvironment, and reducing airflow across the ocular surface [35]. However, the use of virtual reality headsets as a means of providing dry eye relief of computer operators in the modern workplace environment has not previously been investigated. Virtual reality headsets may potentially effect a similar therapeutic benefit to heated moisture goggles [36], through producing a warm periocular micro-environment from continuous heat production. The virtual platform might also offer additional benefits, allowing the workplace to be teleported to more relaxing settings, such as the beach or home environment. Furthermore, the screens within the headsets are optically focussed at distance, providing a comfortable viewing environment without the need for reading glasses. The purpose of this randomised crossover study was therefore to compare the effects of virtual reality headset wear and conventional desktop computer display use on ocular surface and tear film parameters.

2. Methods

2.1. Subjects

This prospective, investigator-masked, randomised crossover study followed the tenets of the Declaration of Helsinki, and was approved by the institutional human participants ethics committee. Participants were required to be 18 years of age or older, with no major ophthalmic or systemic diseases (other than dry eye disease, anterior blepharitis, or meibomian gland dysfunction), no previous ophthalmic surgery, no contact lens wear, and no use of topical or systemic medications known to affect the eye. Eligible participants were enrolled after providing written informed consent, and were required to attend two visits on separate days within a two-week period.

A total of 20 eligible participants were recruited, exceeding sample size requirements for the desired study power calculated using NCSS PASS 2002. Non-parametric adjusted power calculations were conducted with tear film lipid layer grade as the designated outcome, and showed that a minimum of 16 participants was required to detect a clinically significant difference of a change in one lipid layer grade, with 80% power ($\beta = 0.2$), at a two-sided statistical significance level of 5% ($\alpha = 0.05$), with the SD of normal values estimated to be at one lipid layer grade [37].

2.2. Interventions

During the two visits, participants were required to engage in 40 min of continuous computer use in the same air-conditioned clinic room, with a mean ± SD room temperature of 21.8 ± 0.7 °C, and a mean ± SD relative humidity of 62.3 ± 3.1%. One visit was randomised to virtual reality headset wear (Oculus Rift DK2, Facebook, USA), and the other visit to conventional desktop computer display use. Cognitive loading was controlled with similar word processing tasks being conducted during the two visits. Randomisation was pre-determined by computer-generated random number allocation prior to participant recruitment, and applied to sequentially enrolled participants, such that the investigator involved in baseline participant assessment had no involvement in the order of device allocation.

2.3. Measurements

Temperature and relative humidity measurements of the periocular microenvironment within the virtual reality headset, and the local environment with conventional desktop computer display use, were conducted at 5-minute intervals during the 40-minute exposure period. A rapid-response thermohygrometer with external probe (Q2Q31, Throughpp, China) was used to conduct temperature and relative humidity measurements locally. The manufacturer claimed precision estimate and resolution of the temperature sensor was ± 1 °C and 0.1 °C, respectively; and the precision estimate and resolution of the relative humidity sensor was ± 5% and 1%, respectively.

Study investigators conducting clinical measurements were masked to the pre-determined treatment randomisation schedule and had no involvement in device allocation during each session. Tear film parameters, ocular temperatures, and bulbar conjunctival hyperaemia assessments were conducted before and immediately after the 40-minute period of computer use at each visit. Clinical tests were performed in ascending order of invasiveness, in order to minimise the impact on tear film physiology for subsequent tests [38].

Infrared thermography (Thermo TVS-200EX, Avio, Japan) was used to assess outer eyelid and corneal temperatures, which were measured at the geometric centre of the cornea. Ocular temperatures were measured with the eyelids closed and then immediately on eye opening, in order to avoid potential differential evaporative effects that exist on the tarsal surface in meibomian gland dysfunction patients after eyelid eversion [39]. Corneal temperature is a surrogate measurement for meibomian gland temperature, due to the close proximity of the adjacent tissues in the closed eye state [40].

Tear meniscus height, non-invasive tear film breakup time, tear film lipid layer grade, and conjunctival hyperaemia assessments were then performed using the Oculus Keratograph 5 M (OCULUS Optikgeräte GmbH, Wetzlar, Germany). The lower tear meniscus height was assessed using high magnification pre-calibrated digital imaging, and three measurements near the centre of the lower meniscus were averaged. Non-invasive tear film breakup time was measured after 2 blinks using automated detection of first break-up, while the subject maintained fixation and was requested to refrain from blinking. Three breakup time readings were averaged in each case [38,41]. Tear film lipid layer thickness was graded according to the modified Guillon-Keeler system: grade 1, open meshwork; grade 2, closed meshwork; grade 3, wave or flow; grade 4, amorphous; grade 5, coloured fringes; and grade 0, non-continuous layer (non-visible or abnormal coloured fringes) [42,43]. Standardised JENVIS bulbar conjunctival hyperaemia area and severity scores were quantified using automated objective evaluation of digital imaging.

Ocular surface staining and infrared meibography were performed at the conclusion of the second visit, due to the invasive nature of these clinical tests. Sodium fluorescein and lissamine green dyes were applied, in turn, to the bulbar conjunctiva in order to evaluate localised areas of epithelial desiccation in the cornea and conjunctiva. Staining was recorded using the modified Oxford grading scheme [44], and lid wiper epitheliopathy was evaluated relative to the Korb grading scheme following lissamine green application [45,46]. Infrared meibography was performed with the Oculus Keratograph 5 M, with the superior and inferior eyelids everted and imaged in turn. From the captured image, the proportion of meibomian glands visible within the tarsal area was

graded according to the five-point Meiboscale [47].

2.4. Statistics

Statistical analysis was performed using Graphpad Prism version 6.02 (California, United States) and MathWorks MATLAB version 9.0 (Massachusetts, United States). The significance of overall device, time, and device-by-time interaction effects on local temperature and relative humidity measurements were assessed using repeated measures two-way analysis of variance (ANOVA). Post-hoc multiplicity-adjusted Sidak testing was conducted to examine the significance of device effects at each time point, and statistical correlation between local temperature and relative humidity measurements was tested using Pearson's product-moment correlation coefficient. Local temperature and relative humidity profiles were visualised using scatter plots, and changes in temperature and humidity were modelled with one-term exponential functions, which provided good fits (all adjusted $r^2 > .74$). Inter-group comparisons of the change in ocular surface and tear film parameters were conducted using the paired t-test, where normal distribution had been confirmed by Kolmogorov-Smirnov testing ($p > 0.05$). Non-normally distributed continuous measures and ordinal data were analysed using the Wilcoxon signed-rank test. All tests were two-tailed and $p < 0.05$ was considered significant. All continuous data are presented as mean ± SD, and ordinal data as median (IQR), unless otherwise stated.

3. Results

The median age of the 20 participants (14 females, 6 males) was 21 years, with an interquartile range of 20–24 years. Baseline ocular surface characteristics are presented in Table 1.

The temperature and relative humidity profiles of the periocular microenvironment within the virtual reality headset, and the local environment with conventional desktop computer display use during the 40-minute exposure period, are illustrated in Fig. 1. Repeated measures two-way analysis of variance detected significant device, time, and device-by-time interaction effects for local temperature and relative humidity profiles (all $p < 0.001$). Post-hoc multiplicity-adjusted Sidak's testing showed that local temperatures were higher with virtual reality headset wear at all time points during the exposure period (all $p < 0.001$). Local relative humidities were greater with conventional desktop computer display use at all time points (all $p < 0.001$), with the exception of measurements conducted at 5 min ($p = 0.15$). Overall, a significant negative correlation was observed between local temperature and relative humidity measurements (Pearson's correlation coefficient = -0.694, $p < 0.001$).

Changes in ocular surface and tear film parameters during the 40-minute exposure period are summarised in Table 2 and Fig. 2. Overall, virtual reality headset wear resulted in increases in outer eyelid (mean difference +0.5 ± 0.6 °C; $p < 0.001$) and corneal temperatures (mean difference, +0.4 ± 0.6 °C; $p = 0.004$), relative to conventional desktop computer display use. This was associated with relative improvements in tear film lipid layer grade (median difference, +1 grade; interquartile range, 0 to +2 grades; $p < 0.001$) and non-invasive tear film breakup time (mean difference, +7.2 ± 12.4 s; $p = 0.02$). No significant differences in tear meniscus height, bulbar conjunctival hyperaemia area or severity were detected between the two exposures (all $p > 0.05$).

4. Discussion

The findings of the current study demonstrate that short-term virtual reality headset wear was associated with clinically significant improvements in lipid layer thickness and tear film stability relative to conventional desktop computer display use. The median difference in lipid layer grading change between virtual reality headset wear and conventional desktop computer display use was +1 grade, while the mean difference in non-invasive tear film breakup time change was +7.2 s. A number of factors might have contributed to the poorer lipid layer grading and non-invasive tear film breakup time observed following 40 min of conventional desktop computer display use in the air-conditioned clinic room. The lower relative humidity and greater airflow velocity of the air-conditioned office environment can widen the water vapour presssure gradients between the ocular surface and the external environment, thereby facilitating increased aqueous tear evaporation and reducing tear film stability [1–3,31,48]. In addition, the suppression of blinking frequency by the high visual and cognitive load during computer operation might further exacerbate the pre-existing tendency towards poorer tear film quality [48,49], through diminishing the delivery of meibum and compromising the distribution of tear film constituents over the ocular surface [50,51]. It is acknowledged that the adverse effects on blinking frequency associated with sustained visual concentration are not eliminated with virtual reality headset wear [49]. However, the headset does create a physical barrier, which might provide some degree of shielding from the higher airflow velocity of the air-conditioned office environment and its destabilising effects on the tear film [31,35].

Furthermore, the results would also suggest that virtual reality headset wear produces a warmer periocular microenvironment, which was demonstrated by the significant device effect detected on repeated measures two-way analysis of variance of the local temperature profile curves. A mean temperature difference of +9.9 °C was observed between the two exposures at the end of the 40-minute period, although only modest relative increases in outer eyelid and corneal temperatures,

Table 1
Ocular surface and tear film parameters of participants at baseline. Data are presented as mean ± SD or median (IQR).

Parameter	Virtual reality headset (n = 20)	Conventional desktop computer (n = 20)
Tear film quality		
Tear meniscus height (mm)	0.25 ± 0.06	0.25 ± 0.07
Tear film lipid layer grade (out of 5)	2 (2-2)	2 (2-2)
Non-invasive tear film breakup time (s)	14.2 ± 8.8	22.3 ± 13.1
Ocular surface characteristics		
Outer eyelid temperature (°C)	36.7 ± 0.3	36.8 ± 0.2
Corneal temperature (°C)	36.7 ± 0.2	36.8 ± 0.2
Bulbar conjunctival hyperaemia area (mm^2)	11.9 ± 5.2	12.5 ± 4.9
Bulbar conjunctival hyperaemia severity score (out of 4)	0.7 ± 0.3	0.7 ± 0.3
Sodium fluorescein staining score (out of 55)	0 (0-0)	
Lissamine green staining score (out of 55)	0 (0-1)	
Superior lid wiper epitheliopathy grade (out of 3)	0 (0-1)	
Inferior lid wiper epitheliopathy grade (out of 3)	1 (0-1)	
Superior lid meibography grade (out of 4)	0 (0-2)	
Inferior lid meibography grade (out of 4)	0 (0-1)	

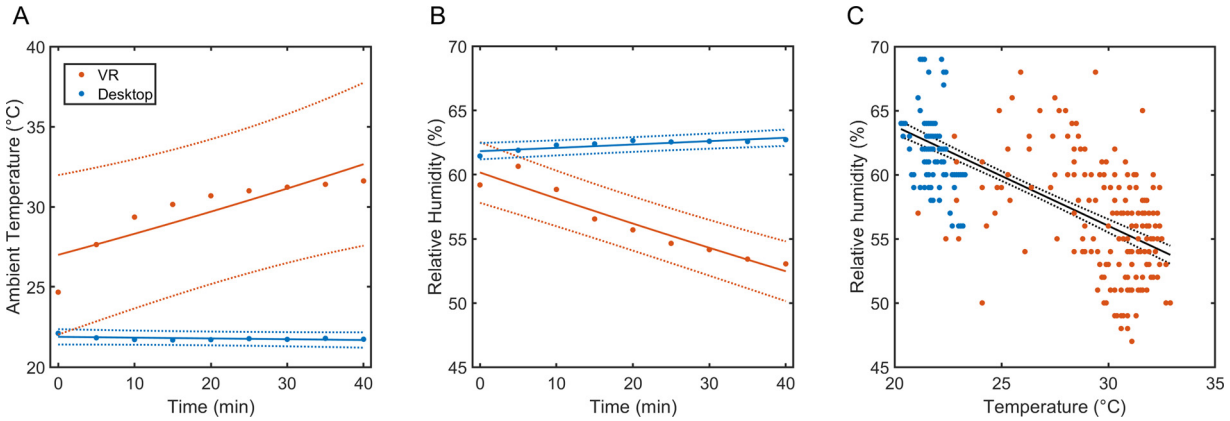

Fig. 1. Temperature and relative humidity profiles of the periocular microenvironment within the virtual reality headset, and the local environment with conventional desktop computer display use during the 40-minute exposure period. Each point represents the mean measurement obtained with virtual reality headset wear (red) or conventional desktop computer display use (blue) at an individual time point. Solid lines represent regression analysis, and dotted lines represent the 95% confidence interval for regression estimates. Graph A illustrates local temperature profiles during the exposure period, graph B illustrates relative humidity profiles during the exposure period, and graph C illustrates a scatter plot of local temperature and relative humidity measurements.

Table 2
Changes in ocular surface and tear film parameters following the 40-minute exposure period with virtual reality headset wear or conventional desktop computer display use. Data are presented as mean ± SD or median (IQR). Asterisks denote statistically significant values ($p < 0.05$).

Parameter	Virtual reality headset (n = 20)	Conventional desktop computer (n = 20)	p
Tear film quality			
Tear meniscus height (mm)	+0.06 ± 0.09	+0.06 ± 0.08	0.55
Tear film lipid layer grade (out of 5)	0 (-0.5 to 0)	+0.5 (0 to +2)	< 0.001*
Non-invasive tear film breakup time (s)	+3.8 ± 10.3	−3.4 ± 11.3	0.02*
Ocular surface characteristics			
Outer eyelid temperature (°C)	+0.5 ± 0.4	0.0 ± 0.3	0.004*
Corneal temperature (°C)	+0.5 ± 0.4	0.0 ± 0.2	< 0.001*
Bulbar conjunctival hyperaemia area (mm^2)	0.0 ± 3.9	−1.1 ± 3.1	0.16
Bulbar conjunctival hyperaemia severity score (out of 4)	0.0 ± 0.2	0.0 ± 0.2	0.37

in the order of 0.4 to 0.5 °C, were effected by virtual headset wear. The application of heat, through a number of eyelid warming devices, has previously been reported to demonstrate a therapeutic effect in patients with meibomian gland dysfunction and evaporative dry eye disease [23,28], through promoting the liquefaction of inspissated lipid secretions, and thereby alleviating blockage of the ductal system and encouraging the delivery of meibum into the tear film [23,52]. The subsequent enhancement in the integrity and quality of the lipid layer can improve tear film stability [52,53], by providing more effective inhibition of aqueous tear evaporation [10]. While it is acknowledged that the change in ocular temperatures following virtual reality headset wear is considerably more modest than those demonstrated by therapeutic eyelid warming devices [40], the potential for the warmer periocular microenvironment produced to contribute towards the improvements observed in tear film lipid layer thickness, in more mildly affected individuals, cannot be excluded. In addition, it is not known whether blinking patterns might differ with virtual reality headset wear than with conventional desktop computer display use, and if such differences might also be related to the differences in lipid layer quality between the two exposures, and this warrants exploration in future studies.

Interestingly, a significant device effect in the relative humidity profile curves was detected, representing a lower relative humidity in the periocular microenvironment within the virtual reality headset. These trends contrast with those previously reported for heated humidity goggles [36]. The discordant findings may be partially explained by the lack of a complete air-tight seal between the virtual reality headset and the periocular skin, which prevents the retention of moisture and allows for the diffusion of water vapour from the local periocular microenvironment within the headset to the external environment of the air-conditioned room. The warmer periocular microenvironment within the virtual reality headset can increase the water vapour carrying capacity of air, meaning that a greater water vapour content is required to maintain the same degree of relative humidity [54]. In this way, the increased local temperature, coupled with the absence of adequate moisture retention, might have resulted in the decrease in relative humidity observed in the periocular microenvironment within the virtual reality headset. Indeed, a significant negative correlation was observed between local environmental temperature and relative humidity in the current study. Although the reduction in local relative humidity and concurrent increase in temperature would be expected to increase the water vapour pressure gradient, and encourage aqueous evaporation and destabilisation of the tear film [1–3,31,48,55], these effects appear to have been offset by the enhanced lipid layer quality and shielding effects of the headset from the higher airflow velocity of the air-conditioned office environment, which would act to inhibit aqueous tear evaporation [10,35]. Indeed, over the 40-minute period, visual reality headset wear effected a signficant increase in non-invasive tear breakup time, relative to conventional desktop computer display use. Nevertheless, it is not known whether the water vapour evaporative driving forces might accumulate with extended periods of virtual reality headset wear and result in delayed effects on the tear film, and future studies with a longer exposure time would be required to investigate this hypothesis.

In addition to the positive effects on tear film quality, the virtual reality platform also offers additional benefits, including increased flexibility of the physical location of the workplace, which might contribute to stress relief and increased productivity of computer operators. The screens within the virtual reality headsets are also optically focussed at distance, providing a comfortable viewing environment

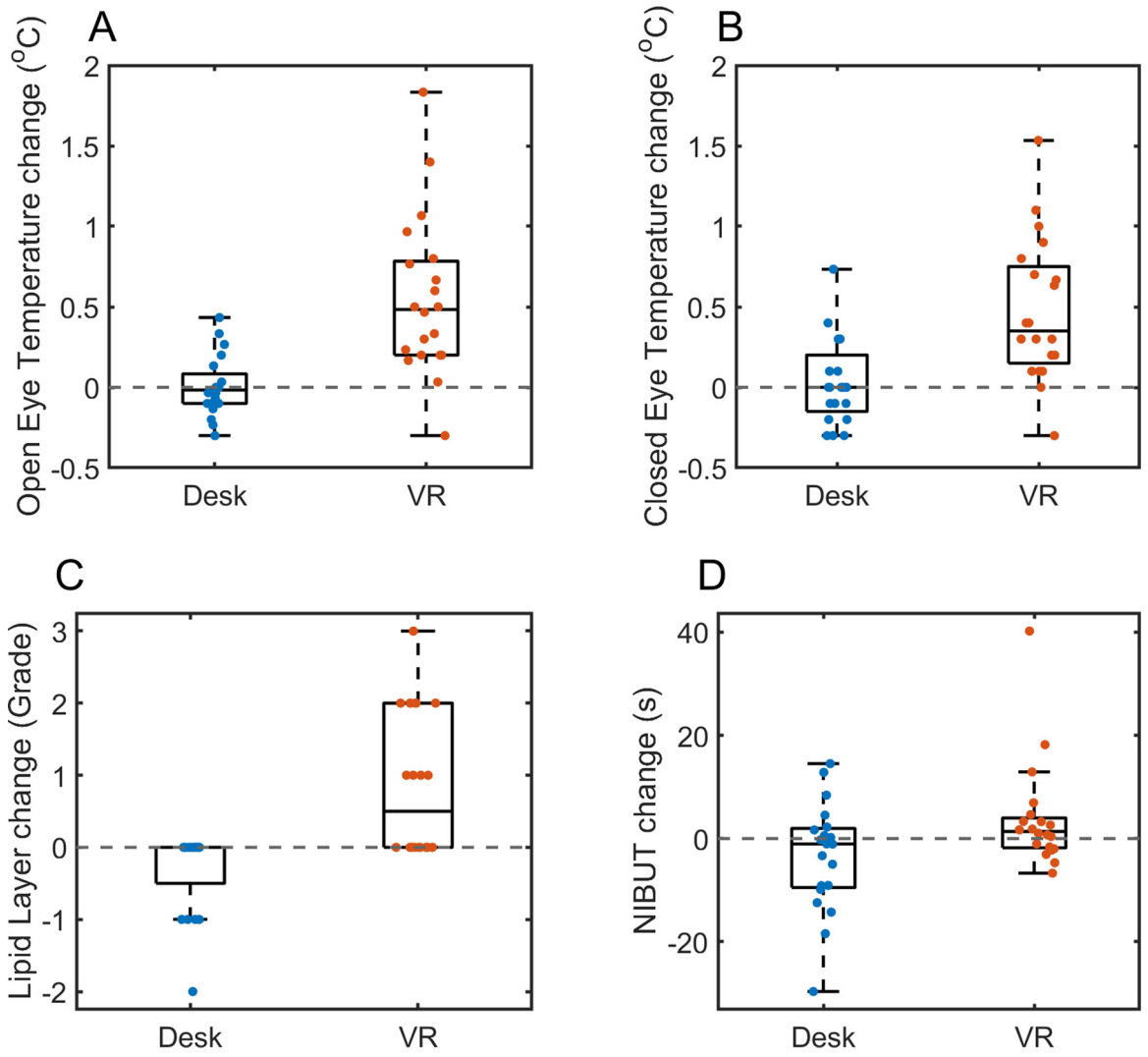

Fig. 2. Changes in ocular surface and tear film parameters following the 40-minute exposure period with virtual reality headset wear or conventional desktop computer display use. Each point represents the change in parameter in an individual participant following exposure to virtual reality headset wear (red) or conventional desktop computer display use (blue). Central bars represent the median change in parameter, boxes represent the interquartile range, and whiskers represent the range. Graph A illustrates the change in outer eyelid temperature, graph B illustrates the change in corneal temperature, graph C illustrates the change in tear film lipid layer grade, and graph D illustrates the change in non-invasive tear film breakup time.

without the need for reading glasses. Furthermore, an earlier randomised crossover study also reported that virtual reality headset wear did not appear to affect the binocular vision status or provide myopic-inducing stimuli, when compared to a real world equivalent task [56].

This study is not without limitations. The 40-minute randomised crossover design precludes the ability to draw conclusions on the long-term cumulative effects on the ocular surface, and the absence of participant-masking precluded the collection of subjective feedback that was free from risk of bias. The assessment of subjective symptomology and blinking patterns would be beneficial in future studies.

In conclusion, despite producing only modest increases in ocular temperatures relative to conventional desktop computer display use, short-term virtual reality headset wear was associated with clinically significant improvements in lipid layer thickness and tear film stability. The results of the current study would suggest that virtual reality headset wear shows promise as an environmental modification option for dry eye relief for computer operators in the modern workplace. However, future studies on patients with dry eye disease and meibomian gland dysfunction, over longer exposure periods, would be required to confirm the findings of this randomised crossover study.

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Declaration of Competing Interest

None.

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