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Viewing distance and eyestrain symptoms with prolonged viewing of smartphones

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Background: This paper investigates viewing distances and eyestrain symptoms in young adults reading from a smartphone for 60 minutes.
Methods: A survey related to common asthenopic (eyestrain) symptoms was administered to subjects before and after they read an extract from a novel on a smartphone for 60 minutes. Subjects rated their symptoms on a scale from zero (not at all) to four (extremely). The viewing distance to the smartphone was measured on a photograph taken of the subject every minute. Each subject used the same smartphone and read the same text.
Results: Subjects were 18 young adults (mean age: 21.5 ± 3.3 years) with self-reported good health, normal visual acuity and no accommodative or binocular vision disorders. The mean viewing distance while using a smartphone over 60 minutes was 29.2 ± 7.3 cm. The viewing distance was significantly greater during the first, second and fifth 10-minute time periods (30.6 ± 7.2 cm, 29.7 ± 7.3 cm and 28.9 ± 8.5 cm, respectively) than during the final 10-minute time period (27.8 ± 7.7 cm) (Wilcoxon, $p = 0.023$, 0.02 and 0.04, respectively). The total symptom score was significantly greater post-experiment (score = 8.06) than pre-experiment (score = 3.56) (Wilcoxon, $p < 0.001$). Symptoms of tired eyes, uncomfortable eyes and blur increased significantly after 60 minutes of smartphone use (Wilcoxon, $p < 0.05$). There was a significant correlation between change in total symptom score and change in viewing distance ($\rho = -0.51$; $p = 0.03$). The only single symptom that correlated with a change in viewing distance was 'uncomfortable eyes' ($\rho = -0.52$, $p = 0.03$).
Conclusion: Viewing distances are closer and eyestrain symptoms are greater after reading from a smartphone for 60 minutes. The viewing distances measured were closer than those previously reported in the literature.

Key words: asthenopia, eyestrain, smartphone, viewing distance

A smartphone is a handheld computer that allows the user to make telephone calls, access the internet and email, store data, view maps, play computer games, listen to music and watch videos. Since the introduction of the Apple iPhone in 2007,[1] mobile phone users have been steadily adopting the use of smartphones. It is estimated that 25 per cent of mobile phone users worldwide use a smartphone and that this figure will increase to 50 per cent by 2017.[2]

The physical dimensions of a smartphone visual display are smaller than other computer devices such as tablets and laptop computers. Although websites and other data displayed on smartphones may be rendered 'mobile-friendly' (that is, in a format compatible with the dimensions of the phone display), the font size displayed is small, prompting users to hold the smartphone at a close viewing distance when reading from the display.[3] Bababekova and colleagues[3] report that the mean viewing distance for reading text messages on a smartphone is 36.2 cm and for internet viewing is 32.2 cm, which is closer than that usually adopted for other computer devices.[4] Close viewing distances increase the visual (accommodation and vergence) demands on the user[5,6] and may increase near point stress in some individuals.[7,8]

Visual discomfort from smartphone usage is likely to be greater if the phone is used for extended periods of time. Survey and data-logging data indicate that smartphones are usually used for brief time periods, for example, to access an email, news updates or check the time.[9,10] Falaki and colleagues[9] report that the median session length is less than one minute but some people may use their phones for more than one hour in any one session. Playing games and accessing maps are common applications associated with extended session lengths.[9] There are currently no published international or Australian standards specifically for the use of smartphones.[4] The International Standard ISO 9241–303[11] recommends that characters on any visual display should subtend an angular size at the eye of at least 16 minutes of an arc (′), preferably 20′ to 22′, calculated using the size of a capital letter. This is approximately three to four times the font size that a person with 6/6 vision can discern and is consistent with other recommendations for acuity reserves, for example, Grundy's recommendation that the visual acuity for a task should be at least twice that required to see the task.[12] Similarly, there is a convention that there should be one-third to one-half of the accommodative amplitude in reserve for prolonged near viewing; however, Wolffsohn and colleagues[13] found that pre-presbyopic subjects (aged 20 to 34 years) could sustain an average of 80 per cent of their amplitude of accommodation when reading printed text held close to their near point of accommodation for 30 minutes, without reporting symptoms. This suggests that it may be possible to comfortably perform prolonged near work with only 20 per cent of accommodative amplitude held in reserve.

The purpose of this study was to:

1. measure the viewing distance adopted by subjects during a 60-minute smartphone viewing period;
2. investigate whether using a smartphone for 60 minutes increases eyestrain symptoms; and
3. determine if there is a relationship between eyestrain symptoms and any change in smartphone viewing distance.

METHODS

Overview

This study was conducted between July and November 2013 at the School of Optometry and Vision Science, The University of New South Wales (UNSW). It consisted of four phases: visual function screening, a pre-experiment symptom survey, one hour reading from a smartphone (referred to in this paper as 'the experimental procedure') and a post-experiment symptom survey. Overall it took approximately 90 minutes for each subject to complete the four phases.

The experimental procedure required subjects to read an excerpt from a novel, *Ten Tiny Breaths*[14] on a smartphone. Photographs were taken of their posture every minute to enable measurements to be calculated of their viewing distance from the phone. Subjects were informed that the study was investigating whether using a smartphone causes eyestrain and they knew that their photograph would be taken throughout the experiment. They were not told that the experimenters would be using the photographs to measure their viewing distance from the smartphone.

This study adhered to the Declaration of Helsinki for research on human subjects and was approved by the UNSW Human Research Ethics Advisory (HREA) panel. Each subject gave written informed consent to participate after explanation of the nature and possible consequences of the study.

Subjects

Subjects were recruited through posters placed around the Kensington Campus of the UNSW. The inclusion criteria were age 18 to 40 years, experience using a smartphone, self-reported good health, no history of eye surgery, eye trauma or eye injuries and no self-reported back or neck pain when using a smartphone. Twenty-six subjects were recruited, of which 19 met the inclusion criteria. The data from one subject were excluded from analysis because this subject moved excessively during the task. Thus there were 18 subjects (mean age: 21.5 ± 3.3 years, range 18 to 29 years, 12 male), whose data were included for analysis.

Visual function screening

A visual function screening examination was conducted to exclude subjects with less than normal visual acuity, gross accommodative dysfunction and disorders of binocular vision. The inclusion criteria were binocular logMAR visual acuity of less than 0.1 at 6.0 metres and at 40 centimetres, less than 0.20 logMAR difference in visual acuity between the two eyes at distance and near, at least 5.00 dioptre binocular accommodative amplitude to rule out early presbyopia, near point convergence of 6.0 centimetres or less, near vertical heterophoria 1.0 prism dioptre or less and near horizontal heterophoria not greater than two esophoria or eight exophoria. Subjects with refractive errors wore their habitual distance correction (spectacles or contact lenses) during the experiment. No one wore a reading addition. Although the inclusion requirement for accommodative amplitude was only 5.00 dioptre, the subjects were younger than 30 years and had ample accommodative reserves to perform sustained near work, whether one uses the usual 50 per cent accommodative reserve or the 20 per cent accommodative reserve suggested by Wolffsohn and colleagues.[13]

The 15 question revised Convergence Insufficiency Symptom Survey (CISS) was used to screen for subjects who were highly symptomatic of eyestrain or lack of concentration when reading. Subjects were excluded if they had a score of 21 or higher.[15] Although the CISS was not designed as a screening tool,[15] it is very comprehensive and subjects were considered less likely to have an existing binocular vision disorder than if another less comprehensive tool was used.

Pre- and post-experiment survey

A survey with seven questions related to common asthenopic (eyestrain) symptoms was administered to subjects before and after the experimental procedure (Table 1). The terminology within the questions are common descriptors given by patients in a clinical setting for eyestrain and correspond to the 'internal symptom factor' category coined by Sheedy, Hayes and Engle,[16] that is, symptoms which may be associated with close viewing distances. Subjects were asked to rate each symptom on a scale ranging from zero ('not at all') to four ('extremely'). If the subject rated each symptom as 'extremely', then this would represent a total maximum score of 28.

Apparatus for the experimental procedure

Subjects were seated in a quiet room for the experimental procedure. A tripod-mounted Canon 1000D SLR camera was positioned two metres away from the subject. This had a remote cable attached to allow photographs to be taken without the experimenters moving in the room or disrupting the subject from the task. Subjects wore a headband that had a 10 cm long scale, subdivided into one-centimetre increments (Figure 1). This was used as a reference for calculating the viewing distances shown in the photographs.

The same smartphone (an iPhone 4S) was used by all subjects. The average illuminance on the reading plane was 344 lux and the average luminance of the white display on the phone was 88 candelas/m^2. The text size was two millimetres (the height of a capital letter H). The smartphone was set to flight-mode and the auto-lock function was disabled during the reading task.

The reading task was an extract from a recently published novel[14] and had 280 Dutch words embedded within the text, spaced approximately one screen page apart on the display. The text has a Coleman-Liau readability index of approximately 7, which means that the text is easy to comprehend at the seventh grade level or junior high school level.

Experimental procedure

Instructions to subjects were threefold. They were instructed to hold the smartphone 'where they would normally hold it' and read the extract from the novel. They were told that there were foreign words incorporated within the text and they should read these words aloud when seen. In this way, the experimenters could monitor the subject's attention to the task.

Subjects were also instructed to scroll down the phone using only one finger to avoid accidently enlarging the font size on the display.

How tired do your eyes feel?	0	1	2	3	4
How uncomfortable do your eyes feel?	0	1	2	3	4
How sore do your eyes feel?	0	1	2	3	4
How sleepy do you feel?	0	1	2	3	4
Do you have a headache?	0	1	2	3	4
Do you have any blurred vision?	0	1	2	3	4
Do you have any double vision?	0	1	2	3	4

Table 1. Pre- and post-experiment symptom survey. Subjects were asked to rate how they felt 'at the moment' on a Likert scale, where 0 = not at all, 1 = very slightly, 2 = slightly, 3 = moderately and 4 = extremely.

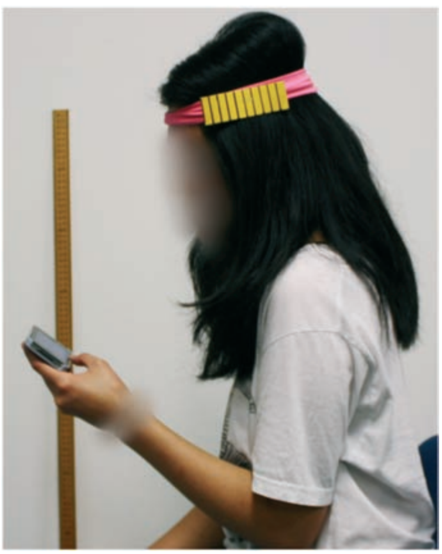

Figure 1. Photograph of a subject wearing the headband with a scale. The identity of the subject has been blurred.

By limiting the use of the phone to one finger, it did not matter what type of phone the subject had experience using, as all smartphones work in this way.

Finally, subjects were instructed to remain seated in a general straight-ahead position with their faces sideways to the camera. In this way, calculations could be made of viewing distance to the display. On occasions when the subject's posture was altered inappropriately during a photograph (for example, if they coughed or stretched their body), an additional photograph was taken immediately after the subject resumed reading.

Analysis of data

The viewing distance of the subject's eyes to the smartphone was calculated on each photograph using the 10 cm scale on the reference headband. Photographs were analysed on a single computer by one author using a ruler with 1.0 mm increments. Repeatability of the measurements was checked by another author, who randomly selected 20 photographs and remeasured the viewing distances. The repeatability coefficient was 0.82, meaning that 95 per cent of the original and repeat measurements were within 0.82 cm of each other. Thus, the method was repeatable.

The non-parametric Friedman test was used to evaluate any change in viewing distance over the entire 60 minutes. Further analysis was conducted by 'binning' the viewing distances into six 10-minute periods and then using the nonparametric Wilcoxon test to compare each 10-minute period. The pre- and post-experiment symptom survey results were compared within-subjects using the Wilcoxon signed-rank test. A Spearman correlation coefficient was calculated to establish if there was a relationship between the change in subjects' viewing distances and the change in their overall symptom survey scores. This was conducted in two ways: variance in viewing distance versus symptom score change and viewing distance versus individual symptom score changes.

Statistical calculations and graphs were performed with GraphPad Software – Prism (Version 6, GraphPad Software, Cary, California, USA).

RESULTS

The mean viewing distance calculated from the photographs at t = 1 minute was 31.0 ± 8.2 cm and over the entire one-hour period was 29.2 ± 7.3 cm. This represents a statistically significant reduction in viewing distance over the 60-minute period (Friedman p = 0.003). When the six 'binned' periods were compared with each other, the viewing distance during the first 10 minutes of the experiment (30.6 ± 7.2 cm), the second 10-minute interval (29.7 ± 7.3 cm) and the fifth 10-minute interval (28.9 ± 8.5 cm) were significantly greater than the viewing distance during the last 10 minutes of the experiment (27.8 ± 7.7 cm) (Wilcoxon signed-rank test, W = 36; p = 0.030, W = 37; p = 0.034 and W = 39; p = 0.043, respectively) (Figure 2).

The mean total symptom score was significantly greater post-experiment (score = 8.06, out of a possible maximum score of 28) than pre-experiment (score = 3.56) (Wilcoxon signed-rank test, W = 3.5; p < 0.001). The change in symptom score was not spread evenly throughout all symptoms (Figure 3). Symptoms of tired eyes, uncomfortable eyes and blur increased significantly after

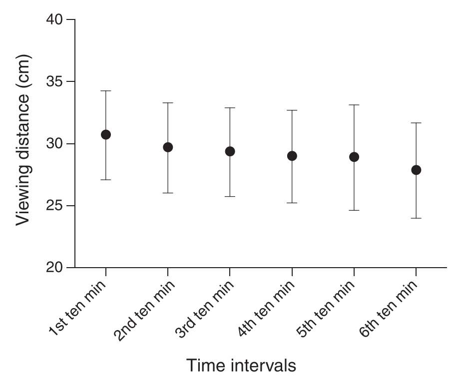

Figure 2. Mean working distance for each 10-minute interval. Error bars indicate 95 per cent confidence intervals.

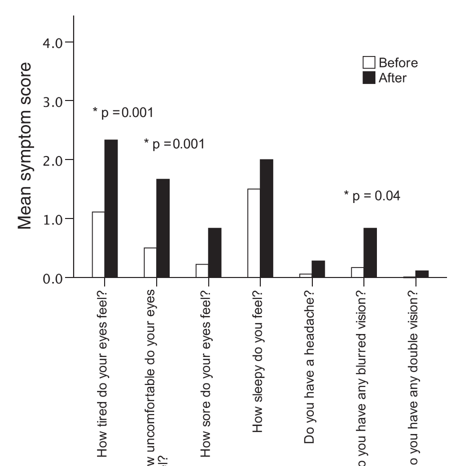

Figure 3. Reported symptoms before and after using smartphone for one hour. * indicates significant difference between before and after symptom scores.

60 minutes of smartphone use (Wilcoxon, $p < 0.05$) but the change in scores for the remaining symptoms listed in Table 1 were not significant (Wilcoxon, $p > 0.05$).

There was a significant correlation between the change in total symptom score and the change in viewing distance, that is, subjects who reduced the viewing distance to a greater extent were more likely to report higher eyestrain symptom scores (Spearman's correlation coefficient $\rho = -0.51$, $p = 0.03$). This relationship is shown in Figure 4. There was also a significant correlation between change in viewing distance and change in the individual symptom score for the symptom of 'uncomfortable' eyes (Spearman $\rho = -0.52$, $p = 0.03$). There was no significant correlation between tired eyes and change in viewing distance (Spearman $\rho = -0.39$, $p = 0.11$) or between 'blur' and change in viewing distance (Spearman $\rho = -0.14$, $p = 0.59$), despite the fact that there was a significant increase in these symptoms after smartphone use.

To test whether the subjects who reported a higher symptom score post-experiment made more frequent adjustments to their posture during the task, a correlation coefficient was calculated for the change in symptom score and variance (SD) in the viewing distance and the final symptom score and variance in the viewing distance during the experiment. There was no significant correlation between these variables (Spearman $p > 0.05$).

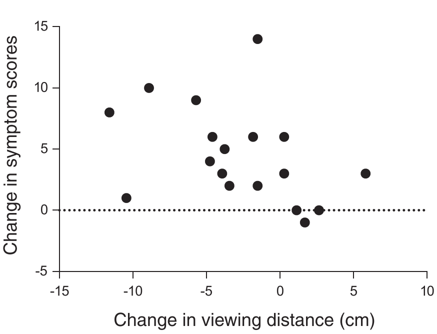

Figure 4. Correlation between change in symptom score and change in viewing distance. A positive change in symptom score indicates a greater severity of symptoms at the end of the hour. A positive change in working distance indicates that the smartphone was held further away at the end of the hour.

DISCUSSION

This study evaluated the viewing distance and eyestrain symptoms in young adults performing a 60-minute reading task on a smartphone. The results show that eyestrain symptoms increased at the end of the 60-minute reading period. Subjects were also more likely to hold the smartphone at a closer viewing distance at the end of the reading task and this correlated with an increase in symptom score. The symptom scores that showed the largest increase after the 60-minute reading task were tired eyes, uncomfortable eyes and blur. The increase in the 'uncomfortable eye' symptom was significantly correlated with a decrease in viewing distance.

Viewing distances measured at the start of the 60-minute reading period (31.0 ± 8.2 cm) compare favourably with those reported by Bababekova and colleagues[3] (32.2 cm for internet viewing) but these viewing distances were not maintained over time and were significantly shorter at the end of the 60-minute reading period. A limitation of Bababekova and colleagues'[3] method (that is, asking the subject to 'hold the phone where they normally would') is that the subjects' self-perceived posture may be different from their actual posture, when engrossed in a task.[17] If this is true, then Bababekova and colleagues'[3] estimates may be overestimates of the viewing distances adopted for hand-held smartphones; however, the viewing tasks in the two studies are different (reading in this study, texting and web-browsing in the study of Bababekova and colleagues[3]) so it is not possible to speculate any further about differences between the results.

People adopt closer viewing distances when viewing small fonts,[17] presumably to increase the angular size of the image on the retina. In this study the angular size of the retinal image was 22.5′ during the first 10 minutes of the experiment and 24.4′ during the last 10 minutes of the experiment. This is slightly larger than the angular size recommendations given in the International Standard ISO 9241–303.[11]

The perceived difficulty for a visual search task is greater when the font is smaller[18] and subjective comfort ratings are reduced in the presence of visual stress associated with small fonts.[19] The size of the font was held constant in this experiment, so it is not possible to draw any further conclusions about any relationship between font size, perceived difficulty and visual comfort.

Subjects were excluded if they had gross accommodative dysfunction, binocular vision disorders or if they were habitually symptomatic. Therefore, the changes in reported symptoms are unlikely to be due to an underlying chronic visual problem. It is possible that the subjects experienced visual stress associated with the visual demands of the task and attempted to minimise eyestrain symptoms at the end of the 60-minute viewing period by shortening the viewing distance to the smartphone and thus, increasing the angular size of the image on the retina. This is similar to the conclusion stated by Rempel and colleagues,[20] when they observed similar postural modifications of subjects using a desktop computer for two hours.

Alternatively, subjects may have held the smartphone closer at the end of the 60-minute period because of transient near work-induced myopia, similar to that reported by Rosenfield and Ciuffreda[21] in a sustained near task held at a 20 cm viewing distance. Holding the phone closer in response to visual stress is a self-defeating strategy because the shorter viewing distance further increases the accommodation/convergence demands.

If this study were repeated, then these issues could be explored in greater depth by asking subjects if they experience blur at a near or far distance and by measuring their visual function (such as refraction, accommodation and heterophoria) pre- and post-smartphone use. Similarly, there may be a biomechanical explanation for the reduced working distance and altered posture of the subjects, for example, fatigue of the arm/shoulder muscles from holding the smartphone for an extended length of time but this was beyond the scope of this study and warrants further investigation.

There are several limitations of this study. Although subjects obeyed the instruction to sit with their body parallel to the camera, there was the risk of parallax errors, when calculating the viewing distance, if their alignment changed relative to the camera. Alternative methods for measuring this for further projects are to use an infrared sensor on the subject's head[18,20] or a head-mounted tool as described by Piccoli and colleagues.[22]

A second limitation of the study relates to the eyestrain symptom survey. Subjects were aware that eyestrain was being measured and may have expected to experience symptoms. They may also have had different thresholds for when they report eyestrain symptoms. The within-subject experimental design mitigates against these variables, with the assumption that subjects used the same criteria for 'eyestrain' during the pre- and post-experimental survey.

It is possible that some subjects scanned the text for Dutch words rather than reading and comprehending the content. Although this is a limitation, all subjects appeared to be engaged in the reading task and symptom scores became larger at the end of the reading period. Future studies could include comprehension questions at the end of the reading period to retrospectively confirm that the subjects were reading rather than scanning the text. It would still be important to include checks during the experimental procedure, such as was done in this study with Dutch words, to ensure that subjects remained attentive to the task throughout the experimental time period.

This study highlights potential visual discomfort issues when people use a smartphone for prolonged reading tasks. Future studies could investigate viewing distances and eyestrain symptoms when performing interactive tasks, such as computer games, assess whether eyestrain symptoms occur with shorter durations of use and quantify changes in binocular visual function before and after viewing a smartphone. This study was limited to people with normal binocular vision, yet showed a significant increase in reported symptoms. Future research could investigate whether people with binocular vision problems report a greater number of eyestrain symptoms under similar experimental conditions. People with self-reported neck and back discomfort were also excluded from this study but including them in future research could add to the body of knowledge, which debates a link between gaze stability and physical posture.[23]

CONCLUSION

Smartphones of the future may become equipped with a greater functional capacity, allowing more diverse use. Understanding the aetiology and consequences of eyestrain under different viewing conditions and the implications this has for short- and long-term use of smartphones is important for developing standards, recommendations and guidelines, especially for a general population, where individuals may have underlying uncorrected disorders of binocular vision.

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