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INVITED REVIEW

Ocular and visual discomfort associated with smartphones, tablets and computers: what we do and do not know

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Smartphone and tablet use in Australia and worldwide is reaching saturation levels and associated visual and ocular discomfort such as headaches, eyestrain, dry eyes and sore eyes are widespread. This review synthesises the available literature and considers these symptoms in the context of a binocular vision and/or ocular surface aetiology. Eye discomfort with smartphones and tablets is discussed alongside similar symptoms reported with desktop computer use. Handheld devices differ from computers in viewing position and distance, screen size and luminance, and patterns of use. Accommodation is altered with handheld device use, with increased lag and decreased amplitude. Smartphone and tablet use results in reduced fusional convergence and possibly a receded near point of convergence. This is similar to what happens with computer use. Findings related to blink rate with smartphone and tablet use are contradictory, perhaps due to the influence of task difficulty, and there is limited evidence related to blink amplitude. Reduced blink rate and amplitude are consistently reported with computer use. Use of handheld digital devices, like computers, may adversely impact tear stability. There is insufficient evidence to support the impact of handheld devices on tear volume, although this is reduced with computer use. The available literature does not conclusively link eye and visual discomfort symptoms reported with handheld digital devices, with changes in binocular vision, blinking or ocular surface. However, there is a gap in our understanding of symptoms which occur with smartphone and tablet use in the context of how these devices are used. In addition, studies are required in high users such as teenagers, and in patients with dry eye or accommodative/binocular vision anomalies, all of whom may have a higher risk of symptoms. A better understanding of symptom aetiology can guide clinical advice to minimise adverse impacts on visual and ocular surface health and discomfort.

Key words: aesthenopia, binocular vision, blinking, computer vision syndrome, digital device, dry eyes, eye strain, ocular surface, smartphone

The use of smartphones and electronic tablets has increased rapidly in Australia and worldwide during the past decade. In 2017, Australian ownership of smartphones was 88 per cent.[1] Usage of smartphones is reaching saturation levels with 95 per cent of those aged 18–34 years using smartphones in 2017.[1] Between 2011 and 2015, the use of smartphones by Australian teenagers increased from less than 25 per cent to 80 per cent.[2]

In 2017, the rate of watching videos on smartphones including streaming has tripled and online shopping has increased 14 per cent compared to 2016.[1] The use of smartphones and tablets is also increasing in the 65 years and older population while the use of desktop computers (hereafter referred to as 'computers') for household purposes such as online banking and shopping is stagnant.[3]

The long-term ocular effects of smartphone and handheld digital device use are unknown. However, a range of short-term ocular surface discomfort, visual discomfort and aesthenopic symptoms are reported with smartphones and tablets use.[4–7] Ocular surface discomfort includes sore eyes, dryness, stinging, burning, itchiness and irritation. Visual discomfort and aesthenopic symptoms includes blurred vision, difficulty in refocusing between viewing distances, headache, eye strain and double vision.

A large study of primary school children in Korea found dry eye symptoms were higher with mobile phone use and reduced when phone use was stopped.[4] Korean adolescents are reported to have more than two times increased ocular discomfort and visual symptoms, when smartphones are used for more than two hours a day.[8]

Several studies have shown one hour of tablet or smartphone use increases eye strain and blur in young adults[5–7,9] by as much as five times.[6] It is unclear whether these collective symptoms are due to effects on the accommodative/vergence system, the ocular surface (including blinking) or a combination of both.

The types of symptoms reported with handheld devices are not dissimilar to those reported with computers, where research to date has focused. Adverse related effects from computer use are similar to those listed earlier and have been termed 'computer vision syndrome'. This syndrome has been reported by 20–40 per cent of computer users and is associated with short- and long-term effects on the accommodative system and ocular surface.[10–12]

In spite of the overlap in symptoms between handheld devices and computers, it is likely that there are key differences in the aetiology of these symptoms. Smartphones and tablets are small handheld devices compared to computers which comprise a larger display oriented in the vertical plane and an external keyboard and mouse.

Laptop computers can be set up on a desk surface with an external keyboard and mouse, similar to a desktop computer, or can be used as a portable device; hence symptoms may vary in people according to their mode of use. Smartphones, tablets and computers differ in terms of viewing position, size, method and pattern of use.

This review evaluates the available literature for the effects of smartphone and tablet use on binocular vision, blinking and ocular surface. The purpose is to consider potential aetiologies underlying the ocular and visual discomfort reported with these devices and to highlight gaps in knowledge. The limited literature on handheld devices is discussed in the context of the extensive literature available on the effects of computer use; similarities and differences within the literature are considered. The effect on accommodation and vergence is discussed first, followed by the impact on blinking and the tear film and ocular surface.

Relevant original research and review journal articles published until December 2017 were identified through searches in Medline and Google Scholar databases. Reference lists of relevant publications were also searched. Search terms used to find relevant articles on common electronic devices were 'smartphone', 'mobile phone', 'cellular phone', 'tablets' and 'e-reader'. Search terms to identify symptoms of eye-related discomfort were 'headache', 'aesthenopia', 'blurred vision', 'double vision' and 'eye strain'.

Articles on the impact of binocular vision were found using the search terms 'accommodation', 'convergence', 'vergence' and 'phoria'. Search terms for impact on ocular surface and blinking were 'tear film', 'blink rate', 'blink amplitude', 'blinking', 'dry eye', 'tear function', 'tear quantity', 'tear break-up time', 'meibomian gland dysfunction' and 'corneal staining'. Searches were carried out using combinations of aforementioned terms. Articles in languages other than English were included and translated by native language speakers. Articles reporting statistical analysis of results were included.

Literature relevant to the symptoms and the impact on binocular vision, blinking, tear film and ocular surface with smartphone and tablet use is summarised in Tables 1 and 2, respectively. Table 3 summarises the literature available on accommodative and vergence changes with computer use along with the impact on symptoms. Table 4 summarises the literature available on the effects on symptoms, blinking, tear film and ocular surface changes of computer use. These summaries are represented as a flow chart in Figure 1.

Accommodation and vergence

The symptoms experienced with digital device use may be associated with changes in the accommodative system, including changes to accommodative accuracy, flexibility (accommodative facility) and/or amplitude.

Accommodation

ACCURACY OF ACCOMMODATION

Lag in accommodation is the amount by which the accommodative response is less than the dioptric stimulus to accommodation.[46] When this difference exceeds the depth of focus, symptoms such as near blur, sore eyes and tired eyes may occur.[47] Several studies of smartphone users under the age of 35 years have concluded there is a greater lag in accommodation after smartphone use than before use[14,15] and the lag exceeded that associated with reading printed texts.[14,18]

Reading from smartphones and tablets at 35–40 cm for 12 and for 30 minutes resulted in a statistically significant greater lag than reading printed texts at the same distance.[14,15] No significant differences in lag between digital devices such as tablets and smartphones are reported after 10 minutes of use at 25 cm viewing distance.[48] Also, no significant difference in lag was found between a handheld e-reader and printed text at 50 cm.[18] This discrepancy, of lag reducing with smartphone use but not with e-reader, could be due to the extended viewing distance of 50 cm with the e-reader.

No studies have directly determined whether the increased accommodative lag with smartphone use causes aesthenopic symptoms.[29–31] One study that investigated both lag and symptoms found no change in lag with a Kindle e-reader read at 50 cm but did find an increase in tired eyes and general eye discomfort.[18] Despite this, an increased lag associated with increased visual discomfort results in an array of aesthenopic symptoms such as blur, headaches and soreness.[49]

The methods for measuring lag of accommodation can influence results. The common clinical method, monocular estimation method, results in a lower lag with a simulated computer screen than printed target.[27] However, a smaller study measuring lag objectively using an auto-refractor with similar targets found an increase in lag when viewing a computer screen.[50] The subjective accommodative lag measurement – monocular estimation method – showed large inter-examiner variability resulting in examiner bias.[27] There is also evidence that accommodation does change in response to the introduced lens in monocular estimation method retinoscopy.[51] Therefore, further studies with objective measurement tools are necessary to gain reliable conclusions.

ACCOMMODATIVE FACILITY

Accommodative facility is the flexibility to focus at a variety of viewing distances. Reduced facility with printed text has been correlated with blurred vision.[52,53]

Smartphones and tablets are often used while multitasking with other activities. This requires the user to quickly adjust accommodation to focus at the screen and then relax accommodation for distant targets to maintain clear vision. Overall, there is a lack of reliable evidence linking aesthenopia associated with smartphone use to accommodative facility. For example, no significant change in binocular or monocular facility was found after reading from a book or viewing a film on a smartphone for 30 minutes.[14] This contrasts with a study that found that binocular facility significantly reduced from 11.5 cycles per minute to 8.75 cycles per minute after 60 minutes of smartphone viewing.[17] Furthermore, reduced binocular facility occurred after reading from a tablet for 30 minutes compared to before task.[20] In particular, it is difficult to make direct comparisons of results due to limited details about the testing methods.

Table 1. Summary of significant effects of smartphone use on symptoms, blinking, ocular surface and binocular vision as reported

Study	Study sample	Task or comparison	Duration, WD	Symptoms	Blink parameters	Tear function and corneal staining	Binocular vision: Accommodation	Binocular vision: Vergence
Park et al.[13] 2012 (Korea)	n = 50	Viewing smartphone and computer screen	20 min 50 cm, smartphone 70 cm computer	Visual fatigue with smartphone only				↑ NPC (cm) with both devices ↑ Exophoria with both devices NPC (cm) with smartphone > NPC with computer Exophoria: smartphone > computer
Park et al.[14] 2014 (Korea)	n = 63 19–26 years	Reading printed text vs viewing film on smartphone	30 min, 40 cm				NRA: phone < print; baseline < print PRA, facility (monocular and binocular): no change from baseline with either task Lag: print < phone; baseline < phone Monocular amplitude: print > phone; baseline > phone	
Park et al.[9] 2014 (Korea)	n = 60 20–30 years	Playing game and viewing film on smartphone	60 min, 40 cm	↑ With both tasks†	↓ BR with both tasks, no difference between tasks	↑ Schirmer with both tasks, no difference between tasks		
Ha et al.[15] 2014 (Korea)	n = 40 20–30 years	Reading text from smartphone and from computer and from print	Duration not specified, 40 cm				Lag: ↓ computer ↓ smartphone	
Moon et al.[4] 2016 (Korea)#	n = 630 8–11 years			↑ With longer hours/day of smartphone use‡				
	n = 60 8–10 years (subgroup with DE)	Stopped smartphone use	1 month	↓		↑ TBUT ↓ Corneal staining		
Kim et al.[8] 2016 (Korea)#	n = 715 mean age 15 years			↑ With longer hours/day and years of smartphone use§				

Study	Study sample	Task or comparison	Duration, WD	Symptoms	Blink parameters	Tear function and corneal staining	Binocular vision: Accommodation	Binocular vision: Vergence
Kwon et al.[16] 2016 (Korea)	n = 40 36–50 years (presbyopes and non-presbyopes)	Viewing film on smartphone	30 min, 40 cm	↑¶ In both groups			↓ Monocular amplitude in non-presbyopes only ↓ Monocular facility, ↓ NRA and ↑ PRA in presbyopes only No change to binocular facility in either group	↓ NFV in both groups No change to PFV or phoria in either group
Long et al.[7] 2017 (Australia)	n = 18 18–29 years	Reading from smartphone	60 min, 28–31 cm	↑**				
Golebiowski et al.[17] 2017 (Australia)	n = 12 18–23 years	Reading from smartphone	60 min, 30–34 cm	↑††	↑ BR	No change in TBUT, lipid layer or TMH	↓ Binocular facility No change in fixation disparity	

BR: blink rate, DE: dry eye, NFV: negative fusional vergence, NPC: near point of convergence, NRA: negative relative accommodation, PFV: positive fusional vergence, PRA: positive relative accommodation, TBUT: tear break-up time, TMH: tear meniscus height; WD: working distance.

All studies were interventional, other than two cross-sectional studies which are indicated with #.

†Bloodshot eyes, warm eyes, pressure in eyes, itchy eyes, sore eyes, blurry vision, foggy vision, want to close eyes.

‡Ocular Surface Disease Index (OSDI).

§Vision blurring, redness, visual disturbance, secretion, inflammation, lacrimation and dryness.

¶Aesthenopia, blur and dryness.

**Tired eyes, uncomfortable eyes and blur – when WD was reduced intra-task.

††Eyestrain, discomfort, tiredness.

Table 1. Continued

It is unclear exactly how smartphones and tablets disturb the flexibility of the accommodative system. It is possible that the added cognitive demand from the multi-functionality of these devices may adversely affect accommodation, consequently affecting the ability to make quick focusing changes.[54] Furthermore, the reduced accommodative facility could be due to near work in general and not related specifically to computers or handheld digital devices.

Little work has been published with regard to the relationship of near work and changes in accommodative facility with print media. Jiang and White[55] found that, after a non-specified '20-minutes near task', monocular accommodative facility did not change. On the other hand, Iribarren et al.[52] found that the cumulative duration of near work over months, whether computer-related or print-related, showed a significant negative correlation with binocular accommodative facility, a test also affected by vergence.

There is also no definitive understanding for how computers affect accommodative facility. Some studies show a decrease in accommodative facility that aligns with aesthenopic symptoms,[30,31] while other studies show no difference or even an improvement after computer use.[28] One study reports both monocular and binocular facility significantly reduced by almost 20 per cent after two hours of computer use[30] with post-task symptoms reported including worsening eyesight, eye strain and headache. These findings were not replicated in a computer task of only 90 minutes; that is, monocular and binocular facility did not change significantly after use.[31] It is possible that the discrepancy of results related to changes in accommodative facility after device or computer use are due to the different demands of the tasks. The differing working distances and detail within the task, such as font size and contrast, may create different demands on the accommodation and vergence systems, thus differently affecting accommodative facility.

AMPLITUDE OF ACCOMMODATION

Accommodative amplitude is the difference, expressed in dioptres, between the refracting power of the eye when adjusted for vision at the far point when accommodation is completely relaxed and when adjusted for vision at the nearest point of clear vision.[51] The usual clinical methods of measuring the amplitude of accommodation, such as the push-up method, are subjective and

Table 2. Summary of significant effects of electronic tablet use on symptoms, blinking, ocular surface and binocular vision as reported

Study	Study sample	Task or comparison	Duration, WD	Symptoms	Blink parameters	Tear function	Binocular vision: Accommodation	Binocular vision: Vergence
Hue et al.[18] 2014 (USA)	n = 20 23–35 years	Reading from Kindle vs printed text	12 min, 50 cm	↑ With Kindle vs text			No difference in lag between tasks	
	n = 20 18–24 years	iPod vs printed text	12 min, 33 cm	No difference between tasks			Greater lag with iPod than printed text	
Argiles et al.[19] 2015 (Spain)	n = 50 18–70 years NDE	Reading from tablet (down gaze) vs printed text (down gaze) vs reading printed text (1° gaze) vs computer (1° gaze) vs viewing distant target	6 min, 40–60 cm		↓ BR with tablet, computer and printed text compared to distance viewing ↑ BR with tablet compared to printed text (downgaze) ↑ Incomplete blinks with tablet and computer compared to printed text			
Kim et al.[5] 2017 (Korea)	n = 59 2–64 years NDE	Viewing movie or playing game on tablet	1 hour, 40 cm	↑[†]		↓ TBUT		
Kim et al.[20] 2017 (Korea)	n = 30 18–29 years	Reading from tablet vs printed book	30 min, WD not specified				↓ Binocular facility with tablet only No difference in lag, NRA, PRA or amplitude between tasks No change in lag, NRA/PRA or amplitude pre- and post-tablet or book task	
Phamonvaechavan et al.[21] 2017 (Thailand)	n = 40 18–30 years	Reading from tablet vs computer	20 min, 50 cm	↑[‡] Pain score and blurred vision, no change in dry eye score post-task with either device			↓ Monocular amplitude post-task with both devices, no difference between devices	↓ PFV post-task with both devices, no difference between devices
Madudcdoc et al.[6] 2017 (USA)	n = 44 21–30 years	Reading from tablet vs printed text	60 min, 38 cm	↑[§]		No difference in Schirmer score with either task, no difference between tasks		

BR: blink rate, NDE: non-dry eye, NPC: near point of convergence, NRA: negative relative accommodation, PFV: positive fusional vergence, PRA: positive relative accommodation, TBUT: tear break-up time, WD: working distance.

[†]Tired eye, sore/aching eye, irritated eye, watery eye, and hot/burning eye.

[‡]Blurred vision: blurred vision while viewing text, blurred vision when looking into the distance at end of near task, difficulty in refocusing my eyes from one distance to another, double vision while viewing the text or at the end of near task; pain score: eye strain, headache, tired eyes; dry eye score: irritated or burning eyes, dry eyes, photophobia.

[§]Eye strain (5×) and irritation.

determine the level of amplitude based on the stimulus location and not accommodative response. Objective measures are needed to provide the true accommodative response. With prolonged near work, adverse changes to amplitude can indicate fatigue[56] that may cause blur and delay in changing focus.[57]

Reduced subjective accommodative amplitude has been shown after digital device use.[14,16,21] For example, reduced accommodative amplitude was reported in subjects who read from a computer and iPad for 20 minutes at a viewing distance of 50 cm. There were no significant differences between these two devices.[21] A statistically significant reduction of 1.17 D in binocular accommodative amplitude and 1.14 D in monocular accommodative amplitude occurred after 30 minutes of watching a movie on a smartphone.[14] This monocular reduction in amplitude was 0.74 D more than from reading a book for 30 minutes.[14] The findings of Kwon et al. found a similar reduction in accommodative amplitude, 0.80 D, after viewing a smartphone for 30 minutes.[16] While the implications of an approximately 1.00 D loss of accommodative amplitude may not seem to be clinically relevant for a young person, the reduction after such short-term use leads to a concern about the effect of longer durations of use.[14,16]

Reduced subjective accommodative amplitude also occurs with computer use.[30,31] A significant decrease in binocular accommodative amplitude was demonstrated after 40 minutes of computer activity.[31] However, it is unclear whether the reduced amplitude is purely due to computer use as other authors report no significant difference between computer and non-computer near tasks.[26] This latter study also reports blurred vision, diplopia and photophobia which were significantly greater with the computer task than with a non-computer near task.[26] The reasons for the reduced amplitude of accommodation with computer use and other near work is unclear. If tonic accommodation adapted to prolonged near work, the measured accommodative amplitude would increase[58] it seems more likely that the reduced amplitude of accommodation is a result of fatigue of accommodation.

The results reported for the above studies could also have been confounded by the measurement method for accommodative amplitude which was largely subjective (for those studies where the measurement method was disclosed). Objective measures may have returned different results since they reflect the true accommodative response.

In summary, accommodative changes occur with smartphone and tablet use. This includes reduced amplitude of accommodation and increased lag. Although asthenopic symptoms are associated with such binocular vision anomalies, there is a lack of studies correlating these anomalies in smartphones and tablets with related symptoms.

Vergence

The convergence and accommodative systems work together during near work and form two components of the triad response to near work (the other being miosis). Cortical commands control the abduction and adduction of the eyes to diverge and converge, for a target moving respectively from near to far or vice versa.[59,60]

Convergence insufficiency, characterised by exophoria at near, is the most common vergence disorder with symptoms occurring with near work. Positive fusional vergence and negative fusional vergence are clinical measures of vergence, measured by increasing base out and base in prism until fusion breaks (to measure convergence and divergence, respectively). Other measures of vergence include the near point of convergence, which is the point where the lines of sight intersect when the eyes are in the position of maximum convergence, heterophoria, and vergence facility. No studies were found investigating vergence facility after handheld device or computer use.

NEGATIVE AND POSITIVE RELATIVE VERGENCE

Much research into the impact of digital devices on the vergence system has measured the change to negative fusional vergence and positive fusional vergence, but the link between these parameters and ocular and visual discomfort symptoms remains inconclusive. Fusional convergence has been shown to reduce after reading on an iPad and on a liquid crystal display screen at 50 cm for 20 minutes in subjects younger than 30 years[21] but this finding was not replicated with smartphones viewed at 40 cm for 30 minutes in similar aged participants.[16] Negative fusional vergence was reduced in both presbyopes and non-presbyopes while the change in positive fusional vergence post task was insignificant.[16]

There is more published literature for vergence changes with computer use than for smartphone use. There are reports that fusional convergence and divergence reduce over six hours of computer use in a day;[23,24,26] however, another group did not replicate this finding in five hours of computer use.[22] This could be due to differences in methodology as the former studies[23,26] used stereograms in-instrument (Keystone telebinocular) compared to the latter who used prism bars in free space to measure fusional vergence. Furthermore, it was the use of computers relative to non-computer near tasks, which significantly decreased fusional convergence.[26]

There are no reports correlating visual discomfort symptoms with altered vergence findings with computer screens or handheld devices.

NEAR POINT OF CONVERGENCE

There are conflicting reports for how digital device use affects near point of convergence. Near point of convergence receded in those who used computers routinely compared to those with sporadic use over four workdays;[25] however, another group did not find this over five hours of continuous computer use in a day.[22] This could be because the latter group took only single measurements while the former took an average of three measurements to measure near point of convergence. A more recent study reported a receding near point of convergence after 20 minutes of both smartphone and computer use. The near point of convergence post-device use was further for the smartphone than the computer.[13] After 10 minutes of recovery, the near point of convergence measurement returned to pre-usage levels for both devices.[13]

OCULAR DEVIATION

Limited evidence is available on the impact on disassociated phoria with digital devices. There is a greater tendency for phoria to shift toward greater exophoria after using computers for a working day.[26] Similar findings were noted with shorter duration (20 minutes) of computer and smartphone use in participants with mean age of 21 years.[13] After a 10 minute recovery, the horizontal phoria measurement with both devices returned to levels found in the first five minutes of use.[13] Although smartphone viewing can induce larger exophoric shifts during device viewing compared to before

Study	Study sample	Task or comparison	Duration, WD	Symptoms	Accuracy	Accommodation parameters			Binocular vision	
						Facility	Amplitude (D)	Relative accommodation	Phoria	Fusional reserves/ vergence
Nyman et al.[22] 1983 (Sweden)*	n = 505 age not specified	Computer task in habitual computer users vs non-users in a normal workday	5 hours, not specified				No difference in both groups No change before and after workday		No difference in both groups No change before and after workday	No difference in both groups No change before and after workday
Gratton et al.[23] 1990 (Italy)*	n = 7 24–32 years	Computer use	6 hours, 40–80 cm	↑†						↓ PFV ↓ NFV
Watten et al.[24] 1994 (Norway)*	n = 43 18–37 years	Computer task	6.5 hours, 40 cm				↓ Amp	↓ PRA and NRA		↓ PFV ↓ NFV
Gur et al.[25] 1994 (Israel)#*	n = 129 24–43 years	Habitual computer users vs sporadic users of computer	4 days, not specified				↓ Amp in habitual users only post-task			NPC receded more in habitual users
Piccoli et al.[26] 1996 (Italy)*	n = 14 20–32 years	Near tasks on computer‡ vs non-computer§	80–170 min, 48–65 cm	↑ With computer than non-computer¶			No difference in both groups		↑ Exophoria with computer task	↓ Fusional convergence (prism dioptres) in computer than non-computer
Penisten et al.[27] 2004 (USA)*	n = 40 20–30 years	PRIO system vs print vs computer	Not specified, 50–70 cm		$Lag_{PRINT} > Lag_{PRIO}$ $Lag_{PRINT} = Lag_{COMPUTER}$ $Lag_{VDT} > Lag_{PRIO}$					
Rosenfield et al.[28] 2010 (USA)	n = 22 age not specified	Reading from computer	25 min, 50 cm			↑ Binocular post-task No change to monocular				
Collier and Rosenfield[29] 2011 (USA)	n = 20 22–30 years	Laptop reading task	30 min, 50 cm	↑ With ortho fixation disparity than exo associated phoria	No change					

Table 3. Summary of significant changes to accommodative and vergence measures reported with computer use as reported

Study	Study sample	Task or comparison	Duration, WD	Symptoms	Accommodation parameters				Binocular vision	
					Accuracy	Facility	Amplitude (D)	Relative accommodation	Phoria	Fusional reserves/ vergence
Seo[30] 2012 (Korea)	n = 48 age not specified	Pre- and post-computer use	2 hours, not specified	↑** Post use	↑ Lag in left eye only	↓ Binocular and monocular	Amp ↓ in left eye only	↓ NRA post-task No change to PRA post-task		
Kwon et al.[31] 2012 (Korea)	n = 60 20–30 years	Playing computer game	90 min, not specified		↑ Lag	No change	↓ Binocular and monocular amp	↓ PRA ↓ NRA		
Ha et al.[15] 2014 (Korea)	n = 40 20–30 years	Reading text on smartphone and on computer and on print	Not specified, 40 cm		Lag: ↓ Computer ↓ Smart-phone					
Phamonvaechavan et al.[21] 2017 (Thailand)	n = 40 18–30 years	Reading on iPad vs computer	20 min, 50 cm	↑††			↓ Mono amp with both devices No difference between devices			↓ Convergence with both devices No difference between devices

Amp: amplitude, NFV: negative fusional vergence, NPC: near point of convergence, NRA: negative relative accommodation, PFV: positive fusional vergence, PRA: positive relative accommodation; PRIO, a simulated display screen, WD: working distance.

All studies were interventional, other than two cross-sectional studies which are indicated with #. Studies known or assumed to be conducted using cathode ray tube (CRT) monitor are marked with*.

†Tired eyes, gritty feeling, general tiredness.

‡Computer tasks: reading, word processing, video game, data entry.

§Non-computer tasks: typewriting, handwriting, text correction.

¶Blurred vision, double vision, light intolerance.

**Headache, aesthenopia, neck pain, worsening of eyesight, eye strain, bloodshot eyes, itchy eyes, excessive tears.

††Blurred vision while viewing text, blurred vision when changing focus from distance to another, blurred vision when looking into distance at end of near task, eye strain, headache, tired eyes, diplopia when viewing text or at end of near task; no change to symptoms of dry eyes, irritated/burning eyes, photophobia.

Table 3. Continued

Study	Study sample	Task or comparison	Duration, WD	Ocular surface symptoms	Blink parameters		Ocular surface parameters		
					Blink rate	Other	Tear stability	Tear volume	Other
Patel et al.[32] 1991 (UK)*	n = 16 17–31 years	Computer game	10 min, not provided		↓		No change in TBUT		
Acosta et al.[33] 1999 (Spain)*	n = 20 19–26 years	Looking at infinity (rest) vs computer game	10–30 min, 53 cm		↓ With computer				
Freudenthaler et al.[34] 2003 (Germany)*	n = 51 18–53 years NDE	Computer use vs conversation	10 min, 40 cm		↓ With computer				
Schlote et al.[35] 2004 (Germany)*	n = 30 18–67 years DE	Computer use vs relaxed conversation	30 min, 40 cm		↓ With computer				
Fenga et al.[36] 2008 (Italy)*#	n = 70 31–56 years computer workers with and without MGD	Hours/day of computer use	Not provided	↑ With longer hours of computer use in MGD group ↓ With longer hours in non-MGD group[†]			No effect on TBUT in either group	↑ Schirmer with longer hours of computer use non-MGD group only, no effect in MGD group	No effect on corneal staining in either group
Himebaugh et al.[37] 2009 (USA)	n = 32 24–72 years DE and NDE	Viewing blank computer monitor vs watching movie on computer vs playing easy computer game vs playing difficult computer game	3 min, 150 cm	No difference between tasks in either group[‡]	↓ With more difficult tasks in both groups	No difference in complete blinks between tasks in either group	No difference in TBUT between tasks in either group		↑ Corneal staining with all tasks in both groups
Nakamura et al.[38] 2010 (Japan)#	n = 1,025 17–73 years office workers	Effect of hours/day and years of computer use					No effect on TBUT or lipid layer	↓ Schirmer with ≥ 2 hour/day and with ≥ 4 years of computer use	
Cardona et al.[39] 2011 (Spain)	n = 25 21–28 years	Viewing of distant target vs slow-paced computer game vs fast-paced computer game	20 min, 50 cm	No change	↓ With both games ↓ With fast game vs slow game	↓ Complete blinks with both games, no difference in slow and fast games	↓ TBUT with both games (fast < slow) ↓ Lipid layer thickness with both games (no difference between games)	↓ TMH with both games, no difference between slow and fast games	
Hirota et al.[40] 2011 (Japan)	n = 11 19–32 years NDE	Computer game	60 min, 40 cm		↓		↓ TBUT		
Uchino et al.[41] 2013 (USA)#	n = 96 22–62 years	Habitual computer use of: < 5 hours/day vs 5–7 hours/day vs > 7 hours/day							↓ Tear mucin in > 7 hours/day group

Table 4. Summary of significant effects of computer use on blinking and ocular surface parameters as reported

Table 4. Continued

Study	Study sample	Task or comparison	Duration, WD	Ocular surface symptoms	Blink parameters		Ocular surface parameters		
					Blink rate	Other	Tear stability	Tear volume	Other
Chu et al.[42] 2014 (USA)	n = 25 22–28 years	Reading from computer vs reading from print	20 min, 50 cm	No change§	No change with either task	↓ Complete blinks with computer vs print			
Wu et al.[43] 2014 (China)#	n = 40 20–47 years DE	Habitual computer use of: < 4 hours/day vs > 4 hours/day		↑ In > 4 hours/day group¶			↓ TBUT and ↓ meibum expression in > 4 hours/day group	No difference in Schirmer	↑ Corneal staining in > 4 hours/day group
Ribelles et al.[44] 2015 (Spain)#	n = 148 40–65 years, females only	Habitual computer users vs non-users		↑ In computer users**	↓	↓ Blink velocity in computer users		↓ Schirmer in computer users	↑ Inflammatory mediators in tears of computer users
Yazici et al.[45] 2015 (Turkey)	n = 77 20–45 years	Pre- and post-routine workday of habitual computers users vs non-users	9 hours, not provided	↑ In computer users only¶			↓ TBUT in computer users only	↓ Schirmer in computer users only	↑ Tear osmolarity in computer users only No change in corneal or conjunct staining in either group

DE: dry eye, MGD: meibomian gland dysfunction, NDE: non-dry eye, TBUT: tear break-up time, TMH: tear meniscus height, WD: working distance.

All studies were interventional, other than five cross-sectional studies which are indicated with #. Studies known or assumed to be conducted using cathode ray tube (CRT) monitor are marked with*.

†Burning, itching, foreign body sensation, dryness, tearing, photophobia, pain, mucus secretion, redness and heaviness.

‡Current Symptoms Questionnaire (9 symptoms from Dry Eye Questionnaire): blurry vision, soreness, irritation, grittiness, burning, stinging, foreign body sensation, light sensitivity. Dry eye subjects; control: grittiness, burning and stinging.

§Blurred vision while viewing text, blurred vision when looking into distance at end of near task, difficulty in refocusing eyes from one distance to another, irritated/burning eyes, dry eyes, eyestrain, headache, tired eyes, photophobia, discomfort in eyes.

¶OSDI: an ocular surface disease symptom questionnaire.

**Itchiness, soreness, irritation, foreign body sensation, photophobia, redness, eye strain, tired eyes, eye pain, blurred vision, vision loss or headache associated with eye pain.

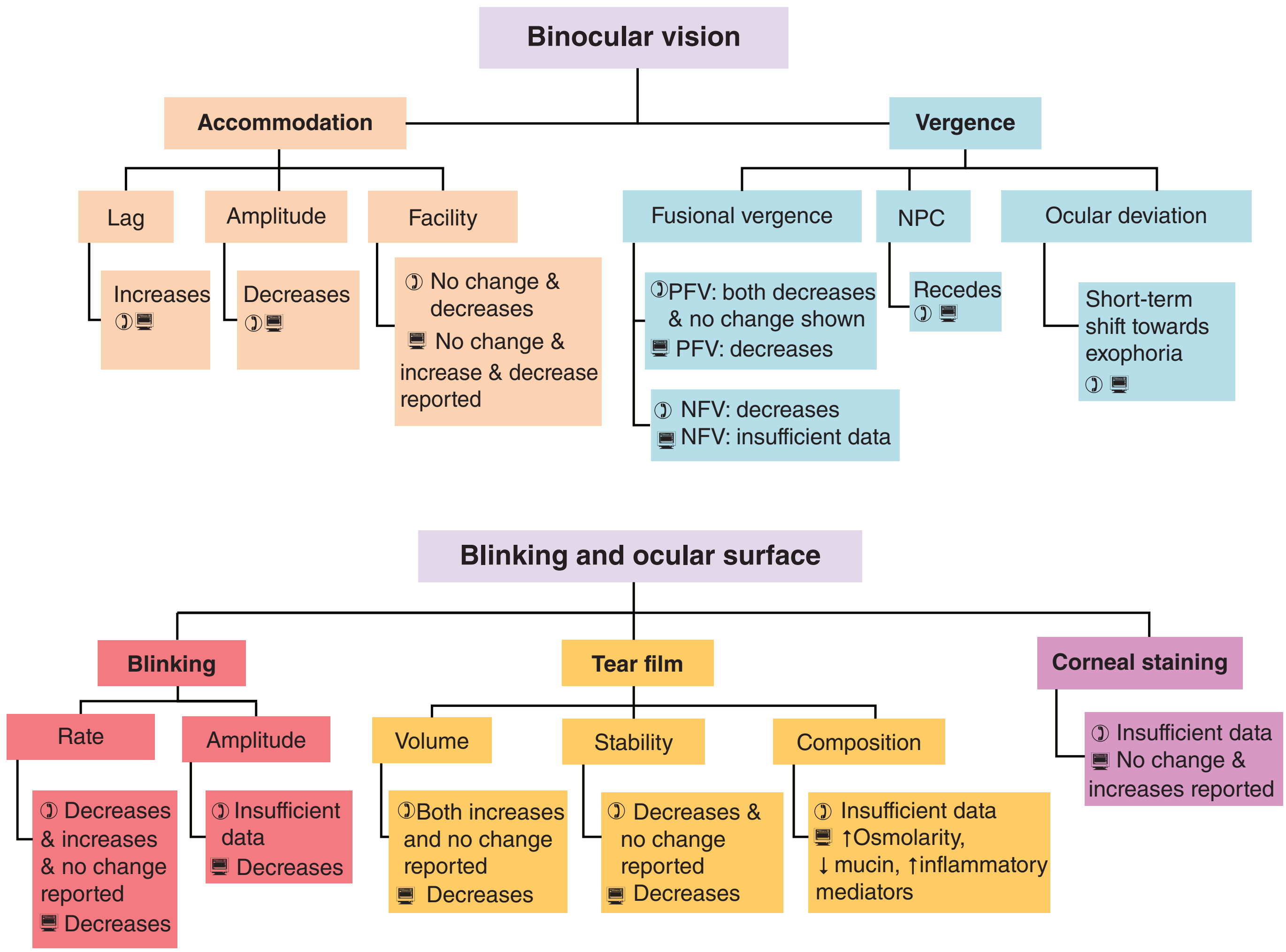

Figure 1. Summary of reported impact on binocular vision, blinking and ocular surface with smartphone and computer use. The symbol denotes computer and denotes smartphone and tablet studies.

device use,[13] this may only be applicable for younger-age adults. A report of an older cohort of adults aged 36–50 years showed no change to esophoria or exophoria with smartphone use for 30 minutes.[16] At this point it appears that any ocular deviation changes induced by short-term (20 minutes) digital device use will recover to normal levels in a relatively short time. There is no evidence for any long-term changes occurring with long-duration use.

In children aged between seven and 16 years and with acute acquired comitant esotropia who used smartphones for more than four hours a day, the eso deviation significantly reduced after ceasing smartphone use for one month.[61] However, it is important to note that this study involved children with only a subset of esotropia and there was no indication that smartphone use caused the esotropia.

Blinking, tear function and dry eye

Digital device use can affect blink patterns, ocular surface homeostasis and tear film function.[4,5,9,17,62] These effects are likely to contribute to a variety of ocular discomfort symptoms (such as dryness, grittiness, foreign body sensation, burning, stinging, sore eyes), blurred vision, and dry eye disease. A study of children aged 10–12 years reported those with dry eye disease were found to be twice as likely to use a smartphone compared to those without dry eye.[62] Longer hours of smartphone use per day increased the likelihood of dry eye disease in this cohort, with almost double the odds noted.[62] This agrees with the other findings of a 13 times higher odds of dry eye in children who used smartphones.[4] The literature on these changes with smartphones, tablets and computers is summarised in Tables 1, 2 and 4 and in Figure 1.

Blinking

The movement of the eyelids during a blink spreads the tear film evenly over the ocular surface. Impaired blinking disturbs the balance of replenishment and evaporation of the tear film[63] resulting in disruption of tear structure and thus homeostasis of the ocular surface. This, in turn, may give rise to symptoms of ocular discomfort.[64]

Blink measurement methods vary between studies and it can be difficult to compare between studies. Methodologies include observation of superior eyelid moving downward, video-recording the lid movement, and electrophysiological signals to recognise blinks.[65] Parameters measured include number of blinks in a certain time frame (blink rate), time between blinks (interblink interval) and amplitude of blink. Definitions of a complete/incomplete blink also vary between studies, with some investigators defining a complete blink as one where the cornea cannot be observed between eyelids[19,42,64] and others qualifying 75 per cent corneal coverage as a complete blink.[39]

BLINK RATE

Reduced blink rate is consistently reported with computer use,[32–35,37,39,44,66] which has been associated with an increase in ocular and visual symptoms.[11] In a study of computer users in an office environment, computer users had reduced blink rate compared to non-users[34,40] and blink rate was reduced by half within minutes of computer viewing compared to immediately prior to computer use.[40]

In contrast, there are conflicting reports for blink rate and the effects of smartphone and tablet use. Park et al.[9] report reduced blink rate after 60 minutes of viewing a film or playing a game on a smartphone, whereas Golebiowski et al.[17] report increased blink rate over 60 minutes of reading from a smartphone. Benedetto et al.[67] found reduced blink rate with reading for one hour from a liquid crystal display e-reader compared to reading from printed text in a similar setup; however, Argiles et al.[19] found reading from tablets resulted in a higher blink rate than when reading the same text in print. It is unclear from the methodologies in many of these reports what the criterion was to classify a 'blink'; specifically, whether only complete blinks were counted.

It is likely that blink rate is task-dependent and not solely due to the device type. When the same reading task is carried out on a computer screen and on printed paper under the same viewing conditions, blink rate does not differ.[42,68] There are substantial differences in blink rate between conversation and computer use – 17 blinks/minute and 6.5 blinks/minute, respectively.[35] Longer inter-blink intervals occur with computer games of 10 or 30 minutes (7.5 seconds) than with a non-computer activity of looking into infinity (4.8 seconds).[33]

There appears to be a causative relationship between task difficulty and reduced blink rate.[37,39,69] It has been shown that blink rate is reduced more when viewing complex print targets compared to simple print targets when both are viewed in down gazes.[69] This needs to be investigated with smartphones as these are most commonly used in down gaze.

Reduced blink rate over three minutes has been found with complex computer games requiring constant attention, compared to watching a movie or simply staring at the screen.[37] Furthermore, when subjects played a fast-paced game, blink rate was lower than when playing a slow-paced game.[39] The effect of cognitive demand on blink rate was also confirmed by Rosenfield et al.,[70] who showed a lower blink rate in a reading task of high compared to low cognitive demand. A similar such reduction was not found between equally difficult tasks viewed on printed paper or tablet screen.[70]

Reduced blink rate increases the inter-blink interval, which enables greater evaporative loss of tears,[63] thus causing increased ocular surface discomfort. This suggests that greater concentration on a computer task may result in increased ocular discomfort as a result of reduced blink rate. These findings need to be replicated with smartphones and tablets, and with tasks requiring concentration, longer screen time and constant cognitive attention from the user.

BLINK RATE AND GAZE ANGLE

Unlike computer screens which usually have a fixed location and limited viewing angles, the viewing angle and viewing distance of smartphones and tablets can be easily and frequently modified by the user.[71] These devices are typically held beneath eye level, in contrast to the primary gaze angle with desktop computer screens.

There is a relationship between gaze angle and blink rate for computer use. Tear film evaporation and stability is more likely to be affected in higher gaze angles because the palpebral aperture is wider, and consequently a greater area of the ocular surface needs to be covered by tear film.[72] Although it is known that the palpebral aperture is smaller in down gaze, it is not known what impact this has on dry eye symptoms. There is evidence that viewing a computer in primary gaze increases the ocular surface area exposed compared to viewing the same task on a computer screen at 25° below primary gaze.[73] A reduced blink rate in lower gaze has been noted in studies of printed texts.[19,68] Handheld devices such as smartphones and tablets are habitually used in various gaze angles. Consequently, symptoms will vary depending on the exposed ocular surface and tear film distribution.

There is substantial ambiguity in the literature in how gaze and device angles are described; this limits comparison between studies. For example, it is unclear if the reported viewing angle is that of the angular motion of the eyes only or whether it includes neck motion, termed flexion.[5,19,74] Insufficient information is also provided for device angle, where tilt of computer screen or tablet is not always clearly identified as being from the horizontal or from the vertical, with often only a numerical angle value provided.[19,39]

BLINK AMPLITUDE

Blink amplitude describes how much of the exposed cornea is covered with the movement of the eyelids during the blink. An almost complete closure of the eyelids is essential to turnover and replenish the tears, as the tears cannot otherwise move outside of the interpalpebral region.[75] As there is no vertical pull of tears via gravity,[75] the cornea is not completely replenished with tears when only a partial or incomplete blink occurs.

A higher proportion of incomplete blinks have been shown to result in increased dry eye symptoms with computer use.[64] There is evidence of a higher proportion of partial blinks with computer tasks compared to reading from hard copy.[19,42] Argiles et al.[19] also observed more incomplete blinks with tablets compared to the same task presented as print, but blink amplitude has not previously been investigated with smartphone use. Task difficulty does not impact blink amplitude.[37,39]

No studies published to date have examined the impact of gaze angle on blink amplitude with digital devices including computers, although gaze angle may play a role in blink amplitude.[76]

In contrast to the consistent effects on blink rate and amplitude shown with computer use, the findings for effects of handheld digital devices on blink rate are inconclusive, and may be confounded by task difficulty and the way the devices are held and used.

Tear function

TEAR VOLUME

Tear volume is a measure of the efficacy of tear production – specifically, of the aqueous component of the tears. This component forms the bulk of the tear film and contains vital antimicrobial, anti-inflammatory and lubricating factors critical to maintenance of the health of the ocular surface. Tear film secretion and quantity in studies of digital device use has been measured by determining tear meniscus height or administering the Schirmer strip test.

Golebiowski et al.[17] found no changes to tear meniscus height after one hour of reading from a smartphone, and Madudoc et al.[6] similarly showed no effect with tablet use over the same time. Park et al.[9] reported increased Schirmer scores after viewing a film or playing games on a smartphone; however, the investigators speculated that reflex tearing may have affected results.

In contrast, reduced tear volume is generally reported with computer use. In the study by Nakamura et al.[38] of office workers in Japan, a decreased Schirmer score was evident for those working on computers for longer than two hours per day or for more than four years of use. Reduced Schirmer scores have been reported after a nine-hour day in computer users compared to non-computer users (janitors)[45] and in a study of female habitual computer users compared to female workers in the same offices who were not computer users.[44] Reduced tear meniscus height was similarly reported after 20 minutes of playing a computer game when compared to viewing of a distant object, but the tear meniscus height did not vary between a slow-paced and a fast-paced game.[39]

Although tear volume appears reduced with computer use, studies investigating the effects of handheld digital devices are conflicting.

TEAR STABILITY

A stable intact tear film is essential to maintain a smooth optical surface to enable clear vision and is facilitated by the outer lipid layer of the tear film. Tear film stability in studies of digital devices has predominantly been determined by measuring the tear break-up time.

Two studies have investigated tear stability with 60 minutes of smartphone and tablet use. Kim et al.[5] reported reduced tear break-up time after 60 minutes of playing a game or watching a movie on a tablet, whereas Golebiowski et al.[17] did not find a change in tear break-up time or lipid layer thickness with 60 minutes of reading from a smartphone.

A study of children aged 9–10 years with dry eye showed tear break-up time improved when smartphone use was stopped for one month.[4] This study also found that a lower tear break-up time (of less than 10 seconds) and/or corneal punctuate erosions were present in children who used smartphones for an average of three hours a day, whereas tear break-up time greater than 10 seconds was found in children who used smartphones for less than an hour a day.[4] Furthermore, the odds of having dry eye disease was 13 times higher in the group who used smartphones for three hours a day.[4]

Reduced tear break-up time occurs with computer use.[39,40,43,45] Reduced tear break-up time and lipid layer thickness have been shown after as little as 20 and 60 minutes of playing a computer game (both slow-paced and fast-paced),[39,40] although an earlier study did not find a difference in tear break-up time after 10 minutes.[32] Decreased tear break-up time was also found after a routine day of work in computer users but not in non-users[45] and in habitual computer users with dry eye who used computers more than four hours per day compared to those who used computers less than four hours per day.[43] The latter study showed adverse changes to the quality of meibum expression in the more than four hours per day group.[43]

In contrast, two studies of computer workers did not find a relationship between hours or years of computer use and the effect on tear break-up time[38] or the tear film lipid layer.[36,38] No effect of task difficulty on tear break-up time was shown in the one study which has examined this, although a reduced blink rate (but no change in blink amplitude) was shown with more difficult tasks in the same study.[37]

TEAR FILM COMPOSITION

Changes to tear film composition such as reduced mucin production, increase of inflammatory markers and tear osmolarity have been reported in computer users[41,44,77] but have not yet been studied with smartphones or tablet use. Higher concentrations of pro-inflammatory mediators were present in the tears of office workers who used computers compared to non-computer users.[44] Reduced concentration of the tear mucin MUC5AC, was found in habitual computer users of more than eight hours per day, compared to those who used computers for less than five hours per day.[41]

Tear osmolarity, a diagnostic marker of dry eye,[78] has been shown to increase after seven hours of computer use by regular users, but the same increase was not seen in non-regular users.[45] Tear osmolarity was found to be a better predictor of dry eye disease in regular computer users as it was associated with corneal staining, tear break-up time and meibomian gland dysfunction, as opposed to ocular surface disease index results.[77]

Corneal staining

There are no reports describing effects of smartphone or tablet use on corneal or conjunctival integrity, as measured with vital dye staining. There are conflicting reports for staining and computer use. Yazici et al.[45] report no change in corneal and conjunctival staining with lissamine green after seven hours of computer work, and Fenga et al.[36] reported no relationship between corneal staining and longer hours of computer use. In contrast, Himebaugh et al.[37] report increased corneal staining after three minutes of watching a movie or playing games on a computer screen.

Tear film and ocular surface effects in dry eye patients

Interestingly, no relationship between computer use and tear volume was found in two studies of computer users with dry eye,[36,43] despite the reduced tear volume generally reported with computer use (discussed earlier). Fenga et al.[36] report that the number of hours of computer use does not affect Schirmer tear secretion in computer workers with meibomian gland dysfunction, while increased tear secretion was apparent with longer hours of computer use in non-meibomian gland dysfunction computer workers.

Similarly, Wu et al.[43] showed that Schirmer tear secretion was not different between office workers with dry eye who performed less than four hours of computer work and those who performed more than four hours of computer work per day. However, the same study did show effects on tear break-up time and corneal staining in both groups.[43] These results suggest that computer use may not impact tear production in individuals with dry eye, perhaps because their tear production is determined to a greater degree by pre-existing ocular surface dysfunction.

In comparison, studies of tear stability in digital device users who have dry eye agree with the findings reported above for more general populations. In a study of tear stability in children with dry eye, tear break-up time improved after smartphone use was stopped.[4] Longer hours of computer use in adults with dry eye are associated with reduced tear break-up time and worse meibum expression scores.[43] In contrast, other studies of computer users with and without dry eyes do not report an effect of hours of computer use or task difficulty on tear break-up time.[36,37] There are no published studies investigating tear secretion in smartphone or tablet users with dry eye.

Use of digital devices by individuals with dry eye appears to increase corneal staining, which is different to little impact on corneal staining in those without dry eye. In children with dry eye, corneal staining was eliminated after smartphone use was stopped for one month.[4] Corneal staining has been observed in individuals with dry eye after using a computer.[37] More corneal staining was evident in habitual computer users with dry eye who used computers for more than four hours per day compared to those who used computers less than four hours per day.[43] In contrast, another study found no relationship between corneal staining and hours of computer use in computer workers with meibomian gland dysfunction.[36]

Further studies are needed to determine whether pre-existing dry eye disease is exacerbated with the use of smartphones or tablets. This will assist development of clinically relevant recommendations.

Summary and future directions

The literature considering use of smartphones and tablets conclusively shows an increase in ocular and visual symptoms such as headaches, eyestrain, dry eyes and sore eyes.[4,6–9] These symptoms are similar to those which occur in computer vision syndrome. A causal link between these symptoms and changes to binocular vision, blinking and/or tear function, has not yet been established, and there is limited literature examining this relationship.

Accommodation has been shown to be altered with smartphone and tablet use, with decreased amplitude[16,21] and increased lag.[14,15] This is similar to what happens with computer use.[21,24,25,31] The evidence for an effect on accommodative facility is inconclusive. In addition, reduced fusional convergence and limited evidence suggests that the near point of convergence recedes with smartphone and tablet use, as occurs with computer use.

Findings for effects of handheld digital devices on blink rate are inconclusive, perhaps due to task difficulty, which also plays a role in reducing blink rate. More incomplete blinks may occur with tablet use, but the effect of smartphones on blink amplitude has not yet been studied. In contrast, both blink rate and amplitude are shown to be compromised with use of computers. Use of handheld digital devices may adversely impact tear stability, similarly with the use of computers. There is insufficient evidence to support an impact of handheld devices on tear volume, although there does seem to be an effect with computer use. Other markers of ocular surface and tear function have not yet been investigated with smartphone or tablet use.

Further research is required into the use of smartphones and tablets to account for the diversity in their use. Smartphones being handheld devices with varying screen sizes, are used with large individual differences in working distance. The luminance of the display can vary automatically or can be adjusted manually, whereas in computers it is usually fixed and not altered often by the user. Research involving computers has examined long hours of use simulating office environments; however, smartphones can be used frequently, but intermittently and outside of 'office' hours in all waking hours.

There is a trend for users to concurrently use multiple digital devices such as tablet, phone and computer screens. This is called dual or triple screening. It is not known whether using multiple devices has a larger impact on the visual system and ocular surface, and the impact on accommodation and vergence when switching views between screens is poorly understood. In addition, most studies of handheld digital devices to date have examined subjects aged 17 years and older. With more than 80 per cent of teenagers using smartphones,[3] the impact on the visual and ocular health of this younger cohort needs to be investigated. Furthermore, normative data of tear break-up time and Schirmer scores for young adults needs to be determined to enable objective evaluation of the impact of handheld digital devices on measures of ocular surface disease.[79] The impact on higher-risk groups such as patients with dry eye or accommodative/binocular vision anomalies also needs to be determined.

Understanding the ocular and visual effects of smartphone and handheld digital device use is essential for developing clinical guidelines to minimise the ocular discomfort of users. Such knowledge would also be valuable for the design of digital devices to minimise the potential for visual and ocular discomfort in the broader population.

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REFERENCES

1. Deloitte. Mobile Customer Survey 2017: The Australian cut. 2017. [Cited 10 Apr 2018.] Available at: https://www2.deloitte.com/content/dam/Deloitte/au/Documents/technology-media-telecommunications/deloitte-au-tmt-mobile-consumer-survey-2017-211117-final.pdf.
2. Australian Communications and Media Authority. Aussie teens and kids online. 2016. [Cited 10 Apr 2018.] Available at: https://www.acma.gov.au/theACMA/engage-blogs/engage-blogs/Research-snapshots/Aussie-teens-and-kids-online.
3. Australian Communications and Media Authority. Communications report 2013–14 series: Report 1—Australians' digital lives. 2015. [Cited 10 Apr 2018.] Available at: https://www.acma.gov.au/~/media/Research%20and%20Analysis/Research/pdf/Australians%20digital%20livesFinal%20pdf.pdf.
4. Moon JH, Kim KW, Moon NJ. Smartphone use is a risk factor for pediatric dry eye disease according to region and age: a case control study. *BMC Ophthalmol* 2016; 16: 188–194.
5. Kim DJ, Lim C, Gu N et al. Visual fatigue induced by viewing a tablet computer with a high-resolution display. *Korean J Ophthal* 2017; 31: 388–393.
6. Maducdoc MM, Haider A, Nalbandian A et al. Visual consequences of electronic reader use: a pilot study. *Int Ophthalmol* 2017; 37: 433–439.
7. Long J, Cheung R, Duong S et al. Viewing distance and eyestrain symptoms with prolonged viewing of smartphones. *Clin Exp Optom* 2017; 100: 133–137.
8. Kim J, Hwang Y, Kang S et al. Association between exposure to smartphones and ocular health in adolescents. *Ophthalmic Epidemiol* 2016; 23: 269–276.
9. Park JS, Choi MJ, Ma JE et al. Influence of cellular phone videos and games on dry eye syndrome in university students. *J Korean Acad Nurs* 2014; 25: 12–23.
10. Uchino M, Yokoi N, Uchino Y et al. Prevalence of dry eye disease and its risk factors in visual display terminal users: the Osaka study. *Am J Ophthal* 2013; 156: 759–766.

11. Portello JK, Rosenfield M, Bababekova Y et al. Computer-related visual symptoms in office workers. *Ophthalmic Physiol Opt* 2012; 32: 375–382.
12. Rosenfield M. Computer vision syndrome: a review of ocular causes and potential treatments. *Ophthalmic Physiol Opt* 2011; 31: 502–515.
13. Park K, Lee W, Lee N et al. Changes in near lateral phoria and near point of convergence after viewing smartphones. *J Korean Ophthalmic Opt Soc* 2012; 17: 5.
14. Park M, Ahn YJ, Kim SJ et al. Changes in accommodative function of young adults in their twenties following smartphone use. *J Korean Ophthalmic Opt Soc* 2014; 19: 253–260.
15. Ha N, Kim C, Jung SA et al. Comparison of accommodative system according to the material and font size of near visual media. *J Korean Ophthalmic Opt Soc* 2014; 19: 217–224.
16. Kwon K, Kim HJ, Park M et al. The functional change of accommodation and convergence in the mid-forties by using smartphone. *J Korean Ophthalmic Opt Soc* 2016; 21: 127–135.
17. Golebiowski B, Long J, Harrison K et al. Smartphone use and effects on tear film, blinking and binocular vision. *Invest Ophthalmol Vis Sci* 2018; 59: 913.
18. Hue JE, Rosenfield M, Saá G. Reading from electronic devices versus hardcopy text. *Work* 2014; 47: 303–307.
19. Argilés M, Cardona G, Pérez-Cabré E et al. Blink rate and incomplete blinks in six different controlled hard-copy and electronic Reading conditions. *Invest Ophthalmol Vis Sci* 2015; 56: 6679–6685.
20. Kim J, Um JY, Sung HN et al. Changes in accommodative function after reading with paper book and E-book on tablet PC. *J Korean Ophthalmic Opt Soc* 2017; 22: 183–190.
21. Phamonvaechavan P, Nitiapinyasagul R. A comparison between effect of viewing text on computer screen and iPad® on visual symptoms and functions. *Siriraj Med J* 2017; 69: 185–189.
22. Nyman KG, Knave BG, Voss MV. Work with video display terminals among office employees: IV. Refraction, accommodation, convergence and binocular vision. *Scand J Work Environ Health* 1985; 11: 483–487.
23. Gratton I, Piccoli B, Zaniboni A et al. Change in visual function and viewing distance during work with VDTs. *Ergonomics* 1990; 33: 1433–1441.
24. Watten RG, Lie I, Birketvedt O. The influence of long-term visual near-work on accommodation and vergence: a field study. *J Hum Ergol* 1994; 23: 27–39.
25. Gur S, Ron S, Heicklen-Klein A. Objective evaluation of visual fatigue in VDU workers. *Occup Med* 1994; 44: 201–204.
26. Piccoli B, Braga M, Zambelli PL et al. Viewing distance variation and related ophthalmological changes in office activities with and without VDUs. *Ergonomics* 1996; 39: 719–728.
27. Penisten DK, Goss DA, Philpott G et al. Comparisons of dynamic retinoscopy measurements with a print card, a video display terminal, and a PRIO® System Tester as test targets. *Optometry* 2004; 75: 231–240.
28. Rosenfield M, Gurevich R, Wickware E et al. Computer Vision Syndrome: Accommodative & Vergence Facility. *Invest Ophthalmol Vis Sci* 2010; 21: 119–122.
29. Collier JD, Rosenfield M. Accommodation and convergence during sustained computer work. *Optometry* 2011; 82: 434–440.
30. Seo E. Changes in accommodative function after VDT work. *J Korean Ophthalmic Opt Soc* 2012; 17: 285–291.
31. Kwon K, Woo JY, Park M et al. The change of accommodative function by the direction of eye movements during computer game. *J Korean Ophthalmic Opt Soc* 2012; 17: 177–184.
32. Patel S, Henderson R, Bradley L et al. Effect of visual display unit use on blink rate and tear stability. *Optom Vis Sci* 1991; 68: 888–892.
33. Acosta MC, Gallar J, Belmonte C. The influence of eye solutions on blinking and ocular comfort at rest and during work at video display terminals. *Exp Eye Res* 1999; 68: 663–669.
34. Freudenthaler N, Neuf H, Kadner G et al. Characteristics of spontaneous eyeblink activity during video display terminal use in healthy volunteers. *Graefes Arch Clin Exp Ophthalmol* 2003; 241: 914–920.
35. Schlote T, Kadner G, Freudenthaler N. Marked reduction and distinct patterns of eye blinking in patients with moderately dry eyes during video display terminal use. *Graefes Arch Clin Exp Ophthalmol* 2004; 242: 306–312.
36. Fenga C, Aragona P, Cacciola A et al. Meibomian gland dysfunction and ocular discomfort in video display terminal workers. *Eye* 2008; 22: 91–95.
37. Himebaugh NL, Begley CG, Bradley A et al. Blinking and tear break-up during four visual tasks. *Optom Vis Sci* 2009; 86: E106–E114.
38. Nakamura S, Kinoshita S, Yokoi N et al. Lacrimal hypofunction as a new mechanism of dry eye in visual display terminal users. *PLoS One* 2010; 5: e11119.
39. Cardona G, García C, Serés C et al. Blink rate, blink amplitude, and tear film integrity during dynamic visual display terminal tasks. *Curr Eye Res* 2011; 36: 190–197.
40. Hirota M, Uozato H, Kawamorita T et al. Effect of incomplete blinking on tear film stability. *Optom Vis Sci* 2013; 90: 650–657.
41. Uchino Y, Uchino M, Yokoi N et al. Alteration of tear mucin 5AC in office workers using visual display terminals: The Osaka Study. *JAMA Ophthalmol* 2014; 132: 985–992.
42. Chu CA, Rosenfield M, Portello JK. Blink patterns: reading from a computer screen versus hard copy. *Optom Vis Sci* 2014; 91: 297–302.
43. Wu H, Wang Y, Dong M et al. Meibomian gland dysfunction determines the severity of the dry eye conditions in visual display terminal workers. *PLoS One* 2014; 9: e105575.
44. Ribelles A, Galbis-Estrada C, Parras MA et al. Ocular surface and tear film changes in older women working with computers. *Biomed Res Int* 2015; 2015: 467039.
45. Yazici A, Sari ES, Sahin G et al. Change in tear film characteristics in visual display terminal users. *Eur J Ophthalmol* 2015; 25: 85–89.
46. Schapero M, Cline D, Hofstetter H. *Dictionary of Visual Science*, 2nd rev ed. Philadelphia: Chilton Book Co., 1968.
47. Marran LF, De Land PN, Nguyen AL. Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency. *Optom Vis Sci* 2006; 83: 281–289.
48. Moulakaki AI, Recchioni A, Águila-Carrasco AJD et al. Assessing the accommodation response after near visual tasks using different handheld electronic devices. *Arq Bras Oftalmol* 2017; 80: 9–13.
49. Tosha C, Borsting E, Ridder WH 3rd et al. Accommodation response and visual discomfort. *Ophthalmic Physiol Opt* 2009; 29: 625–633.
50. Wick B, Morse S. Accommodative accuracy to video display monitors: Poster #28. *Optom Vis Sci* 2002; 79: 218.
51. Rosenfield M, Logan N. *Optometry: Science, Techniques and Clinical Management*, 2nd revisted ed. London: Elsevier Health Sciences, 2009.
52. Iribarren R, Fornaciari A, Hung GK. Effect of cumulative nearwork on accommodative facility and asthenopia. *Int Ophthalmol* 2001; 24: 205–212.
53. Hennessey D, Iosue RA, Rouse MW. Relation of symptoms to accommodative infacility of school-aged children. *Optom Vis Sci* 1984; 61: 177–183.
54. Davies LN, Wolffsohn JS, Gilmartin B. Cognition, ocular accommodation, and cardiovascular function in emmetropes and late-onset myopes. *Invest Ophthalmol Vis Sci* 2005; 46: 1791–1796.
55. Jiang BC, White JM. Effect of accommodative adaptation on static and dynamic accommodation in emmetropia and late-onset myopia. *Optom Vis Sci* 1999; 76: 295–302.
56. Chase C, Tosha C, Borsting E et al. Visual discomfort and objective measures of static accommodation. *Optom Vis Sci* 2009; 86: 883–889.
57. Blehm C, Vishnu S, Khattak A et al. Computer vision syndrome: a review. *Surv Ophthalmol* 2005; 50: 253–262.
58. Schor CM, Johnson CA, Post RB. Adaptation of tonic accommodation. *Ophthalmic Physiol Opt* 1984; 4: 133–137.
59. Gamlin PD. Neural mechanisms for the control of vergence eye movements. *Ann N Y Acad Sci* 2002; 956: 264–272.
60. Gamlin PD, Yoon K. An area for vergence eye movement in primate frontal cortex. *Nature* 2000; 407: 1003–1007.
61. Lee H, Park S, Heo H. Acute acquired comitant esotropia related to excessive smartphone use. *BMC Ophthalmol* 2016; 16: 37.
62. Moon JH, Lee MY, Moon NJ. Association between video display terminal use and dry eye disease in school children. *J Pediatr Ophthalmol Strabismus* 2014; 51: 87–92.
63. Belmonte C, Nichols JJ, Cox SM et al. TFOS DEWS II pain and sensation report. *Ocul Surf* 2017; 15: 404–437.
64. Portello JK, Rosenfield M, Chu C. Blink rate, incomplete blinks and computer vision syndrome. *Optom Vis Sci* 2013; 90: 482–487.
65. Doughty MJ. Consideration of three types of spontaneous eyeblink activity in normal humans: during reading and video display terminal use, in primary gaze, and while in conversation. *Optom Vis Sci* 2001; 78: 712–725.
66. Tsubota K, Nakamori K. Dry eyes and video display terminals. *N Engl J Med* 1993; 328: 584–584.
67. Benedetto S, Drai-Zerbib V, Pedrotti M et al. E-readers and visual fatigue. *PLoS One* 2013; 8: e83676.
68. Koslowe KC, Waissman H, Biner-Kaplan M. The blink frequency relationship between reading from a computer screen and reading from a printed page. *Optom Vis Develop* 2011; 42: 168.
69. Cho P, Sheng C, Chan C et al. Baseline blink rates and the effect of visual task difficulty and position of gaze. *Curr Eye Res* 2000; 20: 64–70.
70. Rosenfield M, Jahan S, Nunez M et al. Cognitive demand, digital screens and blink rate. *Comput Human Behav* 2015; 51: 403–406.
71. Long J, Rosenfield M, Helland M et al. Visual ergonomics standards for contemporary office environments. *Ergonomics Australia* 2014; 10: 7.
72. Tsubota K, Nakamori K. Effects of ocular surface area and blink rate on tear dynamics. *Arch Ophthalmol* 1995; 113: 155–158.
73. Nielsen PK, Søgaard K, Skotte J et al. Ocular surface area and human eye blink frequency during VDU work: the effect of monitor position and task. *Eur J Appl Physiol* 2008; 103: 1–7.
74. Köpper M, Mayr S, Buchner A. Reading from computer screen versus reading from paper: does it still make a difference? *Ergonomics* 2016; 59: 615–632.
75. Miller K, Polse KA, Radke CJ. Black-line formation and the "perched" human tear film. *Curr Eye Res* 2002; 25: 155–162.
76. Shila R. The effect of ocular surface conditions on blink rate and completeness. 2011. Masters Thesis. Queensland University of Technology, Brisbane, Australia.
77. Fenga C, Aragona P, Di Nola C et al. Comparison of ocular surface disease index and tear osmolarity as markers of ocular surface dysfunction in video terminal display workers. *Am J Ophthalmol* 2014; 158: 41–48.e2.
78. Craig JP, Nichols KK, Akpek EK et al. TFOS DEWS II definition and classification report. *Ocul Surf* 2017; 15: 276–283.
79. Chidi-Egboka NC, Briggs NE, Jalbert I et al. The ocular surface in children: a review of current knowledge and meta-analysis of tear film stability and tear secretion in children. *Ocul Surf* 2018; https://doi.org/10.1016/j.jtos.2018.09.006.