Impact of digital device usage on binocular vision and refractive status

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10.5281/zenodo.19061946

Abstract:

The rapid integration of digital devices into everyday life has significantly increased visual demands among teenagers, leading to growing concerns regarding ocular health. Prolonged near work on smartphones, tablets, and computers may result in digital eye strain, early refractive changes, and disturbances in binocular vision functions due to stress on accommodative and vergence mechanisms. The present study aimed to evaluate the impact of prolonged digital device usage on binocular single vision parameters and refractive status among teenagers by comparing high users (≥4 hours/day) and low users (<4 hours/day). An observational study was conducted among 201 emmetropic participants aged 13 to 19 years who had been using digital devices for at least six months. A comprehensive ocular assessment was performed which included measurement of near point of accommodation, accommodative facility, positive and negative relative accommodation, near point of convergence, fusional vergence ranges, stereopsis, and refractive status. In addition, a structured questionnaire was administered to document subjective visual symptoms associated with digital device use. The findings revealed that high digital device users demonstrated significantly reduced accommodative amplitude, decreased accommodative facility, lower positive fusional vergence, and a receded near point of convergence when compared with low users ($p<0.05$). Participants with higher screen exposure also reported a greater frequency of symptoms such as headaches, blurred near vision, and visual fatigue. Furthermore, subtle subclinical myopic shifts were observed among high users, suggesting a possible association between prolonged near work and early refractive instability. The study indicates that excessive screen time among teenagers may adversely affect binocular single vision efficiency and increase the risk of visual discomfort and early refractive changes. Preventive strategies including regular breaks during screen use, increased outdoor activities, proper ergonomic viewing conditions, and periodic eye examinations are recommended to maintain ocular health in the digital era.

Keywords:

Digital Device Usage, Binocular Vision, Refractive Status, Screen Time, Accommodative Lag, Convergence Insufficiency, Myopia Progression.

1. Introduction:

Binocular vision is a complex visual function that enables both eyes to work together simultaneously to perceive a single clear image and to appreciate depth and spatial relationships. This visual ability depends on the coordinated functioning of several physiological systems including ocular anatomy, motor regulation of eye movements and sensory integration within the brain. When these systems operate harmoniously the visual cortex combines the slightly different retinal images from both eyes into one unified perception allowing individuals to experience clear vision and depth perception (1). Any disruption in one or more of these mechanisms can lead to binocular vision disorders that may cause symptoms such as visual fatigue, headaches, blurred vision and difficulty in performing near tasks such as reading or digital screen viewing (2).

2. Anatomical and motor components of binocular vision:

The anatomical structure of the visual system forms the basic framework necessary for binocular vision. The forward placement of the eyes within the skull allows the visual fields of both eyes to overlap significantly which is essential for fusion and depth perception. Proper functioning of the cornea, crystalline lens, retina,

ISSN: 3048-9407; SJRTDDS
Scienxt Journal of Recent Trends in Drug Delivery System

optic nerves and extraocular muscles ensures that light entering the eyes is accurately focused and transmitted to the brain for interpretation. Any structural abnormality caused by congenital malformation, trauma, neurological disease or developmental disorders may disrupt ocular alignment and impair binocular coordination (3). The motor component of binocular vision is responsible for controlling eye movements and maintaining proper alignment of both eyes while viewing objects at different distances. Six extraocular muscles attached to each eye coordinate movements in different directions including horizontal, vertical and rotational gaze. These muscles are controlled by cranial nerves and central neural pathways that ensure synchronized ocular motion. Functional disturbances in this motor system may occur even when anatomical structures appear normal. Such disturbances may arise due to neurological disorders, muscular weakness or abnormal neural signaling and may result in conditions such as diplopia, convergence problems and visual discomfort (4).

2.1. Sensory integration and stereopsis:

The sensory system of binocular vision involves the brain's ability to combine visual information received from both eyes into a single perceptual image. This process is known as sensory fusion and it occurs primarily in the visual cortex. One of the most important outcomes of sensory fusion is stereopsis which enables perception of depth and three-dimensional structure. Stereopsis occurs because each eye views an object from a slightly different angle and the brain interprets these small differences between retinal images to create depth perception (5). Accurate stereopsis is essential for tasks requiring hand eye coordination, spatial awareness and reading efficiency. Disruption of binocular sensory mechanisms can reduce stereoacuity and may indicate underlying issues in vergence or accommodative systems (6).

2.2. Binocular alignment and vergence mechanisms:

For clear and comfortable binocular vision the eyes must maintain precise alignment while focusing on objects located at different distances. This coordination is achieved through vergence movements which adjust the angle of the visual axes. Convergence occurs when the eyes rotate inward while focusing on near objects whereas divergence occurs when the eyes move outward to view distant objects. Additional mechanisms such as proximal vergence and fusional vergence assist in maintaining stable retinal alignment and single binocular vision (7). Heterophoria is a latent deviation of the eyes that becomes evident when binocular fusion is disrupted for example during cover testing. When both eyes remain perfectly aligned the condition is referred to as orthophoria. In contrast heterotropia represents a constant ocular deviation that is present even when both eyes are open and functioning together. These conditions are commonly grouped under strabismus which represents a significant form of binocular vision disorder (8).

2.3. Strabismus and binocular vision disorders:

Strabismus occurs when the eyes fail to maintain proper alignment under normal visual conditions. Depending on the direction of deviation it may present as esotropia exotropia hypertropia or hypotropia. The condition may be constant or intermittent and its effects vary depending on the age of onset and duration of misalignment. Early onset strabismus may interfere with the normal development of binocular vision and stereopsis often leading to amblyopia or suppression of one eye. In contrast strabismus acquired later in life may produce symptoms such as diplopia headaches and visual discomfort (9).

2.4. Accommodation and near vision mechanisms:

Accommodation is the process through which the eye changes its optical power to maintain a clear image of objects located at different distances. This is achieved by contraction and relaxation of the ciliary muscles which alter the curvature of the crystalline lens. During near vision tasks the eye activates the near triad which consists of accommodation convergence and pupillary constriction. These three responses work together to ensure that near objects remain clear and single (10). Disturbances in accommodative function may lead to various disorders including accommodative insufficiency accommodative spasm inertia of accommodation ill sustained accommodation and accommodative infacility. These conditions may produce symptoms such as blurred vision eye strain headaches and difficulty sustaining near tasks especially during prolonged reading or digital device use (11).

2.5. Convergence anomalies and visual efficiency:

Convergence plays a crucial role in maintaining single binocular vision during near activities. Convergence insufficiency is one of the most common binocular vision disorders particularly among students and individuals who engage in prolonged near work. It is characterized by a receded near point of convergence reduced positive fusional vergence and symptoms such as headaches eye strain blurred vision and difficulty concentrating during reading (12). Another vergence disorder known as convergence excess occurs when the eyes converge excessively during near tasks. It is typically associated with esophoria at near and reduced negative fusional vergence. Both convergence insufficiency and convergence excess can significantly affect visual comfort and efficiency especially in individuals who frequently use digital devices for academic or professional activities (13).

2.6. Refractive errors and visual health:

Refractive errors occur when the optical system of the eye fails to focus incoming light precisely on the retina resulting in blurred vision. The most common types include myopia hyperopia and astigmatism. These conditions may affect individuals of all ages and are typically corrected using spectacles contact lenses or refractive surgery. Myopia occurs when the eyeball is elongated causing distant objects to appear blurred while hyperopia occurs when the eye is relatively short leading to difficulty focusing on near objects (14). According to global health estimates uncorrected refractive errors remain one of the leading causes of visual impairment worldwide. Increasing evidence suggests that environmental and lifestyle factors including prolonged near work and reduced outdoor exposure contribute to the development and progression of refractive errors particularly myopia among children and adolescents (15).

2.7. Digital device usage and visual demands:

The rapid growth of digital technology has significantly increased visual demands in modern life. Devices such as smartphones tablets laptops and desktop computers are now commonly used for educational recreational and professional purposes. Although these devices provide numerous benefits they also require prolonged near viewing which places substantial strain on the accommodative and vergence systems of the eyes (16). Digital displays differ from printed text because characters on screens are formed by pixels with blurred edges and varying brightness patterns. This makes it more difficult for the eyes to maintain stable focus compared with printed material. As a result the eyes repeatedly adjust accommodation while attempting to maintain clarity leading to visual fatigue and eye strain during prolonged screen use (17).

2.8. Digital eye strain and visual symptoms:

The term digital eye strain describes the group of ocular and visual symptoms associated with prolonged use of digital screens. These symptoms include headaches blurred vision dry eyes neck pain eye fatigue and difficulty maintaining focus. Children and adolescents may be particularly vulnerable because they often use digital devices for extended periods without taking adequate breaks and may not recognize early signs of visual discomfort (18). Increased reliance on digital technology for education communication and entertainment has raised concerns about its potential effects on binocular vision and refractive development. Prolonged screen exposure may alter accommodative responses increase convergence demand and contribute to the onset of visual discomfort or binocular dysfunction. Therefore systematic evaluation of binocular vision parameters and refractive status in frequent digital device users is essential (19).

2.9 Need for the present study:

Although several studies have investigated the relationship between screen time and visual discomfort relatively few have simultaneously evaluated both binocular vision parameters and refractive status among teenagers. Adolescence represents a critical stage of visual development and lifestyle habits established during this period may influence long term ocular health. Understanding how prolonged digital device use affects accommodation convergence stereopsis and refractive status is therefore important for preventing visual disorders and promoting healthy screen habits (20).

2.10. Review of literature:

The widespread use of digital devices like smartphones, tablets, laptops and desktop computers has increased at an unprecedented rate during the late 20th and early 21st century's rapid technological change(151). They are now a commonplace aspect of people's lives used for communication, employment, education and entertainment (151). According to Twenge et al, the average amount of time spent in front of digital screens has significantly increased for both adults and children, according to recent global surveys, in some studies, children spend as much as 6 to 8 hours a day in front of digital screens(152). Vision scientists, physicians and public health officials were concerned about the possible effects of extended near work on the eyes because of this sudden shift in visual behavior. The effects of digital device use on binocular vision and refractive status specifically the onset and progression of myopia are two major areas of concern. Three-dimensional vision and depth perception depend on binocular vision which necessitates precise synchronization of accommodation (focusing) and vergence (eye alignment)(153). Headaches, visual discomfort and poor visual performance can result from disturbances in these processes(154). Globally, the prevalence of refractive errors, of which myopia or nearsightedness was the most common with East Asia frequently having a higher rate than other regions. Later in life, myopia linked to major eye conditions like myopic maculopathy, glaucoma and retinal detachment(155). According to epidemiological data, prolonged near visual tasks and little time spent outside are major environmental factors that contribute to the development and progression of myopia(156). A lot of research has been done on the effects of prolonged use of a digital screen on the visual system including binocular coordination and refractive development because digital work is still frequently done in a near working style which requires intense concentration at short distances without breaks(67,79,119,137).

ISSN: 3048-9407; SJRTDDS
Scienxt Journal of Recent Trends in Drug Delivery System

2.11. Visual requirements for using digital devices:

Long-term near focus, typically needed for digital devices frequently at distances under 40 cm, necessitating constant accommodation and convergence. Furthermore, screens emit light and their flicker and blue light spectra may affect the comfort and physiology of the eyes(169). Prolonged near work puts a lot of strain on the binocular vision mechanisms which can result in symptoms like eye strain, visual fatigue and accommodationvergence abnormalities. It also causes less blinking and less than ideal postures.

3. Use of digital devices epidemiology:

3.1. Trends in screen time worldwide:

Globally, the use of digital devices has increased significantly in the last 20 years for people of all ages. People's work, learning and social interactions have changed because of the near constant screen exposure brought about by smartphones, tablets and portable computers. According to the Nielsen Total Audience Report (2023), children between the ages of 8 and 18 spend roughly 6.5 hours a day in front of screens including computers and smartphones while adults use digital media for an average of 7 hours(170). According to a 2019 study by Twenge et al, adolescents in developed nations use digital devices for 6 to 9 hours every day and a significant portion of them work near constantly for more than 4 hours every day(152). Due to remote work and online education, the COVID-19 pandemic hastened this trend and increased screen time even more(171).

3.2. Use trends by socioeconomic status, age and region:

Age, socioeconomic status and geography all have a substantial impact on screen time. While exposure to screens is rapidly increasing in middle-income countries, children under five in high-income countries typically spend 1-2 hours a day on screens(172). The highest usage was seen in adolescents and young adults who frequently go over recommended limits. Due in part to unequal access, urban populations use digital devices more frequently than those in rural areas(173–175). Socioeconomic factors also affect the kind and length of device use which has an impact on the risks to visual health.

3.3. Types of devices and their usage features:

Depending on the device, the visual requirements vary. According to Blehm et al(176), smartphones are usually held closer(20-30 cm), tablets at 30-40 cm and desktop computers at 50-70 cm. Smartphones may require more accommodations and vergence due to their smaller screens and closer viewing distances. Variations in text size, contrast and screen brightness also affect visual strain and comfort(124). Visual stress is further increased by usage patterns like uninterrupted viewing, dim lighting and bad posture.

4. Effect of digital devices on binocular vision:

4.1. Immediate impact on vergence and accommodation:

The immediate effects of near work on binocular vision parameters have been the subject of several experimental investigations. After extended near tasks on digital devices, accommodating responses typically exhibit a decreased facility and an increased lag(76). According to a study by JaschinskiKruza(177), using a computer for 30 minutes dramatically reduced accommodative amplitude and facility resulting in temporary blur and eye strain. It has been demonstrated that prolonged screen time alters vergence control, frequently decreasing positive fusional vergence and causing the near point of convergence to shift farther away, both of which make it more difficult to maintain comfortable single vision(12). Asthenopia, headaches and diplopia are symptoms of temporary dysfunctions in the accommodation-vergence system which are reflected in these changes.

4.2. Convergence insufficiency and accommodative dysfunction clinical findings:

Children and young adults who use digital devices frequently are more likely to suffer from binocular vision disorders. Long-term near work and screen use have been closely linked to convergence insufficiency(CI) which is characterized by difficulty or inability to maintain eye alignment for near tasks(178). Double vision, headaches, eye pain and diminished reading comprehension are some of the symptoms.

Additionally prevalent are accommodative infacility and accommodation insufficiency which show up as fatigue, blurred vision and trouble focusing when using screens(71). Although diagnosing accommodative and vergence disorders can be challenging due to their overlapping symptoms, frequent users of digital devices should have thorough evaluations of their binocular vision.

4.3. Effects on stereopsis and sensory fusion:

Long-term near work may interfere with sensory fusion processes which could result in abnormal retinal correspondence or suppression. This may impair depth perception by decreasing stereo-acuity(179). Although results are conflicting and more research is required, some studies demonstrate quantifiable reductions in stereopsis following prolonged near tasks.

4.4. Effects of screen flicker and blue light:

High-energy visible light particularly blue wavelengths emitted by digital screens has been linked to disruption of the circadian rhythm and ocular discomfort(180). Although it is unknown how blue light directly affects binocular vision, phototoxic effects and retinal stress may make accommodative and convergence fatigue worse. Reduced accommodative stability and visual discomfort can result from irregular refresh rates and screen flicker(181). These elements emphasize how crucial device settings and technology are to visual ergonomics.

4.5. Comparative effects by type of device:

According to recent studies, smartphones place higher demands on accommodation and vergence than larger devices because of their small screens and close viewing distances(182). Due to accommodation-vergence conflict, virtual reality(VR) devices which produce artificial three-dimensional environments, present special difficulties and frequently result in severe visual discomfort and fatigue(124).

5. Effect of digital devices on refractive status:

5.1. The prevalence of myopia and the use of digital devices:

With its prevalence rising to epidemic levels in some East Asian countries and steadily rising globally, myopia or nearsightedness has emerged as a significant global public health concern(113). Research shows that the environment has a significant impact on the development of myopia particularly when it comes to close work activities and less time spent outside(141). Prolonged near work on digital devices has been associated with an increased risk of myopia onset and progression in a few cross-sectional and longitudinal studies(142). For example, Lin et al(183) discovered that children who used smartphones and tablets for more than two hours a day had a significantly higher odds ratio for the development of myopia than children who used screens less frequently.

Similarly, a study by Lanca and Saw(142) found that faster axial elongation is the anatomical correlate of myopia progression and was linked to higher digital device usage.

5.2. Initial binocular function and refractive status:

Pre-existing binocular vision abnormalities or refractive errors alter a person's vulnerability to issues brought on by digital devices. Myopes tend to have lower accommodative facility and higher lag of accommodation compared to emmetropes(202,203) which may exacerbate strain during near work. Hyperopes may put in more accommodative effort which raises the risk of fatigue. People who have reduced fusional vergence reserves or latent or manifest heterophorias(differences in eye alignment) were more likely to experience convergence insufficiency or digital eye strain when using screens for extended periods of time(12).

5.3. Aspects of the environment and behavior:

Spending time outside may prevent the development of myopia by increasing viewing distances and light intensity(156). Myopia risk was exacerbated by decreased outdoor activity and increased use of digital devices. Visual comfort and binocular function were significantly impacted by ergonomic factors including screen height, viewing distance and ambient lighting. Accommodative demand and convergence stress were increased by poor posture and dim lighting(176).

5.4. Cultural and socioeconomic factors:

Risks to visual health were influenced by screen time patterns that were shaped by cultural norms, educational policies and access to digital devices. For instance, myopia prevalence was higher in East Asian nations which was correlated with high near-work demands and severe educational pressure(155). Economic disparities can exacerbate health inequities in ocular outcomes by influencing the type and quality of devices used as well as access to vision care services(204).

6. Methodology:

6.1. Ethical clearance:

The study adhered with the Declaration of Helsinki's principles and was approved by the Institutional Review Board and Ethics Committee. The children and their parents or guardians who were present during the examination gave their informed consent.

6.2. Study design and study centre:

To investigate the relationship between exposure to digital devices and visual outcomes, an observational study was carried out for ten months from September 2024 to July 2025 in the Department of Ophthalmology at Shri Ram Murti Smarak Institute of Medical Sciences, Bareilly as well as at Shri Ram Murti Smarak Institute of Paramedical Sciences, Bareilly.

ISSN: 3048-9407; SJRTDDS
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6.3. Sampling technique:

Purposive sampling was employed in this study to choose participants to examine how using digital devices affects refractive status and binocular vision.

6.4. Sample size:

Purposive sampling was used to select the sample meaning that only participants who met our inclusion and exclusion criteria were included in the study and the complete enumeration process was adopted.

6.5. Inclusion criteria:

1. Individuals that use digital devices for the duration of at least 6 months
2. Age group between 13 to 19 years
3. Emmetropic individuals

6.6. Exclusion criteria:

1. Pre-existing ocular surface disorder
2. Pre-existing binocular vision abnormality
3. Pre-existing refractive error
4. Any ocular diseases
5. Any neurological diseases
6. Any systemic diseases
7. Any surgical intervention

7. Methods:

For this study, 201 emmetropic teenagers between the ages of 13 and 19 years who had been using digital devices for at least six months were enlisted. To rule out any neurological, systemic or ocular diseases, each participant had a comprehensive general and ocular examination prior to the task. This study included participants without a history of asthenopia who had a best corrected visual acuity (BCVA) of 6/6 and N6 while excluding those with squint, amblyopia, systemic and ocular diseases and a history of ocular surgery. Participants were categorized as low digital device users (those who used digital devices for less than four hours in a day for at least six months) or high digital device users (those who used digital devices for four hours or more than four hours in a day for at least six months) based on their answers to a basic questionnaire that was given to them following a general and ocular examination. A questionnaire was also used to assess subjective findings. All the procedures necessary for evaluating binocular single vision and refractive status were performed in a well-lit room.

7.1. Measurement of accommodation:

An RAF (Royal Air Force) ruler was used to measure the near point of accommodation (NPA). One end of this instrument was placed on the subject's forehead or nasal bridge at a 45-degree angle while the test was being conducted. The participant was instructed to focus on the target (the N8 line of letters) on the movable slider keeping the target as clear as possible to measure the near point of accommodation. The target was then moved towards the participant's eyes using a ruler and we asked them to report when it initially became and remained blurry. We measured the distance in centimeters at which the target blurred to document the near point of accommodation. To ensure accuracy, we took an average of the measurements after repeating them two or three times. Each subject's average amplitude was determined using Hofstetter's formula(137). The eye's maximum capacity to relax or stimulate accommodation while preserving sharp, binocular single vision was assessed using NRA and PRA. While minus lenses were used for Positive Relative Accommodation (PRA) and plus lenses were used for Negative Relative Accommodation (NRA). To reduce the impact of the accommodation facility on the PRA measurement, NRA was conducted prior to PRA. To perform NRA, we make sure the subject was seated comfortably in a welllit room and given instructions to fixate binocularly on a near chart hold at 40 cm which is typically a line of letters around N9. We asked the participant to confirm whether the target was clear or single before the task began and we gave them instructions to report any instances in which the target became blurry or failed to clear up. We then started adding plus spherical lenses in binocular increments of +0.25 dioptre (D) asking the participant if the target remained clear and single after each addition. We kept increasing the plus power until the subject reported persistent blur that did not go away with more effort and at that point the test was terminated. We noted the power as the NRA value which was the total amount of plus power added at that time. NRA typically falls between +2.00 D and +2.50 D(137).

To conduct PRA, we make sure the subject was seated comfortably in a welllit room and given instructions to fixate binocularly on a near chart hold at 40 cm which is typically a line of letters around N9. We asked the participant to confirm whether the target was clear or single before the task began and we gave them instructions to report any instances in which the target became blurry or failed to clear up. We then started adding minus spherical lenses in binocular increments of -0.25 dioptre (D) asking the participant if the target remained clear and single after each addition. The test ended when the subject reported persistent blur that did not go away with more effort, so we kept adding minus power. We recorded the PRA value as the total amount of minus power added at that moment. PRA typically ranges from -2.37 D to -3.37 D(137). The accommodative facility was measured using an accommodative flipper of +/-2.00 D. Each participant was told to sit comfortably in a well-lit room and to keep their binocular focus on the near visual target usually an N6 print size which was positioned at a standard working distance of 40 centimeters during the test. The test used spherical flipper lenses with a dioptre (D) of ±2.00 which were alternately placed in front of both eyes. The process started with the flipper lens plus side (+2.00 D) held in place. The subject was then asked to report when the target became clear. We then flipped the lenses to the minus side (-2.00 D) and the subject reported once more when the target was visible. For a total of 60 seconds or one minute, this cycle of switching between plus and minus lenses continued. One cycle per minute (cpm) was used to represent each complete cycle which included a single distinguishable response from both the plus and minus lenses. The accommodative facility score was determined by counting the number of cycles completed in a minute. We kept an eye out for any indications of suppression, loss of fusion, excessive blinking or delayed responses during the procedure. A failure was recorded and the type of lens causing the issue was identified if the subject could not clear the image on either lens in 15 seconds. After the test, participants were questioned about any symptoms they might have had including headaches, double vision, eye strain or visual discomfort. 12 cpm is the typical value(137).

7.2. Measurement of vergence:

NPC was carried out to determine the near point of convergence or amplitude of convergence by using an RAF (Royal Air Force) ruler. We hold the RAF ruler horizontally at a 45-degree angle, one end against the participant's forehead or nose bridge and ask them to focus on the target, a vertical line with a dot in the middle on the movable slider. We told them to keep the target as clear or single as possible to measure the near point of convergence. The target was then moved towards the participant's eyes using a ruler and we asked them to report when it first doubled and remained doubled. We measured the distance in centimeters at which the target doubled to document the measurement of the near point of convergence. To ensure accuracy, we took an average of the measurements after repeating them two or three times. NPC typically ranges between 6 and 9 cm(225). Divergence or negative fusional vergence (NFV) amplitudes were measured using base-in (BI) prisms while convergence or positive fusional amplitudes (PFV) were measured using base-out (BO) prisms. Each participant was told to sit comfortably in a well-lit room to perform NFV and we made sure that the testing space was evenly lit to make sure the best possible visibility and to minimize variability in accommodative demand. To keep focus and good vision throughout the test, a central fixation target was positioned at a standard working distance of 40 centimeters. Using a prism bar, we introduced base-in prisms in front of the eyes to start the evaluation. We closely monitored the participant's eye movements and verified subjective reports while instructing them to maintain single and clear vision on the central target. Prisms were increased in increments of two prism dioptre (Δ). The break point was identified as the prism value at which the participant initially reported seeing double. Once the participant had reached the break point, we progressively decreased the prism power until they were able to see with both eyes again. This was noted as the recovery point. Each NFV measurement was performed twice to ensure accuracy and reduce variability and the average of the two trials was computed for both break and recovery values. To avoid vergence fatigue or adaptation, participants received enough rest in between trials. Every measurement was recorded in prism diopter(Δ). Care was taken to be sure that the participant was not in discomfort or experiencing visual strain during the procedure and that the accommodation remained stable. Blur/Break/Recovery: 13/21/13 is the typical value for BI(137).

Each participant was told to sit comfortably in a well-lit room to perform PFV and we made sure that the testing space was evenly lit to guarantee the best possible visibility and to reduce variability in accommodative demand. To keep focus and good vision throughout the test, a central fixation target was positioned at a standard working distance of 40 centimeters. Using a prism bar, we introduced base-out prisms in front of the eyes to start the evaluation. We closely monitored the participant's eye movements and verified subjective reports while instructing them to maintain single and clear vision on the central target. Prisms were increased in increments of two prism dioptre(Δ). The break point was identified as the prism value at which the participant initially reported seeing double. Once the participant had reached the break point, we progressively decreased the prism power until they were able to see with both eyes again. This was noted as the recovery point. Each PFV measurement was performed twice to ensure accuracy and reduce variability and the average of the two trials was computed for both break and recovery values. To avoid vergence fatigue or adaptation, participants received enough rest in between trials. Every measurement was recorded in prism dioptre(Δ). Care was taken to make sure that the participant was not in discomfort or experiencing visual strain during the

ISSN: 3048-9407; SJRTDDS
Scienxt Journal of Recent Trends in Drug Delivery System

procedure and that the accommodation remained stable. Blur/Break/Recovery: 17/21/11 is the typical value for BO(137).

7.3. Measurement of stereopsis:

In a quiet examination room with standardized lighting, stereo-acuity was assessed using the Titmus stereo fly test. The test booklet was placed about 40 cm away from each participant's comfortable seat. Participants were told to put on the polarized glasses that came with the test before it began. To make certain that everyone understood the task, the test was thoroughly explained to each participant. The three components of the Titmus Fly Test evaluated varying degrees of stereoscopic vision. Gross stereopsis was assessed using the Fly Test which is the first section. Participants were instructed to reach out and touch the wings of a large image of a fly with its wings outstretched. When the participant reached above the page's surface which suggests the perception of depth at around 3000 seconds of arc then it was noted as a typical response that indicates stereopsis. The Animal Test which evaluated intermediate stereopsis was the second section. Nine animals with stereoscopic disparity were grouped in three rows in this section. To assess stereopsis, participants were asked to identify the animal in each row that seemed elevated or closer than the others. The examiner recorded the responses between 400 and 100 seconds of arc. The Circle Test which assessed fine stereopsis was the last and most accurate section. To create the illusion of three dimensions, participants were shown nine sets of four circles each of which had one circle with a horizontal disparity. In each set, they had to determine which circle looked the closest or raised. The test was repeated one after the other until the participant either went wrong or lost the ability to notice the difference. The participant's level of stereopsis which was measured in seconds of arc was the smallest disparity at which they could correctly identify the stereoscopic image. Finer depth perception was indicated by lower values. Throughout the process, the polarized glasses were examined to make sure they were positioned correctly and care was taken to prevent glare on the test booklet. Thus, the Titmus Fly Test offered a thorough evaluation of each participant's stereoscopic function covering both fine and gross depth perception.

7.4. Squint evaluation:

Under standardized clinical settings, each participant underwent the cover/uncover test to assess the presence of a squint (strabismus). A fixation target was positioned at 6 m for distance and 33 cm for near during the examination which was conducted in a well-lit room. The procedure started with an initial examination of the participant's eyes to detect any misalignment while they were fixated on the target. One eye was covered with an occluder during the cover phase and any movements made for fixation were monitored in the uncovered eye. The presence of a manifest squint (tropia) was indicated by any such movement. After that, in the uncover phase, the cover was taken off and the previously covered eye was closely examined for any signs of re-fixation movement. To ensure a thorough assessment, we repeated the process, switching the occluder between the two eyes. Both near and distance fixation were tested and the results were interpreted by looking at the movements of the eyes. A positive result for strabismus was noted for any regular movement seen throughout the procedure. To determine the degree of deviation in the eye, we employed a synoptophore and the Prism Bar Cover Test (PBCT). Participants who presented with strabismus had their angle of deviation measured using a synoptophore. The tool made it possible to accurately measure the subjective and objective squint angles. To ensure stability throughout the process, each participant was seated comfortably with their forehead and chin firmly resting on the synoptophore's headrest. The right slides were chosen and the device was adjusted based on the subject's interpupillary distance. As the corneal reflexes were observed through the synoptophore, the objective angle of deviation was first determined using the alternating cover test. After that, the instrument's arms were adjusted until both eyes' visual axes lined up and there was no movement when either eye was alternately occlude. For both horizontal and vertical deviations, the angle at which this alignment took place was expressed in degrees. The subjective angle of deviation was evaluated after the objective measurement. The synoptophore's arms were moved by the participants until the two images, one for each eye, were perceived as fused or aligned. The angle at which this alignment took place was noted in degrees. During the evaluation, any abnormal retinal correspondence or suppression was observed. Care was taken to make sure appropriate fixation and subject cooperation throughout the process.

The purpose of the prism bar cover test was to measure the amount and direction of ocular deviation objectively. Every subject underwent the test in natural lighting. To ensure effective cooperation and focus on the target, each participant was given a comfortable seat and an explanation of the process beforehand. A prism bar was added to measure the misalignment following the cover/uncover test. With the apex pointing in the direction of the deviation, the proper prism bar, horizontal or vertical was positioned in front of one eye. The prism strength was gradually increased during the alternating cover test until there was no more movement when the occluder was switched. This neutralization point which was measured in prism dioptre(Δ) indicated the deviation's magnitude.

Additionally, phoria or tropia were detected in the horizontal and vertical planes using a Maddox rod. To improve visibility of the light source used during the test, each participant was seated comfortably in a room with low lighting. To relax accommodation and make sure accurate results, the subject was told to focus on a far-off point light source, usually positioned at a distance of six meters. In front of the right eye, the Maddox rod which is made up of several parallel red cylindrical lenses was positioned with the cylinders orientated vertically for testing vertical deviations and horizontally for testing horizontal deviations. The left eye which was still exposed, looked straight at the white light. The Maddox rod was positioned with the cylinders aligned horizontally to create a vertical red line through the right eye to measure the horizontal deviation. The participant was asked if the red line seemed to move to the right or left or if it seemed to go through the white light. An esophoria or esotropia was indicated if the red line appeared to the right and an exophoria or exotropia was suspected if it appeared to the left. The Maddox rod was rotated 90 degrees to align the cylinders vertically, creating a horizontal red line. The same procedure was repeated to determine vertical deviations, if the subject reported that the red line appeared above then it indicated right hyper and left hypo deviations, if the line appeared below then it indicated right hypo and left hyper deviations. During the test, care was taken to ensure accurate fixation and clear participant understanding and all responses were crosschecked for consistency.

To determine whether binocular single vision was present and to identify diplopia or suppression, the Worth four dot test (W4DT) was used. To improve the test light's visibility, the test was carried out in a room with low lighting levels. Every participant was told to put on red-green goggles, covering the left eye with the green filter and the right eye with the red filter. The W4DT target which had four lights, two green (left and right), one white (bottom) and one red (top) was displayed at a standard 6 m distance. We recorded the participant's answers after asking them to focus on the target and describe the number and color of lights they saw. It was considered normal binocular single vision to see four lights, two green, one red and one white (appearing as a combination of red and green). The participant's left eye was suppressed if they saw only two red lights and their right eye was suppressed if they saw three green lights. Diplopia was indicated by reports of five lights which were a mix of red and green. The functional state of the participant's binocular vision system was evaluated using the test results.

7.5. Refractive error evaluation:

Dry retinoscopy was used to get an unbiased estimate of each participant's refractive status. To make it easier to observe the retinoscopic reflex, the procedure was carried out in a dark room. To control accommodation, each participant was seated comfortably upright and kept their attention fixed on a non-accommodative distant target that was positioned six meters away. The examination was conducted using a streak retinoscope. As we moved the streak across the eye in both horizontal and vertical directions, we saw the reflex movement through the pupil. To neutralize the reflex movement, lenses from a trial lens set were placed in front of the eye. The reflex filled the pupil and showed no visible movement indicating that the far point of the eye coincided with our working distance. This was the endpoint of neutrality. The other eye underwent the same process and we noted the gross findings. The final refractive error was calculated by subtracting the gross findings from the working distance which was usually 50 cm (or +2.00 D).

Wet retinoscopy was used to temporarily paralyze accommodation to measure the refractive error accurately and objectively. One percent cyclopentolate hydrochloride was used to induce cycloplegia. Each eye received one drop of the solution and to ensure a complete cycloplegic effect, a second drop was given five minutes later. To allow for maximum cycloplegia and mydriasis, the retinoscopy procedure was started 30 minutes after the initial instillation. The participant was seated comfortably and focused on a 6 m distance, a non-accommodative target during the examination which took place in a dark room. The pupillary reflex was observed using a streak retinoscope. To neutralize the reflex, lenses from a trial lens set were placed in front of the eye while the retinoscope streak was moved in both horizontal and vertical meridians. When the reflex fully filled the pupil and showed no movement, the far point had been brought within our working distance and this was the endpoint of neutrality. The net refractive error was calculated by subtracting the dioptric value of the working distance (usually +2.00 D for 50 cm) and the tonus of allowance of the used drug (usually +0.75 D) from the gross findings after neutrality was reached. The fellow eye underwent the same process and the final refractive status was noted. Once sufficient cycloplegia was established usually demonstrated by a pupil diameter of at least 6 mm and loss of accommodation upon near fixation, all findings were recorded. Based on the participant's signs, symptoms and investigations, binocular vision abnormalities and their refractive status were determined. To evaluate the effect of digital device usage on binocular vision and refractive status, the results of the two groups were compared.

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8. Questionnaire:

A questionnaire was divided into three sections: Section 1 was related to digital device (type of digital device usage, mode of digital device while using and the illumination of digital device), Section 2 was related to the respondents (duration of usage in a day, length of usage, illumination of room while using, position of usage, distance of usage, breaking time between the usage of digital device) and Section 3 includes the associated symptoms with the use of digital device such as eyestrain, headache, itching, blurred vision, pricking and burning sensation.

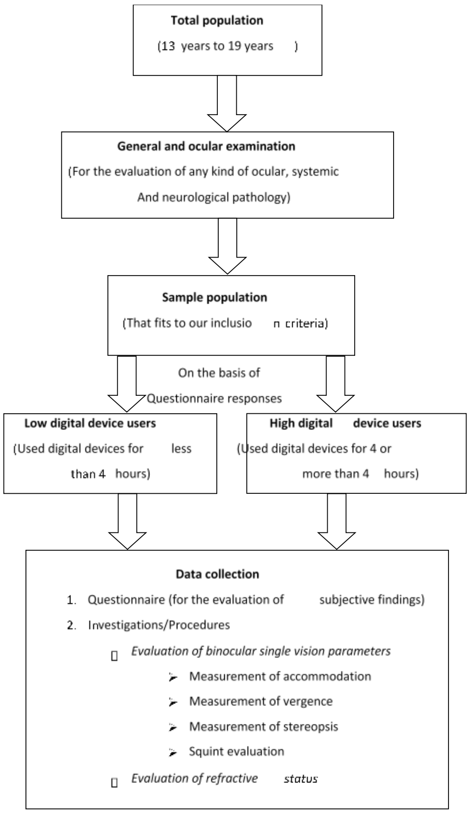

Figure. 1: Flow chart depicts the methodology

8. Plan for data analysis:

After being verified for accuracy and completeness, the gathered data was imported into Microsoft Excel and then exported to the Statistical Package for the Social Sciences (SPSS) software version 26.0 for statistical analysis. With categorical variables like accommodative anomalies, convergence insufficiency, refractive errors and ocular symptoms represented as frequencies and percentages, descriptive statistics were employed to summarize the data. The relationship between digital device usage categories (low digital device usage vs high digital device usage) and categorical outcome variables was investigated using the Chi-square test of independence for inferential analysis. The Fisher's Exact test was used to guarantee statistical accuracy in situations where the expected cell counts were less than five. Statistical significance was defined as a p-value of less than 0.05 and high significance as a p-value of less than 0.001. For clarity, the analyzed results were displayed as tables and charts. The Discussion chapter provided additional interpretation of the findings about the review of existing literature.

8.1. Analysis and interpretation:

Overall Cohort (N = 201)

Table. 1: Age distribution of total participants

Age (in years)	Frequency	in %
13-15 years	80	40%
15-17 years	88	44%
17-19 years	33	16%
Total	201	100%

Table. 1 shows that out of a total of 201 participants, majority of participants (44%) were aged 15-17 years followed by 13-15 years (40%) and 17-19 years (16%).

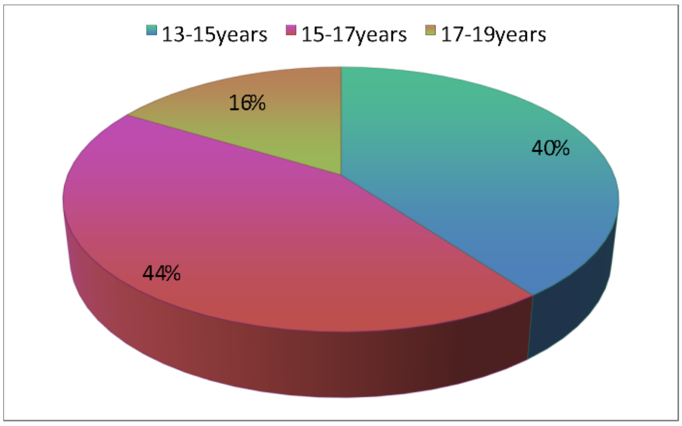

Figure. 2: Age distribution of total participants

Table. 2: Gender distribution of total participants

Gender	Frequency	in %
Male	93	46%
Female	108	54%
Total	201	100%

Majority of the participants were female (54%) compared with male (46%) which was clearly depicted in Table. 2.

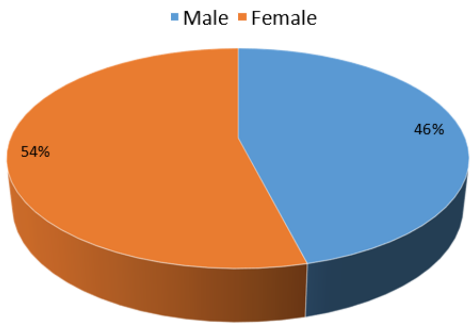

Figure. 3: Male-female ratio

8.2. Assessment of low digital device users (participants who used digital devices for less than 4 hours in a day from at least 6 months):

Overall Cohort (N = 110)

Out of a total of 110 participants who used digital devices for less than 4 hours in a day from at least 6 months, majority of the participants (41%) were aged 13-15 years followed by 15-17 years (38%) and 17-19 years (21%) which was shown in Table. 3. Table. 4 shows the majority of the participants were female (56%) than male (46%).

Table. 3: Age distribution of the participants (<4 hours)

Age (in years)	Frequency	in %
13-15 years	45	41%
15-17 years	42	38%
17-19 years	23	21%

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Total	110	100%

Table. 4: Gender distribution of the participants (<4 hours)

Gender	Frequency	in %
Male	48	44%
Female	62	56%
Total	110	100%

8.3. Questionnaire analysis:

Table. 5: Digital devices used (<4 hours)

Digital devices	Frequency	in %
Laptop	6	5%
Television	13	11%
Smartphone	99	84%
Others: Specify:	0	0%
Total	118	100%

Table. 5 represents that the most commonly used digital device among participants were smartphone (84%) followed by televisions (11%) and laptops (5%). No participants reported using other types of digital devices.

Table. 6: Brightness of digital device (<4 hours)

Brightness of digital device	Frequency	in %
Low	37	34%
Medium	70	64%
High	3	2%
Total	110	100%

Table. 6 depicts that the majority of participants (64%) used their digital devices at medium brightness followed by 34% at low brightness and only 2% used at high brightness.

Table. 7: Mode of digital device while using (<4 hours)

Mode while using digital device	Frequency	in %
Bright	70	64%
Dark	40	36%
Total	110	100%

Table. 7 indicates that 64% of total participants used digital devices in bright mode while 36% preferred using them in dark mode.

Table. 8: Duration of digital device use with room light switched off (<4 hours)

<table>
<tr><th rowspan="2">Room's light off while using digital device</th><th colspan="6">Duration</th><th colspan="2" rowspan="2">Total</th></tr>
<tr><th colspan="2"><1 hour</th><th colspan="2">1-3 hours</th><th colspan="2">>3 hours</th></tr>
<tr><td rowspan="2">Yes</td><td>N</td><td>%</td><td>N</td><td>%</td><td>N</td><td>%</td><td>N</td><td>%</td></tr>
<tr><td>0</td><td>0%</td><td>34</td><td>100%</td><td>0</td><td>0%</td><td>34</td><td>31%</td></tr>
<tr><td>No</td><td colspan="6">76</td><td>76</td><td>69%</td></tr>
</table>

Total	110	100%

Table. 8 shows that among participants who used digital devices for less than 4 hours, 31% reported using them with room lights off, all of whom did so for 1-3 hours. However 69% using them with room lights on indicating greater awareness of proper lighting conditions during screen use.

Table. 9: Posture while using digital device (<4 hours)

Posture while using digital device	Frequency	in %
Sitting on a chair	32	29%
Lying on the bed	78	71%
Total	110	100%

Table. 9 depicts the posture of participants while using digital device in which majority of participants (71%) preferred using digital devices while lying on the bed whereas only 29% used them while sitting on a chair.

Table. 10: Distance from digital device while using (<4 hours)

Distance from digital device while using	Frequency	in %
Less than 25 cm	41	37%
Within 25-40 cm	39	35%
At an arm's distance	30	28%
Total	110	100%

Table. 10 indicates that most participants used digital devices at a close distance with 37% sitting less than 25 cm away and 35% within 25-40 cm and only 28% maintained an arm's distance.

Table. 11: Frequency of digital device usage per week (<4 hours)

How often digital devices used	Frequency	in %
1-2 times/week	32	29%
3-4 times/week	5	5%
5-6 times/week	6	5%
Everyday	67	61%
Total	110	100%

Table. 11 shows that a majority of participants (61%) used digital devices daily while 29% used them 1-2 times a week and only a small proportion used devices less frequently.

Table. 12: Symptoms associated with digital device usage (<4 hours)

Symptoms	Yes		No		Total	
	Freq	in %	Freq	in %	Freq	in %
Eyestrain and headache	49	45%	61	55%	110	100%
Blurring of vision, itching, pricking sensation and burning sensation	49	45%	61	55%	110	100%

Table. 12 represents that 45% of participants reported experiencing eyestrain and headache and an equal percentage experienced symptoms like blurring of vision, itching, pricking and burning sensation. However a slight majority (55%) did not report these symptoms.

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8.4. Assessment of accommodation:

Table. 13: Near point of accommodation assessment (<4 hours)

NPA	Frequency	in %
Accommodation excess (<8 cm)	4	4%
Normal (8 to 10 cm)	95	86%
Accommodation insufficiency (>10 cm)	11	10%
Total	110	100%

Table. 13 depicts that the majority (86%) of subjects had normal amplitude of accommodation while 10% had accommodation insufficiency and 4% had accommodation excess.

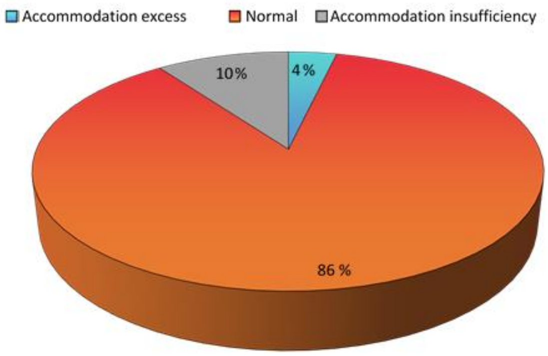

Figure. 4: Near point of accommodation assessment (<4 hours)

Table. 5: Negative Relative Accommodation assessment (<4 hours)

NRA	Frequency	in %
Accommodation excess (<+2.00 D)	51	46%
Normal (+2.00 D to +2.50 D)	30	27%
Accommodation insufficiency (>+2.50 D)	29	27%
Total	110	100%

Table. 14 indicates that 46% of subjects had excessive accommodation while 27% had normal NRA values and insufficiency of accommodation.

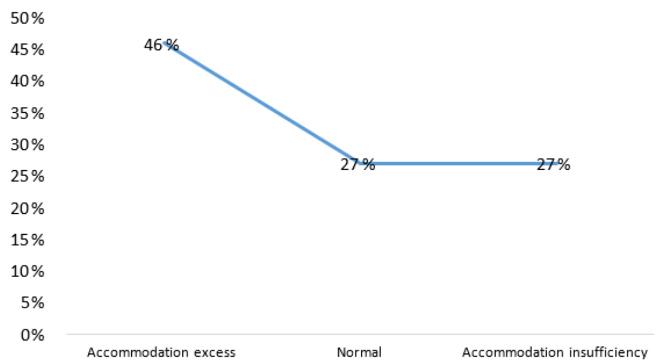

Figure. 6: Negative Relative Accommodation assessment (<4 hours)

Table. 15: Positive Relative Accommodation assessment (<4 hours)

PRA	Frequency	in %
Accommodation excess (>-3.37 D)	48	44%
Normal (-2.37 D to -3.37 D)	33	30%

Accommodation insufficiency (<-2.37 D)	29	26%
Total	110	100%

Table. 15 shows the assessment of accommodation through PRA values in which 44% of subjects had excessive accommodation and 30% showed normal PRA values. Only 26% showed the insufficiency of accommodation while using digital devices for less than 4 hours.

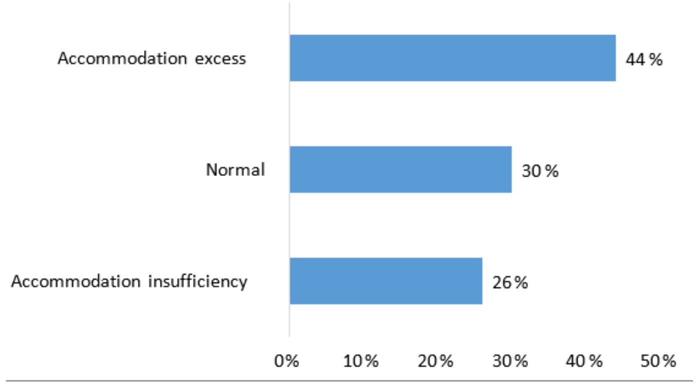

Figure. 7: Positive Relative Accommodation assessment (<4 hours)

Table. 16: Assessment of accommodative facility (<4 hours)

Accommodative facility	Difficulty with plus		Difficulty with minus		No difficulty		Total	
	N	in %	N	in %	N	in %	N	in %
Low (<12 cpm)	45	69%	20	31%	0	0%	65	59%
Normal (12 cpm)					38	100%	38	35%
High (>12 cpm)					7	100%	7	6%
Total							110	100%

Table. 16 indicates that 59% of participants had low accommodative facility in which 69% had accommodation excess and 31% had accommodation insufficiency. Near to half participants (35%) had normal accommodative facility while only 6% had high accommodative facility?

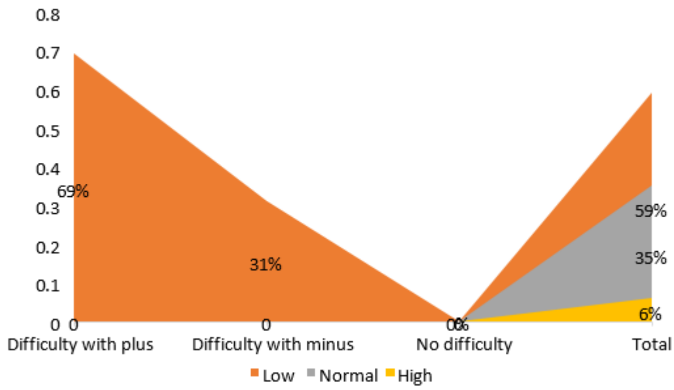

Figure. 8: Assessment of accommodative facility (<4 hours)

8.5. Assessment of convergence:

Table. 17: Near point of convergence assessment (<4 hours)

NPC	Frequency	in %
Convergence excess (<6 cm)	0	0%
Normal (6-9 cm)	89	81%

Convergence insufficiency (>9 cm)	21	19%
Total	110	100%

Table. 17 depicts that the majority of the participants (81%) had normal convergence while only 19% had convergence insufficiency and no participant showed excessive convergence.

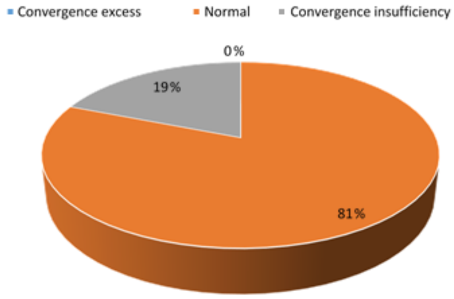

Figure. 9: Near point of convergence assessment (<4 hours)

Table. 18: Negative Fusional Vergence assessment (<4 hours)

NFV	Break		Recovery	
	Freq	**in %**	**Freq**	**in %**
Convergence excess (<21/13)	50	46%	45	41%
Normal (21/13)	30	27%	40	36%
Convergence insufficiency (>21/13)	30	27%	25	23%
Total	110	100%	110	100%

Table. 18 shows that out of total participants (break+recovery), majority exhibited convergence excess (46% break, 41% recovery) while 27% break with 36% recovery had normal NFV values and 27% break with 23% recovery had convergence insufficiency.

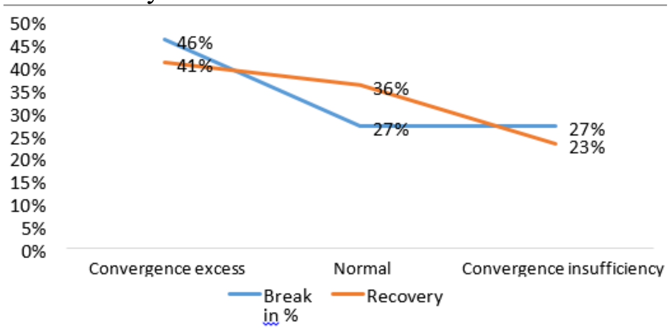

Figure. 10: Negative Fusional Vergence assessment (<4 hours)

Table. 19: Positive Fusional Vergence assessment (<4 hours)

PFV	Break		Recovery	
	Freq	**in %**	**Freq**	**in %**
Convergence excess (>21/11)	34	31%	13	12%
Normal (21/11)	25	23%	30	27%
Convergence insufficiency (<21/11)	51	46%	67	61%
Total	110	100%	110	100%

Table. 19 indicates that out of total participants (break+recovery), majority had convergence insufficiency (46% break, 61% recovery) while 23% break with 27% recovery had normal PFV values and 31% break with 12% recovery had convergence excess.

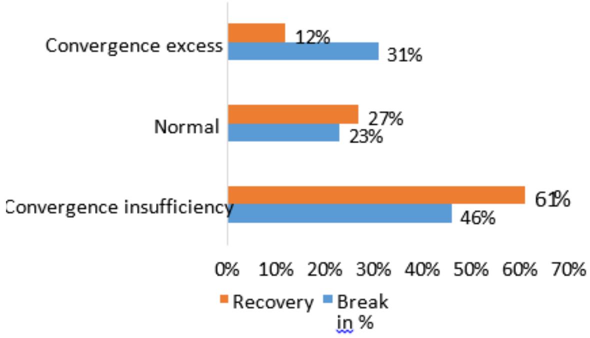

Figure. 11: Positive Fusional Vergence assessment (<4 hours)

8.6. Assessment of stereopsis, strabismus, diplopia and suppression:

Table. 20: Assessment of Stereopsis (<4 hours)

TFT	**Frequency**	**in %**
Present	99	90%
Absent	11	10%
Total	110	100%

Table. 20 shows that stereopsis present in near to total participants (90%) while only 10% participants showed absence of stereopsis.

Table. 21: Squint evaluation through synoptophore (<4 hours)

Synoptophore test	**Frequency**	**in %**
Orthophoria	110	100%
Esophoria	0	0%
Exophoria	0	0%
Hyperphoria	0	0%
Hypophoria	0	0%
Total	110	100%

Table. 21 depicts that all the participants (N = 110) had orthophoria and none of them showed esophoria, exophoria, hyperphoria and hypophoria.

Table. 22: Squint evaluation through cover/uncover test (<4 hours)

Cover/Uncover test	**Distance**		**Ne**	**ar**
	Frequency	**in %**	**Frequency**	**in %**
Orthophoria	110	100%	107	97%
Esophoria	0	0%	0	0%
Exophoria	0	0%	3	3%
Hyperphoria	0	0%	0	0%
Hypophoria	0	0%	0	0%
Total	110	100%	110	100%

Table. 22 indicates that out of total participants (N=110), all of them showed orthophoria for distance while for near, majority (97%) showed orthophoria and only 3% indicates exophoria and none of them shows esophoria, hyperphoria and hypophoria.

Table. 23: Prism Bar Cover Test (<4 hours)

PBCT	Frequency	in %
0 PD	107	97%
More than 0 PD	3	3%
Total	110	100%

Table. 23 shows that near to total participants (97%) had zero prism dioptre in prsim bar cover test and only 3% showed the PBCT value more than zero prism dioptre.

Table. 24: Squint evaluation through maddox rod test (<4 hours)

Maddox rod test	Frequency	in %
Orthophoria	108	98%
Esophoria	0	0%
Exophoria	2	2%
Hyperphoria	0	0%
Hypophoria	0	0%
Total	110	100%

Table. 24 depicts that near to total participants (98%) had orthophoria through maddox rod test and only 2% had exophoria.

Table. 25: Worth four dot test assessment (<4 hours)

W4DT	Frequency	in %
Normal	83	75%
Right eye suppression	12	11%
Left eye suppression	15	14%
Diplopia	0	0%
Total	110	100%

Table. 25 shows that majority of participants (75%) had normal W4DT values, 14% had left eye suppression while 11% had right eye suppression and none of them had diplopia.

8.7. Assessment of refractive status:

Table. 26: Refractive status assessment (<4 hours)

Refractive status	Dry retinoscopy				Wet retinoscopy			
	RE		LE		RE		LE	
	N	in %	N	in %	N	in %	N	in %
Emmetropia	40	36%	35	31%	45	41%	40	36%
Myopia	45	41%	47	43%	46	42%	45	41%
Hyperopia	5	5%	5	5%	5	5%	5	5%
Astigmatism	20	18%	23	21%	14	12%	20	18%
Total	110	100%	110	100%	110	100%	110	100%

Table. 26 indicates that in dry retinoscopy, myopia (41% in RE and 43% in LE) is the most common refractive error in both eyes followed by emmetropia (36% in RE and 31% in LE). While wet retinoscopy reveals a higher prevalence of myopia (42% in RE and 41% in LE) followed by emmetropia (41% in RE and 36% in LE)

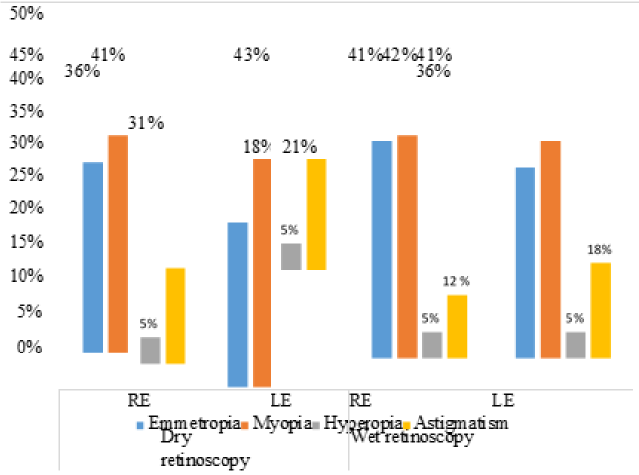

Figure. 12: Refractive status assessment (<4 hours)

8.8. Assessment of high digital device users (participants who used digital devices for 4 hours or more than 4 hours from at least 6 months):

Overall Cohort (N = 91)

Out of a total of 91 participants who used digital devices for 4 hours or more than 4 hours from at least 6 months, majority of the participants (51%) were aged 15-17 years followed by 13-15 years (38%) and 17-19 years (11%) which was shown in Table 27. Table 28 shows the majority of the participants were female (51%) than male (49%).

Table. 27: Age distribution of the participants (≥4 hours)

Age (in years)	Frequency	in %
13-15 years	35	38%
15-17 years	46	51%
17-19 years	10	11%
Total	91	100%

Table. 28: Gender distribution of the participants (≥4 hours)

Gender	Frequency	in %
Male	45	49%
Female	46	51%
Total	91	100%

8.9. Questionnaire analysis:

Table. 29: Digital devices used (≥4 hours)

Digital devices	Frequency	in %
Laptop	8	8%
Television	8	8%
Smartphone	82	84%
Others: Specify:	0	0%
Total	98	100%

Table. 29 shows that the most commonly used digital device among participants were smartphone (84%) followed by televisions (8%) and laptops (8%). No participants reported using other types of digital devices.

Table. 30: Brightness of digital device (≥4 hours)

Brightness of digital device	Frequency	in %

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Low	18	20%
Medium	68	75%
High	5	5%
Total	91	100%

Table. 30 depicts that the majority of participants (75%) used their digital devices at medium brightness followed by 20% at low brightness and only 5% used at high brightness.

Table. 31: Mode of digital device while using (≥4 hours)

Mode while using digital device	**Frequency**	**in %**
Bright	69	76%
Dark	22	24%
Total	91	100%

Table. 31 indicates that 76% of total participants used digital devices in bright mode while 24% preferred using them in dark mode.

Table. 32: Duration of digital device use with room light switched off (≥4 hours)

Room's light off while using digital device	**Duration**						**Total**	
	<1 hour		**1-3 hours**		**>3 hours**			
Yes	N	%	N	%	N	%	N	in %
	1	4%	24	77%	6	19%	31	34%
No	60						60	66%
Total							91	100%

Table. 32 shows that among participants who used digital devices for 4 hours or more than 4 hours, 34% reported using them with room lights off, in which majority (77%) did so for 1-3 hours, 19% did for more than 3 hours and only 4% did for less than 1 hour. However 66% using them with room lights on.

Table. 33: Posture while using digital device (≥4 hours)

Posture while using digital device	**Frequency**	**in %**
Sitting on a chair	30	33%
Lying on the bed	61	67%
Total	91	100%

Table. 33 depicts the posture of participants while using digital device in which majority of participants (67%) preferred using digital devices while lying on the bed whereas only 33% used them while sitting on a chair.

Table. 34: Distance from digital device while using (≥4 hours)

Distance from digital device while using	**Frequency**	**in %**
Less than 25 cm	33	36%
Within 25-40 cm	33	36%
At an arm's distance	25	28%
Total	91	100%

Table. 34 indicates that most participants used digital devices at a close distance with 36% sitting less than 25 cm away and 36% within 25-40 cm and only 28% maintained an arm's distance.

Table. 35: Frequency of digital device usage per week (≥4 hours)

How often digital devices used	**Frequency**	**in %**

1-2 times/week	14	15%
3-4 times/week	8	9%
5-6 times/week	7	8%
Everyday	62	68%
Total	91	100%

Table. 35 shows that a majority of participants (68%) used digital devices daily while 15% used them 1-2 times a week and only a small proportion used devices less frequently.

Table. 36: Symptoms associated with digital device usage (≥4 hours)

Symptoms	**Yes**		**No**		**Total**	
	Freq	**in %**	**Freq**	**in %**	**Freq**	**in %**
Eyestrain and headache	42	46%	49	54%	91	100%
Blurring of vision, itching, pricking sensation and burning sensation	40	44%	51	56%	91	100%

Table. 36 depicts that 46% of participants reported experiencing eyestrain and headache and 44% experienced symptoms like blurring of vision, itching, pricking and burning sensation. However a slight majority (54% and 56% respectively) did not report these symptoms.

8.10. Assessment of accommodation:

Table. 37: Near point of accommodation assessment (≥4 hours)

NPA	**Frequency**	**in %**
Accommodation excess (<8 cm)	30	33%
Normal (8 to 10 cm)	25	27%
Accommodation insufficiency (>10 cm)	36	40%
Total	91	100%

Table. 37 represents that the majority (40%) of subjects had accommodation insufficiency while 33% had accommodation excess and 27% had normal amplitude of accommodation.

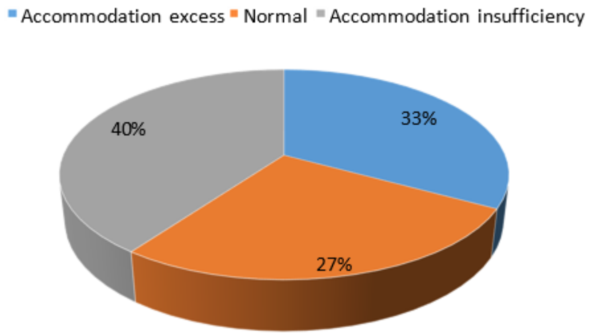

Figure. 13: Near point of accommodation assessment (≥4 hours)

Table. 38: Negative Relative Accommodation assessment (≥4 hours)

NRA	**Frequency**	**in %**
Accommodation excess (<+2.00 D)	51	56%
Normal (+2.00 D to +2.50 D)	6	7%
Accommodation insufficiency (>+2.50 D)	34	37%
Total	91	100%

Table. 38 indicates that 56% of subjects had excessive accommodation while only 37% showed accommodation insufficiency and 7% had normal NRA values.

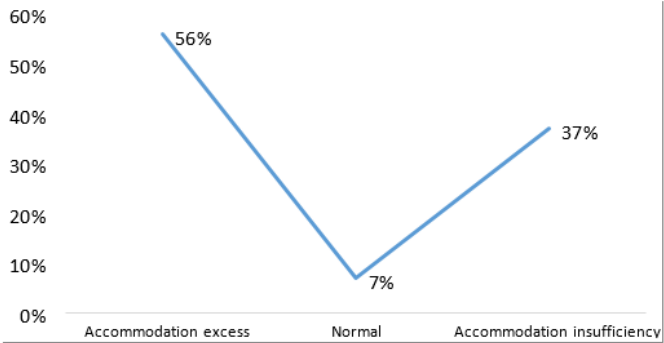

Figure. 14: Negative Relative Accommodation assessment (≥4 hours)

Table. 39: Positive Relative Accommodation assessment (≥4 hours)

PRA	Frequency	in %
Accommodation excess (>-3.37 D)	54	59%
Normal (-2.37 D to -3.37 D)	11	12%
Accommodation insufficiency (<-2.37 D)	26	29%
Total	91	100%

Table. 39 shows the assessment of accommodation through PRA values in which 59% of subjects had excessive accommodation and 29% showed accommodation insufficiency. While only 12% had normal PRA values.

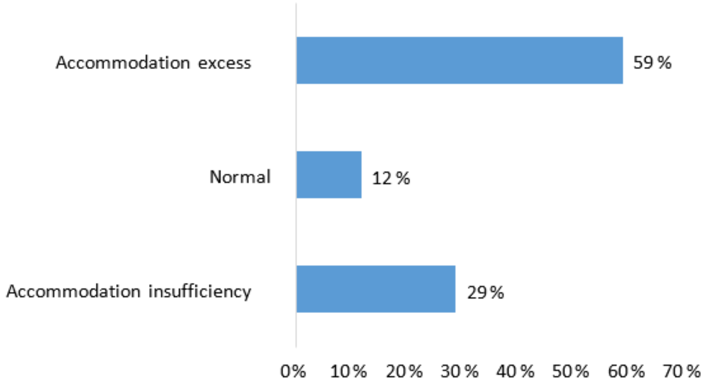

Figure 15: Positive Relative Accommodation assessment (≥4 hours)

Table. 40: Assessment of accommodative facility (≥4 hours)

Accommodative facility	Difficulty with plus		Difficulty with minus		No difficulty		Total	
	Freq	in %	Freq	in %	Freq	in %	Freq	in %
Low (<12 cpm)	49	75%	16	25%	0	0%	65	71%
Normal (12 cpm)					16	100%	16	18%
High (>12 cpm)					10	100%	10	11%
Tota			1				91	100%

Table. 40 represents that 71% of participants had low accommodative facility in which 75% had accommodation excess and 25% had accommodation insufficiency. Only 18% participants had normal accommodative facility while 11% had high accommodative facility.

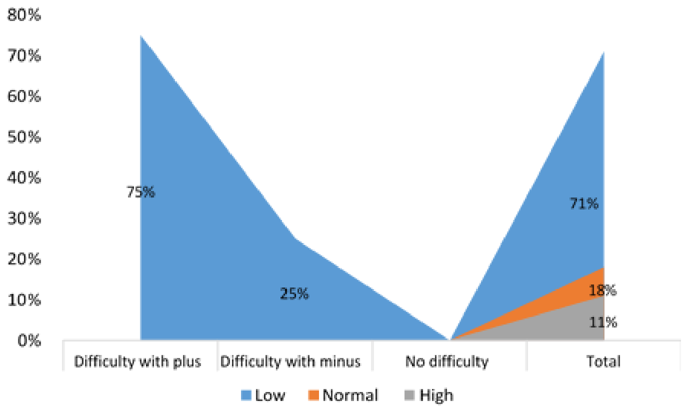

Figure. 16: Assessment of accommodative facility (≥4 hours)

8.11. Assessment of convergence:

Table. 41: Near point of convergence assessment (≥4 hours)

NPC	Frequency	in %
Convergence excess (<6 cm)	10	11%
Normal (6-9 cm)	11	12%
Convergence insufficiency (>9 cm)	70	77%
Total	91	100%

Table. 41 indicates that the majority of the participants (77%) had convergence insufficiency while only 12% had normal convergence and 11% showed excessive convergence.

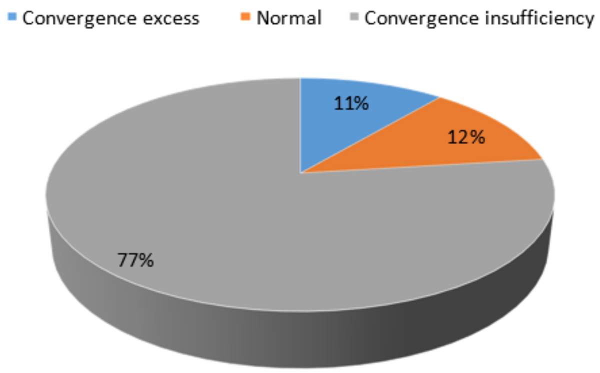

Figure. 17: Near point of convergence assessment (≥4 hours)

Table. 42: Negative Fusional Vergence assessment (≥4 hours)

NFV	Break		Recovery	
	Freq	in %	Freq	in %
Convergence excess (<21/13)	62	68%	59	65%
Normal (21/13)	10	11%	5	5%
Convergence insufficiency (>21/13)	19	21%	27	30%
Total	91	100%	91	100%

Table. 42 depicts that out of total participants (break+recovery), majority exhibited convergence excess (68% break, 65% recovery) while 21% break with 30% recovery had convergence insufficiency and only 11% break with 5% recovery had normal NFV values.

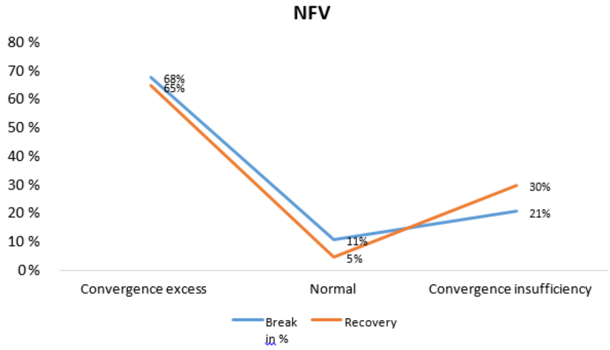

Figure. 18: Negative Fusional Vergence assessment (≥4 hours)

Table. 43: Positive Fusional Vergence assessment (≥4 hours)

PFV	Break		Recovery	
	Freq	in %	Freq	in %
Convergence excess (>21/11)	31	34%	32	35%
Normal (21/11)	5	5%	5	5%
Convergence insufficiency (<21/11)	55	61%	54	60%
Total	91	100%	91	100%

Table. 43 indicates that out of total participants (break+recovery), majority had convergence insufficiency (61% break, 60% recovery) while 34% break with 35% recovery had convergence excess and only 5% break with recovery had normal PFV values.

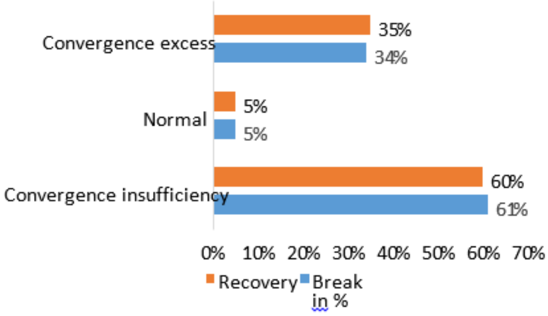

Figure. 19: Positive Fusional Vergence assessment (≥4 hours)

8.12. Assessment of stereopsis, strabismus, diplopia and suppression:

Table. 44: Assessment of Stereopsis (≥4 hours)

TFT	Frequency	in %
Present	79	87%
Absent	12	13%
Total	91	100%

Table. 44 shows that stereopsis present in near to total participants (87%) while only 13% participants showed absence of stereopsis.

Table. 45: Squint evaluation through synoptophore (≥4 hours)

Synoptophore test	Frequency	in %
Orthophoria	91	100%
Esophoria	0	0%

Exophoria	0	0%
Hyperphoria	0	0%
Hypophoria	0	0%
Total	91	100%

Table. 45 depicts that all the participants (N = 91) had orthophoria and none of them showed esophoria, exophoria, hyperphoria and hypophoria.

Table. 46: Squint evaluation through cover/uncover test (≥4 hours)

Cover/Uncover test	**Distance**		**Ne**	**ar**
	Frequency	**in %**	**Frequency**	**in %**
Orthophoria	91	100%	90	99%
Esophoria	0	0%	0	0%
Exophoria	0	0%	1	1%
Hyperphoria	0	0%	0	0%
Hypophoria	0	0%	0	0%
Total	91	100%	91	100%

Table. 46 indicates that out of total participants (N=91), all of them showed orthophoria for distance while for near, majority (99%) showed orthophoria and only 1% indicates exophoria and none of them shows esophoria, hyperphoria and hypophoria.

Table. 47: Prism Bar Cover Test (≥4 hours)

PBCT	**Frequency**	**in %**
0 PD	90	99%
More than 0 PD	1	1%
Total	91	100%

Table. 47 represents that near to total participants (99%) had zero prism dioptre in prism bar cover test and only 1% showed the PBCT value more than zero prism dioptre.

Table. 48: Squint evaluation through maddox rod test (≥4 hours)

Maddox rod test	**Frequency**	**in %**
Orthophoria	91	100%
Esophoria	0	0%
Exophoria	0	0%
Hyperphoria	0	0%
Hypophoria	0	0%
Total	91	100%

Table. 48 shows that all of the total participants had orthophoria through maddox rod test.

Table. 49: Worth four dot test assessment (≥4 hours)

W4DT	**Frequency**	**in %**
Normal	72	79%
Right eye suppression	15	16%
Left eye suppression	4	5%

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Diplopia	0	0%
Total	91	100%

Table. 49 indicates that majority of participants (79%) had normal W4DT values, 16% had right eye suppression while only 5% had left eye suppression and none of them had diplopia.

8.13. Assessment of refractive status:

Table. 50: Refractive status assessment (≥4 hours)

Refractive status	Dry retinoscopy				Wet retinoscopy			
	RE		LE		RE		LE	
	N	in %	N	in %	N	in %	N	in %
Emmetropia	11	12%	4	4%	11	12%	11	12%
Myopia	53	58%	47	52%	43	47%	37	41%
Hyperopia	6	7%	6	7%	8	9%	7	7%
Astigmatism	21	23%	34	37%	29	32%	36	40%
Total	91	100%	91	100%	91	100%	91	100%

Table. 50 represents that in dry retinoscopy, myopia is the most common refractive error with the prevalence of 58% in RE and 52% in LE followed by astigmatism at 23% in RE and 37% in LE. While wet retinoscopy reveals a higher prevalence of myopia (47% in RE and 41% in LE) followed by astigmatism (32% in RE and 40% in LE).

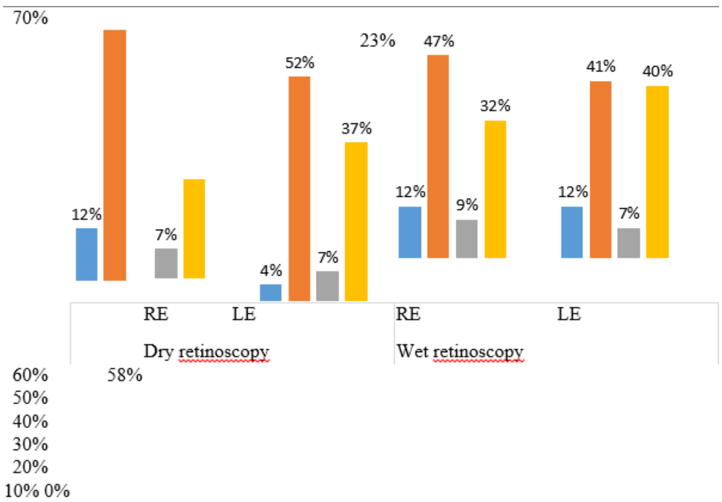

Figure. 20: Refractive status assessment (≥4 hours)

8.14. Association between the duration of digital device usage and binocular single vision parameters:

Table. 51: Association between duration of digital device usage and NPA

Duration	NPA		Total	p-value
	Normal accommodation	Abnormal accommodation (Excess+Insufficiency)		<0.00001*
<4 hours	95 (86%)	15 (14%)	110 (100%)	

4 & >4 hours	25 (27%)	66 (73%)	91 (100%)	

*Chi-square test is used for association, chi-square=71.7899

Table. 51 shows that there is highly statistically significant difference (p<0.00001) between the near point of accommodation and duration of digital device usage.

Table. 52: Association between duration of digital device usage and accommodation through NRA

Duration	NRA		Total	p-value
	Normal accommodation	Abnormal accommodation (Excess+Insufficiency)		0.000141*
<4 hours	30 (27%)	80 (73%)	110 (100%)	
4 & >4 hours	6 (7%)	85 (93%)	91 (100%)	

*Chi-square test is used for association, chi-square=14.4849

Table. 52 indicates that there is statistically significant difference (p=0.000141) between the negative relative accommodation and duration of digital device usage.

Table. 53: Association between duration of digital device usage and accommodation through PRA

Duration	PRA		Total	p-value
	Normal accommodation	Abnormal accommodation (Excess+Insufficiency)		0.002236*
<4 hours	33 (30%)	77 (70%)	110 (100%)	
4 & >4 hours	11 (12%)	80 (88%)	91 (100%)	

*Chi-square test is used for association, chi-square=9.3448

Table. 53 depicts that there is a significant association (p=0.002236) between the duration of digital device usage and accommodation abnormalities assessed through positive relative accommodation.

Table. 54: Association between duration of digital device usage and accommodative facility

Duration	Accommodative facility		Total	p-value
	Normal accommodation	Abnormal accommodation (High, difficulty with plus and minus)		0.006921*
<4 hours	38 (35%)	72 (65%)	110 (100%)	
4 & >4 hours	16 (18%)	75 (82%)	91 (100%)	

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*Chi-square test is used for association, chi-square=7.2933

Table. 54 represents that there is significant association (p=0.006921) between the duration and accommodative facility.

Table. 55: Association between duration of digital device usage and NPC

Duration	NPC		Total	p-value
	Normal convergence	Abnormal convergence (Excess+Insufficiency)		<0.00001*
<4 hours	89 (81%)	21 (19%)	110 (100%)	
4 & >4 hours	11 (12%)	80 (88%)	91 (100%)	

*Chi-square test is used for association, chi-square=94.3524

Table. 55 shows that there is highly statistically significant difference (p<0.00001) between the near point of convergence and duration of digital device usage.

Table. 56: Association between duration of digital device usage and convergence through NFV (Break)

Duration	NFV (Break)		Total	p-value
	Normal convergence	Abnormal convergence (Excess+Insufficiency)		0.003999*
<4 hours	30 (27%)	80 (73%)	110 (100%)	
4 & >4 hours	10 (11%)	81 (89%)	91 (100%)	

*Chi-square test is used for association, chi-square=8.2842

Table. 56 indicates that there is statistically significant difference (p=0.003999) between the break value of negative fusional vergence and duration of digital device usage.

Table. 57: Association between duration of digital device usage and convergence through NFV (Recovery)

Duration	NFV (Recovery)		Total	p-value
	Normal convergence	Abnormal convergence (Excess+Insufficiency)		<0.00001*
<4 hours	40 (36%)	70 (64%)	110 (100%)	
4 & >4 hours	5 (5%)	86 (95%)	91 (100%)	

*Chi-square test is used for association, chi-square=27.3113

Table. 57 depicts that there is highly significant association (p<0.00001) between the duration of digital device usage and convergence ability as measured by negative fusional vergence (recovery).

Table. 58: Association between duration of digital device usage and convergence through PFV (Break)

Duration	PFV (Break)		Total	p-value
	Normal convergence	Abnormal convergence (Excess+Insufficiency)		0.000643*
<4 hours	25 (23%)	85 (77%)	110 (100%)	
4 & >4 hours	5 (5%)	86 (95%)	91 (100%)	

*Chi-square test is used for association, chi-square=11.6472

Table. 58 represents that there is significant association (p=0.000643) between the convergence ability measured by positive fusional vergence (break) and duration of digital device usage.

Table. 59: Association between duration of digital device usage and convergence through PFV (Recovery)

Duration	PFV (Recovery)		Total	p-value
	Normal convergence	Abnormal convergence (Excess+Insufficiency)		0.000051*
<4 hours	30 (27%)	80 (73%)	110 (100%)	
4 & >4 hours	5 (5%)	86 (95%)	91 (100%)	

*Chi-square test is used for association, chi-square=16.4248

Table. 59 shows that there is statistically significant difference (p=0.000051) between the recovery value of positive fusional vergence and duration of digital device usage.

Table. 60: Association between duration of digital device usage and stereopsis

Duration	**Stereopsis**		**Total**	**p-value**
	Present	**Absent**		0.479892*
<4 hours	99 (90%)	11 (10%)	110 (100%)	
4 & >4 hours	79 (87%)	12 (13%)	91 (100%)	

*Chi-square test is used for association, chi-square=0.4991

Table. 60 indicates that there is no significant association (p=0.479892) between the duration of digital device usage and stereopsis status.

Table. 61: Association between duration of digital device usage and strabismus

Duration	**Strabismus**		**Total**	**p-value**
	Ortho	**Hetero-deviation**		1.0*
<4 hours	107 (97%)	3 (3%)	110 (100%)	
4 & >4 hours	90 (99%)	1 (1%)	91 (100%)	

*Fisher exact test is used for association, fisher exact=0.628

Table. 61 depicts that there is no statistically significant difference between the duration of digital device usage and strabismus.

Table. 62: Association between duration of digital device usage and Binocular Single Vision through Worth four dot test

Duration	**Worth four dot test**		**Total**	**p-value**
	Normal BSV	**Abnormal BSV**		0.537968*
<4 hours	83 (75%)	27 (25%)	110 (100%)	
4 & >4 hours	72 (79%)	19 (21%)	91 (100%)	

*Chi-square test is used for association, chi-square=0.3793

Table. 62 represents that there is no significant association between the duration of digital device usage and binocular single vision as measured by worth four dot test.

8.15. Association between the duration of digital device usage and refractive status:

Table. 63: Association between duration of digital device usage and right eye dry retinoscopy

Duration	**Dry retinoscopy (RE)**		**Total**	**p-value**
	Emmetropia	**Ametropia**		0.000083*
<4 hours	40 (36%)	70 (64%)	110 (100%)	
4 & >4 hours	11 (12%)	80 (88%)	91 (100%)	

*Chi-square test is used for association, chi-square=15.4993

Table. 63 shows that there is strong and significant association (p=0.000083) between the duration of digital device usage and refractive errors (ametropia) in right eye.

Table. 64: Association between duration of digital device usage and left eye dry retinoscopy

Duration	**Dry retinoscopy (LE)**		**Total**	**p-value**
	Emmetropia	**Ametropia**		<0.00001*
<4 hours	35 (31%)	75 (69%)	110 (100%)	
4 & >4 hours	4 (4%)	87 (96%)	91 (100%)	

*Chi-square test is used for association, chi-square=23.9479

Table. 64 indicates that there is highly statistically significant difference (p<0.00001) between the duration of digital device usage and refractive errors (ametropia) in left eye.

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Table. 65: Association between duration of digital device usage and right eye wet retinoscopy

Duration	Wet retinoscopy (RE)		Total	p-value
	Emmetropia	Ametropia		<0.00001*
<4 hours	45 (41%)	65 (59%)	110 (100%)	
4 & >4 hours	11 (12%)	80 (88%)	91 (100%)	

*Chi-square test is used for association, chi-square=20.5825

Table. 65 depicts that there is an extremely statistically significant association (p<0.00001) between the duration of digital device usage and ametropia (refractive error) in right eye even more pronounced than in dry retinoscopy results.

Table. 66: Association between duration of digital device usage and left eye wet retinoscopy

Duration	Wet retinoscopy (LE)		Total	p-value
	Emmetropia	Ametropia		0.000083*
<4 hours	40 (36%)	70 (64%)	110 (100%)	
4 & >4 hours	11 (12%)	80 (88%)	91 (100%)	

*Chi-square test is used for association, chi-square=15.4993

Table. 66 represents that there is a strong and significant association (p=0.000083) between the duration of digital device usage and ametropia (refractive error) in left eye.

9. Discussion:

9.1. Overview of study findings:

With an emphasis on accommodative and convergence functions, the current study examined how teenage use of digital devices affected binocular vision parameters and refractive status. 201 people in all were divided into two groups: those who used digital devices for less than four hours in a day and those who used them for four hours and more than four hours in a day for at least six months. Version 26.0 of the SPSS software was used to analyze the data. Baseline characteristics and clinical parameters were summarized using descriptive statistics and relationships between device usage categories and categorical outcomes like refractive errors, accommodative anomalies and convergence insufficiency were evaluated using the chi-square test of independence. The Fisher's exact test was used to make sure the analysis was reliable in situations where the expected cell frequencies were less than five. Values below 0.001 were taken as highly significant and a p-value of less than 0.05 was taken to be statistically significant. The results of this study showed strong statistical associations between extended use of digital devices and abnormalities in accommodation, convergence and refractive status. While stereopsis and gross binocular single vision were largely unaffected. These results are in line with the increasing amount of research that links prolonged screen time to accommodative dysfunctions, digital eye strain and the development of myopia in teenagers (76,119,124,137,183,223,224). With reference to previous research, the following sections address the implications of these findings which demonstrate the substantial impact that excessive near work and screen time have on modifying visual efficiency in teenagers.

9.2. Distribution of demographics:

The majority of participants in this study were between the ages of 15 and 17 (44%) followed by those between the ages of 13 and 15 (40%) and 17 and 19 (16%). The percentage of females was slightly higher (54%) than that of males (46%). Similar age and gender trends in the use of digital devices have been found in earlier research with teenagers being the most at risk because of their greater dependence on smartphones for both entertainment and academic purposes (226,227). The study's female participant majority could reflect their greater willingness to participate but prior research also suggests that women report ocular symptoms more frequently, possibly as a result of their heightened sensitivity to visual discomfort (228).

9.3. Patterns of device use:

According to the results, smartphones were the most popular gadgets in both the low usage (84%) and high usage (84%) groups followed by laptops and televisions. Many participants preferred bright mode backgrounds (64% v/s 76%) and reported using devices at medium brightness (64% in low usage vs. 75% in high usage).

71% of low digital device usage participants and 67% of high digital device usage participants reported using devices while lying on the bed, frequently at close viewing distances (less than 25 cm for 37% of low usage participants and 36% of high usage participants). Since close viewing distances and extended near tasks impose higher accommodative and convergence demands, these behaviors are consistent with the risk factors for myopic development and accommodating stress that have been identified(142,229,230).

Furthermore, over two-thirds of participants said they used digital devices on a daily basis with 61% of those who used them infrequently and 68% of those who used them frequently. This is in line with global trends as teenage use of digital media has increased significantly especially since the pandemic with average daily screen time frequently exceeding six hours (231,232). Significantly, extended use in dimly lit areas (31% in low usage and 34% in high usage) may worsen accommodative strain as a result of low ambient illumination and high contrast levels which may aggravate digital eye strain symptoms (192).

9.4. Symptoms of using digital devices:

Nearly half of the participants in both the low and high digital device usage groups reported headaches, blurred vision, eye strain and symptoms of ocular discomfort like burning, itching and pricking sensation. 46% of high usage participants reported having a headache and eyestrain compared to 45% of low usage participants. Similarly, visual disturbances were reported by 44% of high usage participants and 45% of low usage participants. These results imply that digital eye strain symptoms were common even at lower exposure levels, although slightly more common in those who spent more time in front of a screen.

This finding is consistent with earlier research showing that between 50 and 65 percent of teenagers and young adults who use screens for prolonged periods of time experience digital eye strain (DES)(76,233,234). Long-term near tasks cause accommodative micro fluctuations, increase tear film instability and decrease blink rate, all of which contribute to ocular fatigue (235). Interestingly, the binocular vision results were significantly worse in high usage participants even though the prevalence of symptoms did not significantly differ between the two groups in this study. This suggests that symptoms alone may understate the level of functional impairment.

10. Accommodation Findings

To maintain comfortable and clear near vision, accommodation is essential. The current study assessed the relationship between digital device usage and accommodative parameters such as Near Point of Accommodation (NPA), Negative Relative Accommodation (NRA), and Positive Relative Accommodation (PRA) and Accommodative Facility. The Chi-square test and Fisher's exact test (when appropriate) were used for statistical analysis. The results showed a strong correlation between abnormalities in accommodative function and extended use of digital devices.

10.1. Near Point of Accommodation (NPA):

The current study found that 73% of high digital device usage participants had abnormal NPA values compared to only 14% of the participants in low digital device usage group which indicates that there was a significant difference ($p<0.00001$) between the extended use of digital device and accommodation abnormalities. According to the association, teenagers who use digital screens more frequently each day are at a higher risk of experiencing spasm or accommodative insufficiency. These findings clearly imply that extended device use impairs accommodative functioning. This is consistent with research by Padavettan et al found that children who used smartphones had excessively lower accommodative amplitude (137). Similarly, Levine et al found that young adults with prolonged near work demands had a significantly lower NPA (236). Ciliary muscle fatigue from prolonged contraction during excessive near fixation may be the underlying mechanism for reducing accommodative flexibility and contributing to visual discomfort (237).

10.2. Negative Relative Accommodation (NRA):

This study found that 93% of high digital device usage participants had abnormal NRA values compared to 73% of low digital device usage participants. This difference was statistically significant ($p=0.000141$). A lower NRA indicates trouble relaxing which could be a sign of spasm or excessive accommodation. These results are consistent with earlier research showing that excessive screen time may lead to accommodative excess as evidenced by lower NRA values (124,140). When plus lenses are introduced then the accommodative system may adapt into a hyperopic shift due to continuous near demand which would reduce the ability to relax accommodation(58).

10.3. Positive Relative Accommodation (PRA):

88% of high digital device usage participants in this study had abnormal PRA values compared to 70% in the low digital device usage group. This difference was statistically significant ($p=0.002236$). A lower PRA

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suggests accommodative fatigue since it shows issues in producing accommodation in response to minus lens. This could be a sign of accommodative fatigue in frequent digital device users which would explain their diminished ability to focus on close tasks (238). These results support earlier findings that the accommodative system's flexibility is disrupted by excessive near screen exposure (239). We found that the accommodative fatigue is one of the main signs of excessive digital exposure which could account for symptoms like headaches, eye strain and blurred near vision.

10.4. Accommodative facility:

We found that 82% of high digital device usage participants had abnormalities compared to 65% of low digital device usage participants. This difference was also statistically significant ($p=0.006921$). A decreased ability demonstrates difficulty in rapidly shifting focus from close to far objects or vice-versa which is a crucial feature for comfortable reading and screen use. Children and young adults with high levels of near device use have been consistently found to have reduced accommodative facilities(84). Long-term accommodative effort decreases the effectiveness of accommodation shifts resulting in increased fatigue and slower reaction times(240). Clinically, the difficulty in focusing on far objects after prolonged near work is a common complaint among people who use digital devices. Similar findings were reported by Hennessey et al and noted that among adolescents, digital eye strain was significantly correlated with reduced accommodative facility(241). The physiological explanation is that prolonged near visual tasks cause accommodative dynamics to slow down which can result in insufficiency, spasm and lag of accommodation(71).

10.5. Interpretation and implications:

All these results point to a significant correlation between extended use of digital devices and various types of accommodative dysfunction. The statistical findings (all $p<0.01$, most $p<0.001$) clearly shows that screen exposure is systematically associated with accommodative stress rather than being random. This is consistent with research from around the world that shows a connection between accommodative fatigue, digital device use and visual symptoms(74,223,242,243). Clinically, these dysfunctions can affect daily comfort, academic performance and reading efficiency. Early screening for accommodative abnormalities in adolescents especially those who report using screens for more than four hours a day, should be a priority in public health initiatives. The 20-20-20 rule, outdoor activities and vision therapy exercises are a few interventions that could help minimize these detrimental impacts(204).

10.6. Convergence findings:

When performing prolonged near tasks like using a digital device then convergence (the capacity of both eyes to turn inward for single binocular vision at close range) is crucial to visual efficiency(244). Near Point of Convergence (NPC), Negative Fusional Vergence (NFV) and Positive Fusional Vergence (PFV) were used in this study to assess convergence. Highly significant correlations between extended device use and convergence anomalies were found through statistical analysis using the Chi-square test and Fisher's Exact test.

10.7. Near Point of Convergence (NPC):

A notable distinction between the two groups in NPC was observed in this study. Just 19% of low digital device usage participants exhibited convergence insufficiency whereas 81% had normal convergence. On the other hand, only 12% of the high digital device usage group's responses were normal and 11% showed excessive convergence, indicating a significant 77% convergence insufficiency. This association was highly statistically significant ($p<0.00001$). This study found that teenagers who spend more time on screens are significantly more likely to develop convergence insufficiency (CI). This finding is in line with earlier research by Chellapan et al, who reported that convergence insufficiency was the most prevalent binocular vision disorders among school-aged children associated with prolonged screen time(84). According to Sheppard and Wolffsohn, close work raises the demand for vergence and prolonged use of digital devices interferes with the normal convergence mechanism resulting in CI symptoms like headaches, diplopia and eyestrain(40). Furthermore, Rosenfield noted that CI symptoms like eye strain, blurred vision and diplopia are often linked to digital eye strain(76). The clinical significance of this finding is further supported by the fact that CI has been linked to decreased academic performance and near task avoidance in adolescents(245). The mechanism probably entails a prolonged accommodative-convergence demand at short working distances which results in diminished convergence reserves and medial recti muscle fatigue(246).

10.8. Negative Fusional Vergence (NFV):

We found that the divergence ability of the eyes among high digital device usage participants was significantly lower than that of low digital device usage participants ($p=0.003999$ for break and $p<0.00001$ for recovery). This indicates that the high digital device usage group's Negative Fusional Vergence (NFV) values were noticeably lower. 89% of high digital device usage participants had abnormal break responses compared to 73% of low digital device usage participants. Similarly, only 5% of high digital device usage participants had normal values for NFV recovery while 36% of low digital device usage participants did. These findings demonstrate that teenagers who spend more time in front of screens have a reduced capacity for fusional divergence. A decrease in NFV indicates that it is difficult to relax convergence to maintain near-sightedness. This is in accordance with research by Christian et al(247) and Abdi et al(248) found that prolonged near screen use lowers fusional divergence ranges which makes people more susceptible to asthenopia. Similarly, Scheiman & Wick found that prolonged near work exacerbates inadequate NFV which is commonly observed in conjunction with CI(12). Teenagers who have lower divergence reserves may experience symptoms of asthenopia, diplopia and decrease reading endurance. The mechanism is probably caused by extended near fixation which makes divergence recovery more challenging by continuously activating convergence and decreasing the resting position of vergence(249).

10.9. Positive Fusional Vergence (PFV):

This study found that high digital device usage participants had significantly lower convergence reserves than the low digital device usage participants and this difference was statistically significant ($p<0.00001$). Only 5% of high digital device usage participants displayed normal PFV break and recovery values with the great majority displaying insufficiency compared to 23-27% of low digital device usage participants. The ability of the eyes to counteract nearsighted exophoric tendencies is reflected in PFV. Convergence insufficiency is characterized by deficits in PFV(250). Reduced PFV capacity indicates that the positive fusional vergence reserves have been reduced by the continuous convergence demand from digital devices leaving little capacity to overcome phorias or maintain comfortable binocular vision(250). Abdi & Rydberg(248) found that school going children with extended near work demands had lower PFV. Similarly, Sterner et al(58) found that children who worked for near for extended periods of time had lower PFV values and were more likely to experience symptoms related to CI. Thus, the current study confirms that prolonged exposure to digital media strains fusional vergence systems resulting in decompensation and CI symptoms.

10.10. Interpretation and implications:

According to the strong correlations between high digital device usage and convergence anomalies, convergence and fusional vergence dysfunctions are the main effects of excessive screen time which are supported by highly significant p-values ($p<0.001$ in many of the cases). These results support international research highlighting the significant risk factor for non-strabismic binocular vision disorders that digital near work poses(251–253). Eye strain, difficulty in focusing on close tasks and poor academic performance are clinical manifestations of convergence dysfunction especially in adolescents enrolled in online classes. The findings emphasize the necessity of regular NPC and fusional vergence testing in school vision screenings from a public health standpoint particularly in populations with high screen exposure. Promoting ergonomic working distances (>30-40 cm), taking frequent breaks according to the 20-20-20 rule and if required engaging in vision therapy exercises that target convergence reserves are some examples of preventive measures(12,254). Timely referrals for eye exams may also be supported by increasing the knowledge of parents and educators about the symptoms of CI.

11. Stereopsis, strabismus and binocular single vision:

11.1. Stereopsis:

In this study, standard clinical techniques were used to measure stereopsis and the findings showed that most participants retained normal depth perception despite regularly using digital devices. According to statistical analysis, stereopsis outcomes and device usage categories did not significantly correlate ($p=0.479892$). This result shows that fine binocular integration as determined by stereopsis was largely unaffected by high digital screen exposure but accommodative and convergence anomalies were strongly linked to it. Prior research pointing out stereopsis and concluded that it usually takes place until unless there are serious binocular vision conditions like strabismus and amblyopia occurs (8,255). However, children who are exposed to digital devices for extended periods of time have been found to exhibit subtle reductions in stereo-acuity which are not detectable by gross stereopsis tests (256). Hussaindeen et al (71) found that stereopsis deficits are less common in non-strabismic binocular vision anomalies like accommodative or convergence dysfunction which is consistent with these findings. Similarly, Wajuihian & Hansraj(257), found that stereopsis usually doesn't change until unless there is a noticeable suppression or deviation. The fact that stereopsis is a more stable binocular function that is less impacted by transient vergence fatigue or accommodative stress may also be the reason for the lack of significant differences in stereopsis in this study (257).

11.2. Strabismus:

Additionally, the analysis showed no statistically significant correlation between using digital devices and having strabismus ($p=1.0$). This suggests that extended screen time does not directly cause manifest strabismus, even though it may cause functional abnormalities like accommodative spasm or CI. This finding is strengthened by earlier research by Sprunger et al(258), highlighted that strabismus is more often linked to neurological or congenital causes than to lifestyle choices like screen time. Furthermore, research in both Asian and Western populations indicates that while increased near work may increase the likelihood of phoria decompensation but it does not always result in tropias(9,259). However, it's crucial to remember that prolonged near work can exacerbate symptoms for teenagers who already have phorias(260).

11.3. Binocular Single Vision (BSV):

According to the Worth Four Dot Test, about 20% of participants had BSV suppression with a slightly higher prevalence in the high digital device usage group. But according to the Chi-square test, this difference was not statistically significant (p=0.537968). This study found that extended use of digital devices may increase vergence stress but it does not seem to substantially impair fusion to the point where it results in suppression that is clinically noticeable. Sarkar et al(90) reported similar findings indicating that high near visual demands primarily worsen convergence anomalies and phoria without significantly changing baseline fusion. Additionally, according to Chhetri et al(251), suppression is typically rare in non-strabismic binocular vision disorders unless it is linked to decompensating heterophoria. The fact that almost one-fifth of participants had suppression even though this finding was not statistically significant, emphasizes how crucial it is to keep an eye on the integrity of binocular vision in prolonged screen users.

11.4. Interpretation and implications:

When combined the findings for BSV, strabismus and stereopsis then this study found that extended use of digital devices influences dynamic binocular functions (accommodation and convergence) as opposed to static sensory outcomes. The idea that digital exposure primarily causes functional fatigue rather than structural binocular breakdown is supported by the lack of significant associations in these parameters. This is encouraging from a clinical standpoint because it implies that although teenagers may struggle with accommodative or convergence issues but their stereopsis and gross fusion are largely unaffected. These results highlight the need for vision screenings to focus on functional binocular vision assessments (NPC, fusional vergence and accommodation) rather than just stereopsis or strabismus evaluations from a public health standpoint. Reducing misconceptions also requires teaching parents and teachers that using digital devices may result in functional visual inefficiency even though it is unlikely to cause strabismus directly.

12. Conclusion:

The current study examined the impact of digital device usage on binocular vision and refractive status among teenagers and showed a strong and statistically significant correlation between extended use of digital devices and various aspects of teenage visual function. With the majority of comparisons displaying p-values<0.001, abnormalities in accommodation (NPA, NRA, PRA and accommodative facility), convergence (NPC, NFV and PFV) and refractive status (myopia and astigmatism) were particularly common among high digital device usage participants. However, there were no significant correlations found for parameters like stereopsis, strabismus and binocular single vision indicating that the use of digital devices primarily affects dynamic functional mechanisms rather than sensory integration. These results are in line with research from around the world confirming that digital lifestyles play a major role in the growing prevalence of accommodative dysfunctions, convergence insufficiency and the advancement of myopia. Long-term accommodative and vergence demands, ciliary muscle fatigue, decreased outdoor activity and ergonomic considerations are probably the mechanisms behind these associations. Crucially, these alterations seem to be functional and possibly reversible with prompt action. Clinically, the findings highlight how critical it is to identify and treat nonstrabismic binocular vision abnormalities and refractive errors in teenagers who spend a lot of time in front of screens. Routine optometric practice should include comprehensive vision screenings, refractive correction and vision therapy when appropriate. From the standpoint of public health, the results illustrate the necessity of policy level guidelines controlling screen use in children and adolescents as well as educational programs encouraging healthy visual habits such as the 20-20-20 rule, appropriate working distances and increased outdoor activity. At last but not the least, we concluded that the daily extended use of digital devices has a quantifiable and negative impact on the visual function of teenagers, specifically on the refractive staus and the development of accommodative and convergence systems. In order to protect visual efficiency and long-term ocular health in the digital age, these problems must be addressed through clinical, public health and preventive measures.

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