SYSTEMATIC REVIEW

Smartphone Use on Accommodation and Vergence Parameters: A Systematic Review

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ABSTRACT

Introduction: The frequency and the trend of smartphone use increase rapidly, and 85% of Malaysians owns a smartphone and spend an average of 187 minutes per day to use the smartphone. **Aims:** To evaluate the potential effects of smartphone use on Accommodation and Vergence of the users. **Methods:** A total of 18 articles were selected in this review following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, and the research question was formulated based on the population, intervention, control, and outcomes (PICO) method. This review was registered with PROSPERO (reference number: CRD42022293325). **Data Sources:** Databases namely PubMed, Web of Science, and Science-Direct were used in the article search using appropriate keywords, phrases, and Medical Subject Heading (MeSH) terms. The inclusion criteria of this review were journal articles published from January 2010 until December 2021 with full articles or abstract in English available. **Results:** Accommodative function has been reported to changed significantly with 20 minutes of smartphone use, with reduced amplitude, facility, relative and increased lag. In addition, vergence function has been reported to be altered significantly with receded near point of convergence. **Conclusion:** Smartphone use has an effect on the accommodation and vergence parameters among adults. Assessments of accommodation and vergence parameters need to be conducted in patients with the symptoms of Computer Vision Syndrome to prevent vision problems. Future reviews are required in younger cohorts with various smartphone features.
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INTRODUCTION

The term “smartphone” refers to a new level of mobile phones that offer integrated services from communications, computing, and mobile sectors (1). Modern smartphone models have the functions of portable media players, low-end compact digital cameras, pocket video cameras, and GPS navigation units. Other than that, recent smartphones commonly have the functions of high-resolution touch screens, the ability to access and display standard webpages, and the accessibility to high-speed data via Wi-Fi and mobile broadband (2). Therefore, the time taken to view the display screen is higher compared to ordinary mobile phones (3).

Moreover, many individuals of all ages use the smartphone for virtual learning and near work. Importantly, the use of electronic devices including smartphones has become more prevalent since the coronavirus (COVID-19) pandemic. Generally, young people use smartphones to watch videos, express themselves, talk to friends, and search for variety information, while elder people use their smartphones to make video calls to their distant children (4). In 2014, 1.85 billion people globally used smartphones. The figure was expected to reach 2.32 billion in 2017 and 2.87 billion in 2020. Malaysia is ranked 27th out of the top 50 countries in terms of smartphone penetration and number of smartphone users, with approximately 19,967,000 users owning smartphones (5). Notably, 74% of Malaysian adults aged 18 to 35 use smartphones in their daily lives (6). Vserv’s Smartphone User Persona Report (SUPR) in 2015 revealed that, Malaysians spent 187 minutes per day or three hours seven minutes per day with their smartphones (7). Therefore, the smartphone addiction proneness (SAP) among children and adolescents is also on the rise (8). For instance, adolescent smartphone possession rates are around 55% in Malaysia (9).

Accommodation occurs when the eye is focused, while vergence occurs when the eyes converge to see near objects (10). Near work can cause degradation in accommodative and vergence functions due to the spasm of ciliary muscle and iris (11). Also, physical characteristics of smartphones such as small visual display and text sizes require a short working distance and consequently increase the demands on eye adjustment and verification (12; 13). Moreover, the extended use of smartphones causes eye fatigue symptoms, miosis, and ocular stress (14; 15). Therefore, this review was conducted to systematically investigate the effects of smartphone use on accommodation and vergence parameters on the adult users and to evaluate the potential effects of smartphone use on accommodation and vergence of the users. This review is predicted to provide detailed analyses and interpretation with the results of previous studies as a reference for clinical assessments, to increase the knowledge and awareness on the effects of smartphone use with a binocular visual system, and to identify strengths and opportunities for future research.

METHODS

Study Design

This study was registered with PROSPERO (reference number: CRD42022293325) and designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis 2020 as an updated guideline for reporting systematic reviews. The PRISMA guideline is a type of tool that aims to help authors in improving the quality of selection of research papers, and the guideline is comprised of four phases. The first stage is identification, where the author identifies related articles from relevant databases. The second stage is screening, whereby the author makes precise selection based on the topic and abstract. The third stage is eligibility, in which the author makes an article selection based on the inclusion and exclusion criteria. Finally, in the fourth stage, all the matched articles or abstracts are reviewed systematically (16).

Next, the research question was formulated based on the population, intervention, control, and outcomes (PICO) method as detailed below:
Population : Adults
Intervention : None
Comparison : Baseline (pre) with post smartphone use
Outcomes : Changes in accommodation and vergence parameters
The main research question of the study was whether smartphone use has any effect on accommodation and vergence parameters on adult users.

Information Source

In this review, the relevant original articles published from January 2010 until December 2021 were identified by searching international databases namely PubMed, Web of Science, and Science-Direct. Besides, a manual search was conducted in Google Scholar to attain more articles that could support to accomplish the final findings. Furthermore, citation searching, websites searching, and studies or reports from previous version of reviews were also incorporated in the search.

Search Strategy

The search strategy was carried out in English using the Medical Subject Heading (MeSH) terms to find the related publications in PubMed database. Phrase searching method was used to identity the related articles with appropriate sentences such as “effect of smartphone on accommodation”, “smartphone use on vergence” and etc. Truncation technique with the asterisk symbol was used to broaden the search in the databases. In addition, appropriate keywords were also used in the searching of other databases or methods according to the subject and title of the study using Boolean operator’s standard. The relevant articles were searched as (“electronic device,” OR “digital handheld,” OR “mobile phone,” OR “visual display,” OR “gadget,” etc.) and (“binocular vision,” “vision,” OR “accommodation,” OR “vergence,” OR “convergence,” OR “phoria,” OR “strabismus,” OR “squint eye,” etc.). The above-mentioned words were also searched with and without combination for accurate findings. Furthermore, citation searching and website searching were also used to identify many more papers.

Criteria of Inclusion and Exclusion

An initial screening process was carried out early on to detect and eliminate any duplicate items. A total of 46 articles were retrieved, and their eligibility based on the inclusion and exclusion criteria was analysed. The inclusion criteria of this review were research articles published from January 2010 until December 2021, full articles or abstract published in English, a study involving adult population, and a topic on smartphone use with accommodation and vergence parameters. Studies reporting irrelevant content such as smartphone-induced eye disease, computer vision syndrome, and smartphone addiction, articles published before the year 2010, use of other types of gadgets besides smartphone, presbyopia, children population, unpublished data, duplicate articles, conference abstract, closed access papers, websites, case reports, and books were all removed.

Quality Assessment

Quality assessment of the selected articles was conducted using the Joanna Briggs Institute (JBI) Critical Appraisal guidelines. The JBI Critical Appraisal tool was used to identify potential biases in the plan and intervention and was adjusted to the type of research design used such as cohort and cross-sectional. The cohort study has eleven predefined checklist items, while the cross-sectional study has eight predefined checklist items. For this systemic review, the criterion assessment was given a score of yes, no, unclear, or not applicable, and each criterion with a yes score was given one point, while the other scores are zero. The assessment score was then determined and added up, and the percentage was calculated (17).

Data Abstraction and Synthesis

The data extracted from all the search strategies were organised, analysed, and summarised in PRISMA flowchart as shown in Fig. 1. A total of 507 abstracts and articles were identified via the online databases and other searching methods. However, 66 articles were excluded from this review based on the exclusion criteria. The final number of papers discovered in this systematic review was 18. All the searched articles were exported to the EndNote software of bibliography to ease the data management. Besides, the information such as author's name, year and country of publication, participant's age, study design, type of task, duration of smartphone use, P-value, and the changes in accommodation and vergence parameters were retrieved from the selected journals and are summarised in Table I.

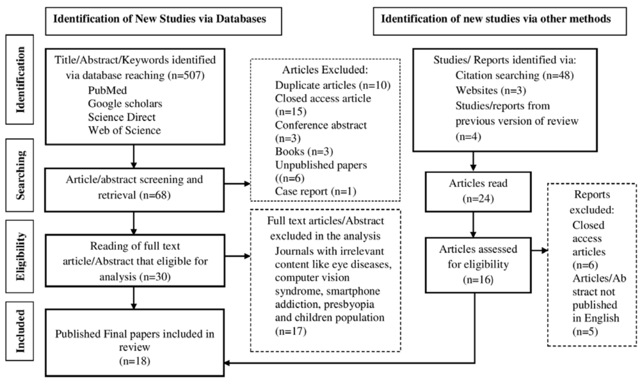

Fig. 1: PRISMA Flow chart of the number of studies screened and included in the systematic review (16)

RESULTS

Following a review of the relevant literature, 18 articles discussing smartphone use on accommodation and vergence parameters among adults were identified and analysed. The results of the data extraction of finalised articles are summarised in Table 1. In addition, a brief definition of accommodation and vergence functions are explained below. An amplitude of accommodation is the closest point to the eye at which the target is sharply focused on retina measured with Royal Air Force (RAF) ruler. Accommodative facility is the capability of the eye to focus on different target at various distance in a given period measured with the help of flippers +/-2.00D. Meanwhile, accuracy of accommodation is measuring the near accommodative response when the eyes are actively accommodating via Monocular Estimation Method (MEM). Relative accommodation measures the maximum ability to relax and stimulate accommodation while maintaining single and clear binocular vision. Next, near point of convergence (NPA) is the point closest to the eye at which a circular target is sharply focused on the retina measured with RAF ruler (18). A vergence is the simultaneous movement of both eyes in as opposite direction to attain or maintain binocular single vision. Lastly, heterophoria is latent ocular deviation in which one of the eyes tends to deviate either horizontally or vertically (19).

DISCUSSION

Amplitude of Accommodation

The use of visual display units (VDU) might stimulate impermanent effects to the eye accommodation status during near visual tasks (20). A reduction in amplitude of

Table I: Summary of effects of smartphone use on Accommodation and Vergence parameters as reported

Author/Year/ Country	Sample size/ type/gender details	Participants' Age	Task Performed	Duration Working	Distance/ Viewing Angle/ Font Size	Study Design	Accommodation Function	Vergence Function	P-value
Narawi et al. (2020) Malaysia (5)	N=40 Male=20 Female=20	19 to 30 years old	Playing word search game on smartphone	20 minutes	WD 40cm	Cross-sectional	↓ Monocular and binocular AA significantly ↓ Monocular and binocular AF significantly ↓ PRA significantly ↑ LAG significantly		P=0.00
Park et al. (2014) Korea (22)	N=63 Male=26 Female=37	19 to 26 years old	Watching movie on smartphone versus reading printed text	30 minutes	WD 40cm Font size 3.5mm	Cross-sectional	↑ LAG significantly ↓monocular/ Binocular AA significantly		P<0.05
Padavettan et al. (2021) India (18)	N=47 Male=17 Female=30	18 to 30 years old	Reading text on smartphone	30 minutes	WD 40cm Optotype N6	Prospective comparative for a duration of 6 months	↓ NRA significantly ↓ PRA significantly ↓ AF significantly ↑ LAG significantly	↓ NPC significantly ↓ PFV significantly ↓ VF significantly	P=0.00
Kang et al. (2021) Korea (10)	N=46 Male=22 Female 24	19 to 39 years old	Watching documentary video in you tube using smartphone	1 hour	WD 30cm	Prospective comparative for more than a week	↓ NPA significantly	↓ NPC significantly Near Phoria shift to Orthophoria	P=0.044

Table I: Summary of effects of smartphone use on Accommodation and Vergence parameters as reported (continued)

Author/Year/ Country	Sample size/ type/gender details	Participants' Age	Task Performed	Duration Working	Distance/ Viewing Angle/Font Size	Study Design	Accommodation Function	Vergence Function	P-value
Seo (2012) Korea (23)	N=48 Male=16 Female=32	University students	Near work on VDT	2 hours	Not specified	Cross-sectional	↑ LAG significantly ↓ Monocular/ Binocular AF significantly ↓ NRA significantly ↓ Monocular AA significantly		P=0.03
Golebiowski et al. (2019) Australia (25)	N=12 Male=3 Female=9	18 to 23 years old	Reading novel on smartphone	60 minutes	WD 30 to 34cm Font size 2mm	Longitudinal study by comparing the effect over time	↓ Binocular AF significantly		P=0.01
S.Kim et al. (2017) Korea (26)	N=131	Adults in their twenties	Watching movie on smartphone	30 minutes	WD 35 to 40cm 10 to 15° downward Font size 3mm	Cross-sectional	↓ Monocular AF in normal and CI group significantly ↓ Binocular AF in normal group significantly ↓ NRA in CI group by 53.8% ↑ PRA in normal group by 48% ↑ LAG in CE group		P<0.05
Zamari et al. (2021) Iran (28)	N=27 Male=11 Female=16	20 to 35 years old	Viewing smartphone	1 hour	Not specified	Cross-sectional	↑ LAG significantly		P=0.001
Ha et al. (2014) Korea (29)	N=40	20 to 30 years old	Reading text in smartphone, computer and printed material	Not specified	WD 40cm Font size 6,8,10,12	Cross-sectional	↓ Accommodative response significantly in smartphone than LCD monitor ↑ LAG significantly in smartphone		P=0.04
J.E Hue et al. (2012) USA (11)	N=20 Male=10 Female=10	18 to 24 years old	Reading text	20 minutes	WD 33cm	Cross-sectional	↑ LAG significantly		P=0.02
Moulakaki AI et al. (2019) Spain (30)	N=18	25 to 30 years old	Reading text on smartphone/ tablet	10 minutes	WD 40cm	Cross-sectional	↑ LAG with smartphone but no significant differences		P>0.05
Porcar et al. (2018) Spain (31)	N=89 Male=43 Female=46	20 to 34 years old of VDU users	Not specified	2 hours of VDT usage per day	Not specified	Cross-sectional	↓ PRA by 17% ↓ Monocular AF by 24%	↓ NFV by 49% ↓ Vergence facility with 3 Prism BI by 20% ↑ Eso by 34%	P<0.05
Park et al. (2012) Korea (32)	N=50 Male=30 Female=20	20 to 30 years old	Watching movie in smartphone and computer monitor	20 minutes	WD 50cm for smart phone WD 70cm for computer	Cross-sectional		↓ NPC significantly with smartphone ↑ Exophoria shift significantly with smartphone use	P<0.001
S. Kim et al. (2017) Korea (33)	N=132 Male=57 Female=75	Adults in their twenties	Watching video in smartphone	30 minutes	WD 35 to 40cm 10 to 15° Font size 3mm	Cross-sectional		↑ NPC in AI and AE groups ↓ AC/A ratio in AE subjects Near phoria shift to Ortho in all groups Distance phoria in normal and AE group change significantly	P<0.05

Table I: Summary of effects of smartphone use on Accommodation and Vergence parameters as reported (continued)

Author/Year/ Country	Sample size/ type/gender details	Participants' Age	Task Performed	Duration Working	Distance/ Viewing Angle/Font Size	Study Design	Accommodation Function	Vergence Function	P-value
S. Kim et al. (2018) Korea (34)	N=33 Normal=22 CI=11	Adults in their twenties	Watching movie on smartphone	30 minutes	WD 38 to 40cm 10 to 15° angle downward Subtitle font size 3mm	Cross-sectional		↓ NPC in normal groups ↓ AC/A ratio in normal group significantly Distance horizontal phoria shift to Ortho in both groups significantly Near Horizontal phoria change significantly in CI	P=0.02
Male Shiva Ram et al. (2018) India (14)	N=100 Male=52 Female=48	18 to 29 years old	Watching smartphone	1 hour duration before go to bed	Not specified	Cross-sectional		↑ CI score significantly (CISS)	P<0.001
J. Kim et al. (2016) Korea (35)	N=30 Male=26 Female=4	Adults in their twenties	Reading on smartphone and paper book	30 minutes	Not specified	Cross-sectional		↓ Near Horizontal Phoria significantly in Eso, Exo, Ortho ↓ PFV significantly with smartphone	P=0.01
Leung et al. (2020) Hong Kong (38)	N=29 Male=12 Female=17	18 to 24 years old	Watching movie in smartphone with walking and sitting	30 minutes	Not specified	Cross-sectional		↑ Exo deviation with sitting ↑ Eso deviation with walking	P=0.003

NOTE. PD: Prism Dioptre, D: Dioptre, NPA: Near Point Accommodation, NPC: Near Point Convergence, AF: Accommodative Facility, AA: Amplitude of Accommodation, PRA: Positive Relative Accommodation, NRA: Negative Relative Accommodation, CI: Convergence Insufficiency, CISS: Convergence Insufficiency Sleeping Scores, NFV: Negative Fusional Vergence, PFV: Positive Fusional Vergence, VDT: Visual Display Terminal, CE: Convergence Excess, AE: Accommodative Excess, AC/A: Accommodation Convergence/Accommodation, VF: Vergence Facility, LCD: Liquid Crystal Display, WD: Working Distance, EXO: Exophoria, ESO: Esophoria, ORTHO: Orthophoria, VDU: Visual Display Unit, N: Total number of cases in population, N6: Normal near vision print size, P-Value: The probability for a given statistical model, %: Percentage, ↓: Decrease, ↑: Increase, °: Degree, cm: Centimetre, mm: Millimetre.

accommodation (AA) is well noticed after using digital devices. This is due to a continued near task viewing of text on digital devices for a long duration (21). Also, a significant decrease of AA was reported monocularly from 9.9 D to 8.76 D and binocularly from 12.01 D to 10.96 D after 20 minutes of smartphone use at a viewing distance of 40 cm, and the reason for AA reduction is due to the high accommodative lag in 20 minutes of smartphone use (5). Similarly, monocular and binocular AA has reduced significantly from 9.30 D to 8.16 D and from 10.62 D to 9.45D, respectively, after watching a movie on a smartphone for 30 minutes. Therefore, near work with smartphone might cause continuous tension to the crystalline lens and eye muscle followed by excessive accommodative adaptation. Also, less blinking during near work might cause extended near point of accommodation (NPA) thus reducing the AA functions (22).

On the other hand, Padavettan et al. (18) reported no significant changes in NPA after reading texts on smartphones for 30 minutes, and this might be because of the strong accommodative reserve observed in the young adults. Furthermore, AA decreases significantly with a prolonged exposure on smartphones for more than one hour, and this is due to the tonic accommodation caused by continuous near work (10; 23). These results elaborate that the changes in AA vary with the font size, types of digital device, age, and duration of near work.

Accommodative Facility

The common symptoms of accommodative facility (AF) dysfunctions are well noticeable when taking a long time to clear the images when seeing from distance to near, and vice versa (24). A significant change in monocular and binocular AF occurs after playing games in smartphones for 20 minutes at a working distance of 40 cm (5). Furthermore, the binocular AF drops significantly with smartphone use from an average of 11.3 cpm on pre-task to 7.8 cpm on post-task, which might be strongly influenced by the vergence facility (25). Any changes found in binocular AF could be secondary to a change in the vergence facility. Besides, monocular AF is also reduced significantly in convergence insufficiency (CI) and normal subjects after 30 minutes of smartphone use with head tilted down gaze, while binocular AF is dropped significantly only in normal subjects (26). Therefore, smartphone viewing in CI subjects causes slow relaxation and more convergence thus increasing the accommodation demand for a clear image. Likewise, binocular AF is dropped significantly after continuous near work on smartphone in middle-aged subjects (18;

23).

In contrast, a study from Korea showed no significant difference in monocular and binocular AF after viewing movies on smartphones for 30 minutes (22). This was because the subjects' non-equivalent ability to adjust their +/– 2.00 D flipper.

Accuracy of Accommodation

Hyperopic defocus might occur either because of the raised levels of accommodation lag when looking at the screen or due to the normal accommodative lag with prolonged exposure that can stimulate anomalous axial elongation of the eyeball. Smaller texts on handheld electronic devices can directly contribute to the development of myopia by increasing the hyperopic defocus at the retina (27).

Accommodative lag increases significantly from 0.40 D to 0.93 D after 20 minutes of smartphone use in young Malaysians (5). Also, binocular accommodative lag increases significantly after 30 minutes of smartphone use in middle-aged groups due to constant stress on accommodative system without a break (22; 18). Also, a significantly high lag of accommodation was reported after two hours of visual display terminal (VDT) work. Therefore, the pixel format of letters on liquid-crystal display (LCD) displays causes a grater lag compared to the printed materials (23). Likewise, Zamari et al. (28) reported a high lag of accommodation after one hour of smartphone use, and the finding is consistent with other studies.

Also, the findings on accommodative lag are significantly higher with gadgets use compared to printed materials because of luminous materials that can induce more eye strain to an accommodative system (29; 11). On the other hand, the accommodative lag increases significantly in a convergence excess (CE) group compared to a control group after 30 minutes of smartphone use at a working distance of approximately 35 to 40 cm. This is because a prolonged smartphone viewing at near field causes eye fatigue in CE subjects thus increasing the lag (26).

Yet, non-statistical significant changes have been found in an accommodative response of relaxed eye, visually strained eye, and eyes with ten minutes of smartphone and tablet use. However, a low of lag of accommodation was found in all stimulus vergence (30). Also, no significant difference was reported in between lag and smartphone use with four different types of font sizes (6, 8, 10, and 12) (29). Moreover, a study among Koreans revealed that the accommodative response also increased slightly after the use of smartphone and tablet for an hour; however, these findings were not statistically significant (10). This is because the objective and subjective techniques for measuring the lag were different, thus it can influence the overall findings. For example, MEM may induce a shorter lag, while an objective method using auto-refractor with similar targets may produce an increase in lag (19). Thus, future studies should include or compare both methods in measuring accommodative lag with different stimuli to minimise the bias and error for consistent findings.

Relative Accommodation

Interestingly, smartphone use has given huge impacts on positive and negative relative accommodation (PRA/NRA). A study by Padavettan et al. (18) revealed a significant decrease in NRA and PRA after 30 min of smartphone use. A decrease in relative accommodation might cause a decline in fusional vergence as both NRA and PRA functions rely on fusional vergence to sustain binocular vision. Also, a study conducted among healthy adults showed that PRA declined statistically significant from –0.87 D to –1.28 D after 20 minutes of smartphone use because of high accommodative demand due to near tasks. However, no significant change was reported in NRA (5). On the contrary, NRA increased statistically significant from 2.18 D to 2.36 D after reading a book compared to watching a movie in a smartphone, which declined marginally from the baseline 2.18 D to 2.04 D. This may be due to the different font sizes used, and the variations of NRA between the two different materials (book vs. smartphone) showed a significant difference (22).

Furthermore, NRA value showed a marginal decline in CI group compared to the normal and convergence excess groups after 30 minutes of smartphone use at a working distance of approximately 35-40 cm. Hence, these results were not statistically significant. Therefore, NRA was found to decline in the CI subjects due to the loss of convergence control, and more accommodation was needed to obtain a clear image. In contrast, PRA was found to increase in the normal group by 48.0% and in the convergence excess group by 20.0% after watching a video on a smartphone (26). NRA also dropped significantly after two hours of VDT work, and a non-significant change was reported on PRA (23). The NRA may drop due to the stable eye fatigue after a prolonged near task. In contrast, a study among 89 Caucasians revealed that PRA reduced in 15 subjects after spending a few hours with a VDU work, while NRA function only reduced in five subjects (31).

Near Point of Convergence

A few studies have reported that NPC function receded with smartphone use. For instance, NPC reduced significantly from 7.39 cm to 8.53 cm after 20 minutes of smartphone viewing. Smartphone use also caused more visual fatigue compared to the monitors, which might be because of the different working distances (32). This finding was concurrent with other studies. A study by Padavettan et al. (18) revealed that NPC receded significantly by 15.8% after the smartphone use, and this decrease may be caused by visual distress with prolonged near tasks.

Likewise, another study revealed that, NPC function increased in Accommodative Excess (AE) and Accommodative Insufficiency (AI) groups as compared to the normal group after watching a video on smartphone for 30 minutes at working distances from 40 cm. However, these finding was not statistically significant. The reason for NPC surge was due to persistent near work which requires a continuous eye adjustment (33). Besides, after watching a movie on a smartphone, NPC showed more tendency to decline in normal eyes compared to this CI group. However, these changes were not statistically significant (34). These changes may be influenced by the individuals' capability to control by the same age.

Similarly, NPC showed a significant reduction from 10.22 cm to 10.46 cm after watching a documentary video on smartphone for one hour at a short working distance (10). Therefore, NPC recedes with a small display size, and extended screening time causes short, term myopia shift because of residual accommodative spasm. Also, a study in India revealed that. using a smartphone for one hour before going to sleep significantly increased the CI score. This may be due to light emitting features the smartphone that induced eyestrain and visual discomfort with extended use (14).

Fusional Vergence

There are few findings describing the effects of smartphone use on positive fusional vergence (PFV) and negative fusional vergence (NFV). For instance, a significant reduction in break and recovery point of PFV was observed from 25.03 PD to 22.83 PD and 15.60 PD to 13.23 PD, respectively, after 30 minutes of VDT work on a smartphone. However, no significant changes were recorded in NFV and PFV after reading a paper book (35). Therefore, VDT work may cause more eye strain compared to other reading materials. Furthermore, prolonged near work may increase eye muscle's tension thus inducing more accommodative and vergence adaptation. Generally, PFV is used to maintain binocular single vision (BSV) while using a mobile phone for a certain period.

Likewise, NFV value was also reported to drop by 49% in healthy Caucasians after two hours of using flat panel displays, hence PFV was only reduced by 6% (31). A study by Padavettan et al. (18) reported that PFV and NFV were reduced significantly after smartphone use because of a tension in the accommodative vergence.

In addition, one study found slight variations in both PFV and NFV after viewing a movie in a smartphone for 30 minutes in normal and CI subjects, but these variations were not statistically significant (34). PFV increased in CI subjects because of internal rectus muscle tension that was relatively high during the short working distance. Moreover, continuous near work also increases vergence adaptation, and continuous eye adjustment is needed to maintain the focus and gaze. Also, NFV increases in CI eyes because of weak convergence that requires more convergence for compensation to sustain binocularity. Further studies need to be done more precisely to analyse the close effects of smartphone use on NFV and PFV parameters. Also, vergence functions are strongly influenced by age where mid-forties subjects may develop ocular discomfort after near task.

Heterophoria

The assessment of heterophoria is very crucial in the diagnosis of various ranges of binocular vision disorders (36). Remarkably, a few studies have reported that continuous digital near work may tend to affect the alignment of visual axes. For instance, after using a smartphone for 30 minutes, the near phoria shifted significantly to more exophoric due to a short working distance and a small display size. However, both exophoric shifts were recovered after 10 minutes of rest (32).

Additionally, a significant reduction was reported in near horizontal heterophoria (exophoria, esophoria, orthophoria) after 30 minutes of reading from a smartphone. No significant changes were observed in near vertical phoria after the smartphone use, and this may vary with the types of digital devices used (35). Furthermore, a significant change was reported in distance heterophoria among normal and AE subjects after watching a video on a smartphone, and near heterophoria shift was found towards the ortho position in all subjects (33). A change in lateral deviation occurred due to a shift phenomenon, which increased the demand of accommodation and convergence adaptation.

One study found that distance horizontal phoria significantly moved to ortho position in normal and CI subjects after 30 minutes of watching a movie on a smartphone. However, near horizontal phoria changed significantly in CI subjects (34). These changes happened due to a close working distance. Also, brightness from the gadgets may cause worse eye irritation, which later can induce oblique angle. Furthermore, no significant changes were identified in distance and near phoria after watching a documentary video for one hour on a smartphone (24), which may vary with the types of tasks performed at a closer distance.

Interestingly, near esophoria notably increased by 34% after using the flat panel display for two hours, while exophoria shift was only reported in nine subjects (31). Eso deviation may occur due to psychological stress in eyeball after sustained near work. Further, an excessive use of smartphone at a close distance may result in accommodative and vergence dysfunction in individuals with low fusional divergence. Also, misalignment of visual axes occurs because of over stimulation of ciliary muscle during prolonged near work (37). Lastly, Leung et al. (38) found an increase in eso deviation after 30 minutes of smartphone use while walking than sitting due to the differences in the vergence adaptation. Smartphone use also causes intermittent diplopia at a distance that may lead to hypertonus of medial rectus muscle, which results in slow progression of esotropia (37).

CONCLUSION

Smartphone use has effects on accommodation and vergence parameters of the adult users. Accommodative function has been shown to be changed significantly with 20 minutes of smartphone use with reduced amplitude, facility, relative and increased lag. In addition, vergence function has been shown to be altered significantly with smartphone use with receded near point of convergence, and the limited findings propose that the fusional vergence declines with smartphone use. The evidence for an effect on phoria is inconclusive; however, there is a greater tendency for near phoria to shift towards exo and eso after using a smartphone. Smartphones with varying display sizes, font sizes, and luminance are widely used by many peoples of all ages in all waking hours. The effects of smartphone use on accommodation and vergence need to be investigated in younger generation with various smartphone features as most studies on smartphones to date have examined subjects aged 18 years and older. Assessments of accommodation and vergence parameters need to be conducted in patients with the symptoms of computer vision syndrome to prevent vision problems.

REFERENCES

1. Sarwar M, Soomro T. Impact of smartphone's on society. European Journal of Scientific Research. 2013;98(2):216-226. Available from: https://www.researchgate.net/publication/236669 025_Impact_of_Smartphone%27s_on_Society.
2. Kwon K, Woo J, Park M, Kim S. The change of accommodative function by the direction of eye movements during computer game. Journal of Korean Ophthalmic Optics Society. 2012;17(2). doi: 10.KS/JAKO201217760873302
3. Choi JH, Li Y, Kim SH, Jin R, Kim YH, Choi W, et al. The influences of smartphone use on the status of the tear film and ocular surface. PLoS One. 2018;13(10):e0206541. doi:10.1371/journal.pone.0206541.
4. Cha SS, Seo BK. Smartphone use and smartphone addiction in middle school students in korea: prevalence, social networking service, and game use. Health Psychology Open. 2018;5(1):1-15. doi:10.1177/2055102918755046.
5. Narawi WS, Razak SA, Azman N. The effect of smartphone usage on accommodation status. Mal J Med Health Science. 2020;16(2):244-247. Available from: https://medic.upm.edu.my/upload/dokumen/2020 042010354734_MJMHS_0456.pdf
6. Vserv. Smartphone Users Persona Report (SUPR). 2015. Available from: https://www.vserv.com/infographic-smartphone-user-persona-report-supr-2015-malaysia/.
7. Ithnain N, Ghazali SE, Jaafar N. Relationship between smart phone addiction with anxiety and depression among undergraduate students in Malaysia. Int J Health Sci Res. 2018;8(1):163-171. Available from: https://www.ijhsr.org/IJHSR_Vol.8_Issue.1_Jan201 8/25.pdf.
8. Chiang JT, Chang FC, Lee KW, Hsu SY. Transitions in smartphone addiction proneness among children: The effect of gender and use patterns. PLoS One. 2019;14(5):e0217235. doi:10.1371/journal.pone.0217235.
9. Kwok SW, Lee PH, Lee RL. Smart device use and perceived physical and psychosocial outcomes among Hong Kong adolescents. Int J Environ Res Public Health. 2017;14(2):205. doi:10.3390/ijerph14020205.
10. Kang JW, Chun YS, Moon NJ. A comparison of accommodation and ocular discomfort change according to display size of smart devices. BMC Ophthalmol. 2021;21:44. doi:10.1186/s12886-020-01789-z.
11. Hue JE, Rosenfield M, Saa G. Reading from electronic devices versus hardcopy text. Work. 2014;47(3):303-307. doi:10.3233/WOR-131777.
12. Long J, Cheung R, Duong S, Paynter R, Asper L. Viewing distance and eyestrain symptoms with prolonged viewing of smartphones. Clin Exp Optom. 2017;100(2):133-137. doi:10.1111/cxo.12453.
13. Bababekova Y, Rosenfield M, Hue JE, Huang RR. Font size and viewing distance of handheld smart phones. Optom Vis Sci. 2011;88(7):795-797. doi:10.1097/OPX.0b013e3182198792.
14. Male SR. Effect of Smartphone activity over Convergence insufficiency score before sleep. Journal of PeerScientist. 2018;1(1):e1000002. doi:10.5281/zenodo.3372280.
15. Antona B, Barrio AR, Gasco A, Pinar A, Gonzalez-Perez M, Puell MC. Symptoms associated with reading from a smartphone in conditions of light and dark. Appl Ergon. 2018;68:12-17. doi:10.1016/j.apergo.2017.10.014.
16. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:71. doi:10.1136/bmj.n71.
17. Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetcu R, et al. Chapter 7: Systematic reviews of etiology and risk. In: Aromataris E, Munn Z (Editors). Joanna Briggs Institute Reviewer's Manual. The Joanna Briggs Institute, 2017. Available from: https://reviewersmanual.joannabriggs.org/
18. Padavettan C, Nishanth S, Vidhyalakshmi S, Madhivanan N. Changes in vergence and accommodation parameters after smartphone use

in healthy adults. Indian Journal Ophthalmol. 2021;69(6):1487-1490. doi:10.4103/ijo.IJO_2956_20.
19. Jaiswal S, Asper L, Long J, Lee A, Harrison K, Golebiowski B. Ocular and visual discomfort associated with smartphones, tablets and computers: what we do and do not know. Clin Exp Optom. 2019;102(5):463–477. doi:10.1111/cxo.12851.
20. Majumder C, Zaimi NZ. Comparison of amplitude of accommodation in different room illumination while using VDU as a target. International Journal of Ophthalmic Research. 2017;3(3):243-248. doi:10.17554/j.issn.2409-5680.2017.03.64. (14)
21. Phamonvaechavan P. A comparison between effect of viewing text on computer screen and ipad on visual symptoms and functions. Siriraj Medical Journal [Internet]. 2017;69(4):185-189. Available from: https://he02.tci-thaijo.org/index.php/sirirajmedj/article/view/96720.
22. Park M, Ahn YJ, Kim SJ, You J, Park KE, Kim SR. Changes in accommodative function of young adults in their twenties following smartphone use. J Korean Ophthalmic Optics Soc. 2014;19(2):253-260. doi:10.14479/jkoos.2014.19.2.253.
23. Seo ES. Changes in accommodative function after VDT work. Journal of Korean Ophthalmic Optics Society. 2012;17(3):285-291. Available from: https://koreascience.kr/article/JAKO201217760887318.page
24. Moodley V. Amplitude, facility and accuracy of accommodation in a primary school population. African Vision and Eye Health. 2008;68(4):147-154. doi:10.4102/aveh.v68i4.196.
25. Golebiowski B, Long J, Harrison K, Lee A, Chidi Egboka N, Asper L. Smartphone use and effects on tear film, blinking and binocular vision. Curr Eye Res. 2020;5(4):428-434. doi:10.1080/02713683.2019.1663542.
26. Kim SR, Park MO, Lee SY, Song JH, Lee JH, Choi HD, et al. The change of accommodative function of vergence anomalies subjects in their twenties after near work with smartphone. J Korean Ophthalmic Opt Soc. 2017;22(1):71-80. doi:10.14479/jkoos.2017.22.1.71.
27. Sah RP, Ramasubramanian V, Reed O, Meyer D, Bradley A, Kollbaum PS. Accommodative behavior, hyperopic defocus, and retinal image quality in children viewing electronic displays. Optom Vis Sci. 2020;97(8):628-640. doi:10.1097/OPX.0000000000001543.
28. Zamani Shahri R, Jafarzadehpour E, Mirzajani A. Study of Lag of Accommodation After Using a Smartphone. Func Disabil J. 2021;4(1):38-38. doi:10.32598/fdj.4.38.
29. Ha NR, Kim CJ, Jung SA, Choi EJ, Kim HJ. Comparison of accommodative system according to the material and font size of near visual media. Journal of Korean Ophthalmic Optics Society. 2014;19(2):217-224. doi:10.14479/jkoos.2014.19.2.217.
30. Moulakaki AI, Recchiqni A, Aguila AJDC, Esteye Taboada JJ, Montes Mico R. Assessing the Accommodation response after near visual tasks using different handheld electronic devices. Arq Bras Oftalmol. 2017;80(1):9-13. doi:10.5935/0004-2749.20170004.
31. Porcar E, Montalt JC, Pons AM, Espana Gregori E. Symptomatic accommodative and binocular dysfunctions from the use of flat-panel displays. Int J Ophthalmol. 2018;11(3):501-505. doi:10.18240/ijo.2018.03.22.
32. Park KJ, Lee WJ, Lee NK, Lee JY, Son JS, Yu DS. Changes in near lateral phoria and near point of convergence after viewing smartphones. J Korean Oph Opt Soc. 2012;17(2):171-176. doi: 10.KS/JAKO201217760872300
33. Kim SR, Kwak H, Kang MS, Kim SI, Park M. The changes in convergence function of accommodative anomalies in their twenties after watching video on a smartphone. Journal of Korean Ophthalmic Optics Society. 2017;22(2):133-142. doi:10.14479/jkoos.2017.22.2.133.
34. Kim SO, Park SI, Yeo H, Kim D, Jeong J, Jang H, et al. The change of convergence functions of convergence insufficiency in their twenties after doing near work using a smartphone. Journal of Korean Ophthalmic Optics Society. 2018;23:47-56. doi:10.14479/jkoos.2018.23.1.47.
35. Kim J, Yang DJ, Choi DY, Kim SR, Park M. Changes in heterophoria and fusional vergence after near work with smartphone and paper book. J Korean Ophthalmic Opt Soc. 2016;21(4):385-392. doi:10.14479/jkoos.2016.21.4.385.
36. Lee HS, Park SW, Heo H. Acute acquired comitant esotropia related to excessive Smartphone use. BMC Ophthalmol. 2016;16:37. doi:10.1186/s12886-016-0213-5.
37. Kaur S, Sukhija J, Khanna R, Takkar A, Singh M. Diplopia after excessive smart phone usage. Neuro-ophthalmology. 2018;43(5):323-326. doi:10.1080/01658107.2018.1518988.
38. Leung TW, Chan CT, Lam CH, Tong YK, Kee CS. Changes in corneal astigmatism and near heterophoria after smartphone use while walking and sitting. PLoS ONE. 2020;15(12):e0243072. doi:10.1371/journal.pone.0243072.