INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE.

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE

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Certificate

*This is to certify that the thesis entitled '*INVESTIGATION OF EFFECTS OF RADIO FREQUENCY(RF) RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE.*' submitted by Firdoos Jaman for the degree of Doctor of Philosophy under Mizoram University, Aizawl, embodies the record of original investigations carried out by him under my supervision. He has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. This work has not been submitted for any degree at any other university.*

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DECLARATION

MIZORAM UNIVERSITY

DECEMBER, 2024

I **FIRDOOS JAMAN**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/ Institute.

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ABBREVIATIONS

- **OD:** Oculus Dexter (Right Eye)
- **OS:** Oculus Sinister (Left Eye)
- **OU:** Oculi Unitas
- **RF:** Radiofrequency Radiation
- **VA:** Visual Acuity
- **CDMA**: Code Division Multiple Access
- **IOP:** Intra Ocular Pressure
- **PH:** Pinhole
- **GPRS:** General Pocket Radio Service
- **1G/2G/3G/4G/5G**: Generations of Wireless Network
- **CDMA**: Code Division Multiple Access
- **EMF**: Electromagnetic Field
- **GPRS**: General Packet Radio Service
- **ICNIRP**: International Commission for Non-Ionizing Radiation Protection
- **OD**: Oculus Dexter (Right Eye)
- **OS**: Oculus Sinister (Left Eye)
- **RF**: Radio Frequency
- **SAR**: Specific Absorption Rate
- **TBUT**: Tear Break-Up Time
- **TDMA/FDMA**: Time/Frequency Division Multiple Access
- **WCDMA**: Wideband Code Division Multiple Access

THIS THESIS IS DEDICATED

TO

MY PARENTS, MY FAMILY,

FRIENDS

AND

MY SUPERVISIOR

CHAPTER- 1

INTRODUCTION AND BACKGROUND OF THE THESIS

This chapter represents the Introduction of the Present Thesis Work done.

CHAPTER - 1

INTRODUCTION

1.1 Introduction to Electromagnetic Waves

The electromagnetic wave is a cornerstone concept in modern physics, introduced through the pioneering work of James Clerk Maxwell in 1864, who demonstrated that light propagates as an electromagnetic wave (Ishino 2018). This discovery revolutionized the understanding of electromagnetic radiation and paved the way for various applications—from visible light to radio waves. Experimental validation came in 1887 when Heinrich Hertz provided conclusive evidence for the existence of electromagnetic waves, solidifying Maxwell's theory.

Electromagnetic waves are generated by oscillating electric and magnetic fields, propagating through space and materials at the speed of light. Their wavelengths vary across a broad spectrum—from microwaves (≥ 100 μm) to millimeter waves—with corresponding differences in their interactions and applications (Ishino 2018). The versatility of electromagnetic radiation supports its application across multiple domains, including communication, radar, thermal imaging, and human vision.

1.1.1. Ubiquitous Electromagnetic Fields

The human body exists within a complex environment of electromagnetic fields (EMFs) originating from various natural and man-made sources. While advancements in electronics have undoubtedly improved quality of life, concerns regarding potential health effects of EMF exposure have emerged. This section explores these concerns and the scientific basis for understanding potential risks.

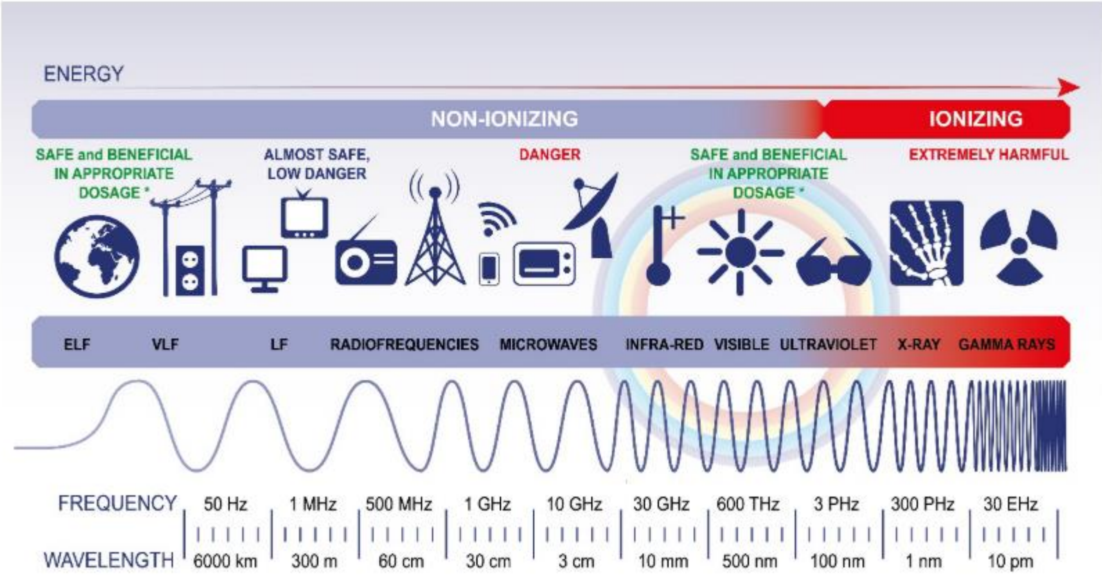


Fig 1.1: Schematic electromagnetic spectrum with different sources(Karaboytcheva 2020)

1.1.2. Mathematical representation of Electromagnetic wave:

The equation of an electromagnetic wave can be represented in several forms, depending on the specific characteristics of the wave. Here are some common equations (Griffiths 2007):

Electric Field Equation:

$$E(z,t) = E_0 \cos(kz - wt + \varphi) \quad \textbf{(1)}$$

Here E_0: amplitude of the electric field, k: wave number (related to wavelength), ω: angular frequency (related to frequency), φ: phase angle

Magnetic Field Equation:

$$B(z,t) = B_0 \cos(kz - wt + \varphi) \quad \textbf{(2)}$$

Here B_0: amplitude of the magnetic field

Electromagnetic Wave Equation (in vacuum):

$$\nabla^2 E = \mu_0 \epsilon_0 \frac{\partial^2 E}{\partial t^2} \quad \textbf{(3)}$$

Here ∇^2: Laplacian operator, μ_0: magnetic constant (permeability of free space), ε_0: electric constant (permittivity of free space)

Electromagnetic Wave Equation (in a medium):

$$\nabla^2 E = \mu \varepsilon \frac{\partial^2 E}{\partial t^2} \quad \textbf{(4)}$$

Here μ: magnetic permeability of the medium, ε: electric permittivity of the medium

Plane Wave Equation:

$$E(x,t) = E_0 \cos(kx - wt + \varphi) \quad \textbf{(5)}$$

$$B(x,t) = B_0 \cos(xz - wt + \varphi) \quad \textbf{(6)}$$

Here x: direction of propagation

Wave Equation in Frequency Domain:

$$\nabla^2 E(k) = -k^2 E(k) \quad \textbf{(7)}$$

Here k: wave number

1.1.2.1. Propagation of Electromagnetic wave

The Poynting vector is a mathematical representation of the directional energy flux of an electromagnetic wave. It is named after John Henry Poynting, who first derived it in the late 19th century. The Poynting vector is a crucial concept in understanding the behaviour of electromagnetic waves and their interactions with matter.

Mathematical Representation: The Poynting vector (S) is defined as (Griffiths 2007):

$$S = \frac{1}{\mu_0}(E \times B) \tag{8}$$

where: E and B is the electric field vector and magnetic field vector, μ_0 is the magnetic constant (permeability of free space)

Physical Interpretation:

The Poynting vector represents the energy flux (flow of energy per unit area per unit time) of an electromagnetic wave. Its direction is perpendicular to both the electric and magnetic field vectors, and its magnitude is proportional to the energy density of the wave.

Properties:

1. Direction: The Poynting vector points in the direction of wave propagation.

2. Magnitude: The magnitude of S is proportional to the energy density of the wave.

3. Units: The units of S are typically Watts per square meter (W/m^2).

Significance:

1. Energy transfer: The Poynting vector helps describe how energy is transferred from the electromagnetic wave to matter.

2. Wave behaviour: It provides insight into the behaviour of electromagnetic waves, including reflection, refraction, and diffraction.

3. Electromagnetic momentum: The Poynting vector is related to the electromagnetic momentum of a wave.

Thus, Poynting vector is a fundamental concept in electromagnetism, describing the directional energy flux of electromagnetic waves. Its mathematical representation and physical interpretation are crucial for understanding various phenomena in physics and engineering.

Table 1.1: Speed, Wavelength and Refractive Index of Electromagnetic wave in different medium ICNIRP (1998)

Electromagnetic wave	Vacuum	Air	Dielectric	Conductor	Water
Speed ($*10^8$)	2.99	≈ c	=v/c	≈0	2.25
Wavelength	C/f	≈c/f	=v/f	≈0	v/f
Refractive Index	1	≈1.003	n>1	n→α	1.33

Electromagnetic waves propagate differently in various mediums due to the unique properties of each medium.

Key factors influencing electromagnetic wave propagation in different mediums include:

- Refractive index (n): determines the speed and wavelength of the wave
- Permittivity (ε): affects the electric field and wave speed
- Permeability (μ): affects the magnetic field and wave speed
- Conductivity (σ): affects wave attenuation in conductors

Understanding how electromagnetic waves propagate in various mediums is crucial for applications like communication systems, optics, and medical imaging.

Propagation of Electromagnetic (EM) Waves in Different Media

The propagation of electromagnetic waves is influenced by the physical properties of the medium, such as its permittivity, permeability, and conductivity. Below is a concise analysis for each state of matter:

(i) Solid: It has high density and structural rigidity. Here, EM waves often interact strongly with the material's lattice structure, leading to phenomena like reflection, refraction, and absorption. In conductors (e.g., metals), EM waves are highly attenuated due to free electron interactions (skin effect). In dielectrics (e.g., glass), waves propagate with minimal energy loss and are crucial in optical fibers and lenses. High refractive index can slow wave propagation significantly.

(ii) Liquid: It has intermediate density and molecular mobility. EM wave propagation is primarily determined by the liquid's polarizability and viscosity. Polar liquids (e.g., water) exhibit strong absorption in specific frequency ranges (e.g., microwaves due to dipolar rotation). Liquids like oil or water are used in sensors and microwave heating due to their selective absorption properties. Molecular vibrations and rotations can result in significant energy dissipation at certain frequencies.

(iii) Gas: It has low density and high molecular freedom. It typically offers low attenuation to EM waves, making them ideal for long-distance propagation (e.g., in Earth's atmosphere). Absorption occurs at specific frequencies corresponding to molecular resonances (e.g., water vapor absorbs in the microwave range). Radio waves and microwaves propagate efficiently through the atmosphere for telecommunications and radar systems. Atmospheric conditions (e.g., humidity, ionospheric layers) can cause scattering or signal degradation.

(iv) Plasma: It consists of ionized gas with free electrons and ions. Plasma supports unique propagation modes due to its ability to reflect, absorb, or transmit EM waves depending on the wave frequency relative to the plasma frequency. Below the plasma frequency, EM waves are reflected; above it, they propagate with attenuation. Plasma is used in fusion reactors, communication systems, and astrophysical phenomena (e.g., solar wind, auroras). Strong dispersion and absorption can complicate wave propagation, particularly in non-uniform or turbulent plasma environments.

Thus, understanding EM wave propagation in these media is critical for optimizing technologies ranging from telecommunications and imaging systems to energy applications and astrophysical observations. Each medium offers distinct advantages and challenges based on its interaction mechanisms with EM waves.

Mathematical representation

Electromagnetic (EM) wave propagation in different media solid, liquid, gas, and plasma is governed by the interaction between the wave's electric and magnetic fields and the medium's intrinsic properties such as permittivity (ϵ), permeability (μ), and conductivity (σ). The wave equation, derived from Maxwell's equations, governs the propagation and is expressed as:

$$\nabla^2 E - \mu\epsilon \frac{\partial^2 E}{\partial t^2} = \mu\sigma \frac{\partial E}{\partial t} \tag{9}$$

where E is the electric field vector. The term ($\mu\sigma\frac{\partial E}{\partial t}$) accounts for the energy loss due to conductivity, which varies significantly across media.

In solids, EM waves interact strongly with the atomic or molecular lattice, with behavior differing between conductors and dielectrics. In conductors, the wave penetration is limited by the skin depth $\left(\delta = \sqrt{\frac{2}{\omega\mu\sigma}}\right)$, where ω is the angular frequency. This leads to high attenuation, making solids like metals effective reflectors. Dielectric solids, on the other hand, allow propagation with minimal losses, governed by the refractive index $= \sqrt{\epsilon_r}$, crucial for optical technologies like fiber optics.

In liquids, the molecular structure and polarity influence wave propagation. The wave's attenuation and phase velocity are affected by the liquid's permittivity, which can be complex: $\epsilon=\epsilon'-i\epsilon''$, where ϵ'' represents dielectric losses. For instance, water absorbs microwaves due to dipolar relaxation, characterized by a resonance frequency, limiting its utility in high-frequency applications while making it ideal for microwave heating.

In gases, the low density and weak intermolecular forces result in efficient wave propagation. The phase velocity is approximately $v = \frac{c}{\sqrt{\epsilon_r \mu_r}}$, where cc is the speed of light in a vacuum. Absorption occurs at specific frequencies due to molecular resonances, such as water vapor in the microwave region. This selective interaction underpins technologies like radar and atmospheric sensing.

Plasma, an ionized gas, introduces unique dynamics due to its free electrons and ions. The propagation depends on the wave frequency relative to the plasma frequency $\left(\omega_p = \sqrt{\frac{n_e e^2}{\epsilon_0 m_e}}\right)$, where n_e is the electron density, e is the electron charge, and m_e is the electron mass. Waves with $\omega < \omega_p$ are reflected, while those with $\omega > \omega_p$ propagate but are subject to dispersion and attenuation. This behavior underpins applications like ionospheric communication and fusion energy research.

Thus, the propagation of EM waves in these media is fundamentally dictated by the interplay of wave properties and material parameters, influencing a wide range of scientific and technological applications.

Electromagnetic (EM) wave propagation in biological tissues

Biological tissue is highly complex due to their heterogeneous and lossy nature, which combines properties of solids and liquids. Biological tissues are characterized by frequency-dependent permittivity (ϵ) and conductivity (σ), which significantly affect wave absorption, reflection, and scattering. The interaction of EM waves with tissues is often modeled using the wave equation as mentioned in (Eq 8) Here the conductivity term dominates at lower frequencies, leading to significant energy dissipation. At higher frequencies (e.g., microwave or terahertz range), dielectric properties (ϵ) play a critical role, and wave absorption is often quantified by the specific absorption rate (SAR), discussed section (in Eq 9). This parameter is crucial for ensuring safety in medical and communication technologies (Albanese, Medina, and Penn 2003)

In biological tissues, the propagation of EM waves depends on water content, cellular structure, and ion concentrations. High water content in tissues such as muscles and organs results in significant absorption of microwave and radiofrequency waves due to the dipolar relaxation of water molecules, making these tissues lossy dielectrics. Fat and bone, with lower water content, exhibit less attenuation and are more transparent to EM waves in these frequency ranges. The penetration depth (δ) is a key parameter, often ranging from millimeters to centimeters depending on the frequency and tissue type (Čáp et al., 2021).

The interaction of EM waves with biological tissues underpins many medical technologies. For example, radiofrequency and microwave frequencies are used in diagnostic imaging (e.g., MRI) and therapeutic applications (e.g., diathermy and hyperthermia treatments). Terahertz waves, which are non-ionizing, hold promise for early cancer detection due to their sensitivity to water content and molecular structure. Optical frequencies are employed in techniques such as photodynamic therapy and optical coherence tomography, which rely on the scattering and absorption properties of tissues (Čáp et al., 2021).

Understanding EM wave propagation in biological tissues is critical for optimizing these technologies while ensuring safety and minimizing undesirable heating effects. Advanced modeling and simulation tools, coupled with experimental measurements, help refine our understanding of how EM waves interact with complex biological systems.

1.2 Phenomena of Light and Radiation

Overview of Light-Matter Interactions and the Compton Effect

Light-matter interactions are foundational to understanding the behavior of electromagnetic waves across the spectrum. One significant phenomenon, the Compton effect, describes the scattering of photons upon interaction with particles, such as electrons. When high-energy photons collide with matter, they transfer some of their energy to electrons, resulting in a decrease in photon energy and a change in its wavelength. This phenomenon is crucial in medical and imaging technologies, as it helps in distinguishing ionizing from non-ionizing radiation effects.

Compton Effect (Compton Scattering)

The Compton effect describes the scattering of high-energy photons (such as X-rays or gamma rays) by electrons, leading to a change in the photon's wavelength and direction. This phenomenon is significant as it confirms the particle-like behavior of light and supports the quantum theory of electromagnetic radiation (Ross and Webster 1925) (Webster and Ross 1925)(Zhu 2023).

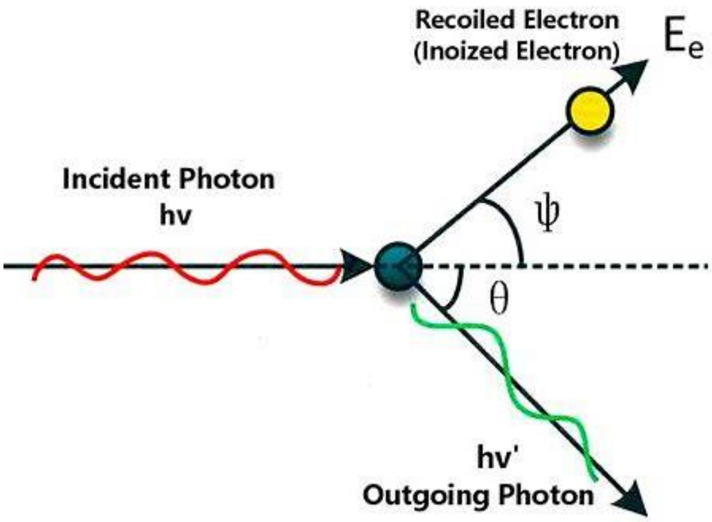


Figure1.2: Schematic representation of compton effect

Mathematical Representation (Csanád 2016);

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e}(1 - \cos\theta) \tag{10}$$

Where,

- m_e: Rest mass of the electron 9.109*10^{-31} kg.

- c: Speed of light 3.0 * 10^8 m/s.

- θ: Scattering angle of the photon (angle between the incident and scattered photon directions)

The term h/m_e is the Compton wavelength of the electron, approximately 2.43

In radiation studies, the Compton effect helps explain how high-energy photons like X-rays and gamma rays impart energy to tissues, often leading to ionization. While RF radiation from mobile devices is non-ionizing, understanding such interactions aids in differentiating its risks compared to ionizing sources, which can alter atomic structures and damage DNA.

Ionization and Non-Ionization Radiation

Electromagnetic radiation is categorized into ionizing and non-ionizing types based on its energy. Ionizing radiation, such as X-rays and gamma rays, possesses enough energy to remove tightly bound electrons from atoms, potentially leading to cellular and DNA damage. Non-ionizing radiation, including RF radiation from mobile phones and microwaves, lacks sufficient energy to ionize atoms but can induce heating and other biological changes.

Energy Transfer and Ionization: In the Compton effect, the energy transfer can be significant enough to ionize atoms by displacing electrons, which is a hallmark of ionizing radiation. Medical imaging techniques like X-rays leverage this principle, where the photon energy is high enough to ionize atoms in body tissues. This ionizing effect is useful in producing images with strong contrast between different tissue densities, as ionizing radiation interacts differently with bones, soft tissues, and air.

Differentiation from Non-Ionizing Radiation: Non-ionizing radiation, such as RF waves used in MRI and ultrasound, lacks the energy to displace electrons. Since non-ionizing radiation doesn't remove electrons, it can interact with tissue without causing ionization, typically only inducing molecular vibrations or rotations. This non-ionizing interaction is safer for long-term exposure but does not produce the same detailed contrast as ionizing radiation.

Applications in Imaging: In techniques like Compton scattering imaging, which is used in certain advanced X-ray imaging methods, scattered photons provide detailed information about internal structures by analyzing the angle and energy reduction in scattered photons. This allows imaging of tissues at different depths and densities and enhances diagnostic capabilities, especially in cases where high-contrast images are required (e.g., detecting tumors or fractures).

Overall, the Compton effect enables the precise application of ionizing radiation in medical imaging, allowing for high-resolution images necessary for accurate diagnostics, while also highlighting the need to distinguish it from non-ionizing radiation to mitigate health risks in prolonged or high-dose exposures.

The health implications of ionizing radiation are well-documented, with clear links to conditions like cancer, whereas non-ionizing radiation's effects are more subtle and often involve thermal responses (Coggle, 2012) . Regulatory bodies set exposure limits based on these effects, with distinct safety standards for occupational and public exposure. Recognizing the difference between these radiation types is essential for risk assessment, particularly in light of the pervasive use of RF-emitting devices.

Electromagnetic Radiation Interactions with Biological Tissue

Electromagnetic radiation (EMR) in the radiofrequency (RF) range interacts differently with biological tissues based on factors like frequency, wavelength, and tissue composition. When RF waves encounter biological material, they can be absorbed, reflected, or scattered. Absorption is particularly significant in tissues with high water content, as RF waves cause dipolar water molecules to oscillate, leading to thermal effects. The degree of interaction is quantified by the Specific Absorption Rate (SAR), which measures the rate at which energy is absorbed per unit mass of tissue.

The SAR is influenced by the electric field strength, tissue conductivity, and density, and is crucial in assessing potential health risks. Penetration depth is another factor that depends on frequency; higher frequencies generally have lower penetration depths, concentrating energy closer to the surface. Studies on SAR in biological tissue emphasize the heating effects and potential for non-thermal biological impacts, including changes at the cellular and molecular levels.

Interaction with the Human Eye

The eye, particularly sensitive to electromagnetic fields, is affected by RF radiation due to its unique anatomy. Its structure includes water-rich tissues, such as the cornea and lens, which are susceptible to heating when exposed to RF radiation. Experimental studies show that RF exposure may lead to increases in eye temperature and changes in ocular properties such as dioptric power and visual acuity.

Proximity to mobile devices, which often emit RF waves, places the eye at increased risk. Extended exposure has been associated with symptoms like blurred vision, eye inflammation, and discomfort due to lacrimation. Findings indicate that RF radiation exposure may influence the dynamics of the tear film, contributing to visual discomfort, especially in users engaged in prolonged screen time.

Microwave Interaction with the Human Body:

- Absorption: Microwaves penetrate the body and are absorbed by tissues, causing heating.
- Reflection: Microwaves are reflected by the body's surface, depending on the frequency and angle of incidence.
- Scattering: Microwaves are scattered by internal structures, such as bones and organs.

Effects of Microwaves on the Human Body:

1. **Thermal Effects**: Microwaves cause tissue heating, potentially leading to burns or other thermal injuries.

2. **Non-Thermal Effects**: Microwaves may cause non-thermal effects, such as changes in cell membrane permeability, gene expression, and neurological effects.

Some specific mathematical equations related to the interaction of microwaves with the human body:

SAR (Specific Absorption Rate) (Alorainy 2003)**:**

$$SAR = \left(\frac{\sigma}{\rho}\right)|E|^2 \quad \textbf{(11)}$$

Here σ: conductivity of the tissue, ρ: density of the tissue, E: electric field strength

Penetration Depth:

$$\delta = \sqrt{\frac{2}{\omega \times \mu \times \sigma}} \quad \textbf{(12)}$$

Here δ: penetration depth, ω: angular frequency, μ: permeability, σ: conductivity

Microwave Absorption:

$$P_{abs} = \left(\frac{1}{2}\right) \times \sigma \times |E|^2 \quad \textbf{(13)}$$

Here P_{abs}: absorbed power, σ: conductivity, E: electric field strength, V: volume of the tissue

Heat Transfer:

$$\nabla^2 T + \frac{Q}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \quad \textbf{(14)}$$

Here: T: temperature, Q: heat source (microwave energy), k: thermal conductivity, α: thermal diffusivity

These equations describe the behaviour of microwaves in the human body and are used in various applications, including safety assessments, medical treatments, and imaging techniques.

Maxwell's Equations (simplified for microwaves):

(i) Gauss law **(iii) Faraday Law** **(15)**

$$(\nabla . E = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

(ii) Gauss Law of Magnetostatic **(iv) Amperes Circuit Law**

$$\nabla . B = 0$$

$$\nabla \times B = \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

Here E and B stand for electric field and B: magnetic field respectively, μ_0: magnetic constant, ε_0: electric constant

These equations describe the behaviour of microwaves in the human body and are used in various applications, including safety assessments, medical treatments, and imaging techniques.

III. Sources of Electromagnetic Radiation

The increased use of electronic devices in recent decades has led to a rise in human exposure to EMFs. These devices, including televisions, microwaves, power lines, mobile phones, and even digital watches, generate electromagnetic radiation. Notably, the conversion of alternating current (AC) to direct current (DC) in many devices increases the frequency of emitted EMFs (Aggarwal and Gupta 2011).

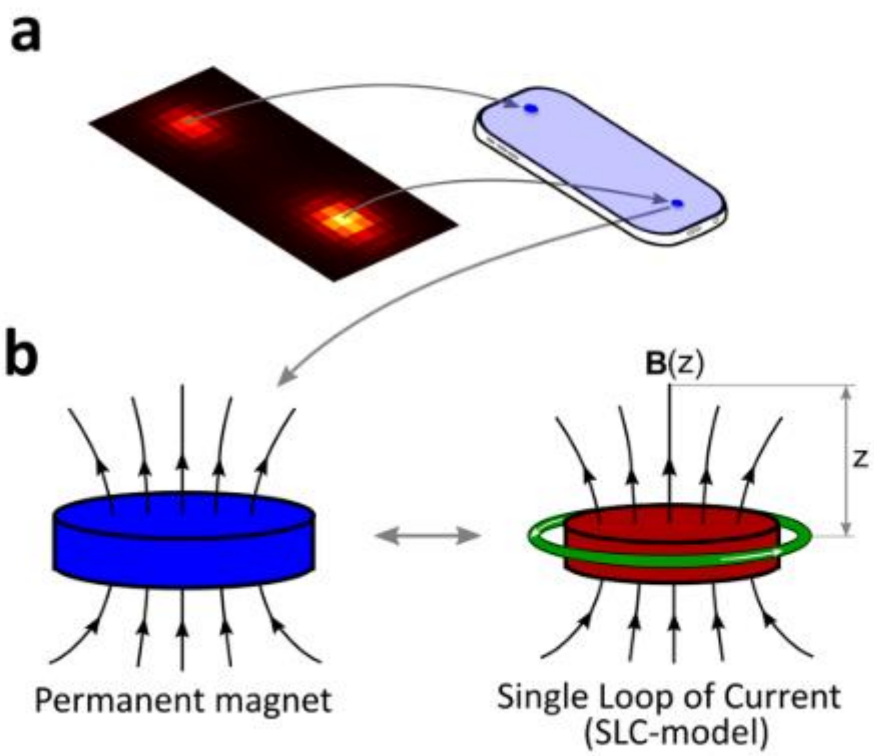


Fig 1.3: (a) Different sources of magnetic hot spot due to built in permanent magnets of the speaker and microphone (b) Simple loop of current (Zastko et al. 2021)

1.3 Potential Health Effects of Electromagnetic Field Exposure

The potential health effects of Electromagnetic field exposure remain a topic of ongoing research. While low-frequency EMFs are generally considered to have minimal impact, high-frequency EMFs pose a potential health concern. Studies suggest that high-frequency exposure (above 10 mG) might be linked to an increased risk of certain cancers and miscarriages in pregnant women. Additionally, some research suggests that low-frequency Electromagnetic field may disrupt melatonin production, potentially contributing to neurological and cardiac issues.

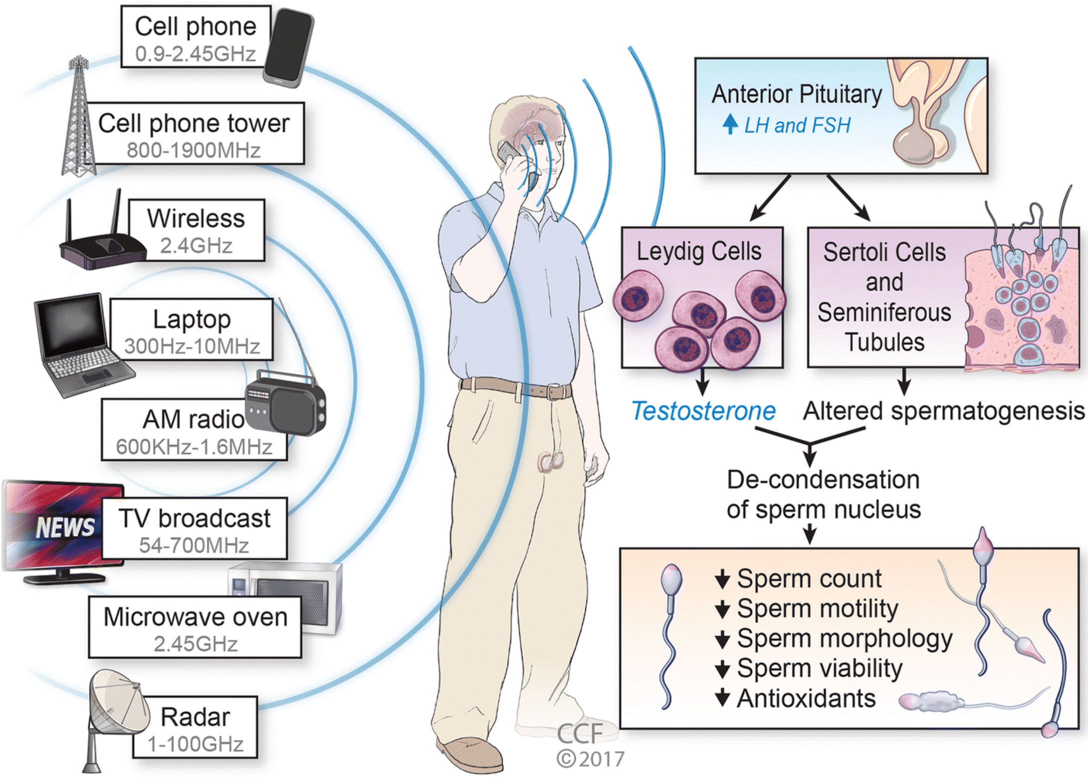


Fig 1.4: **Different Source of EMF Exposure and various health effect** (Kesari, Agarwal, and Henkel 2018)

Common sources of RF-EMF include mobile devices, laptops, Wi-Fi routers, and microwave ovens, all of which emit non-ionizing radiation.

Impacts on Male Reproductive Health: Sperm Quality: Exposure to RF-EMF results in a notable decline in sperm count, motility, morphology, and viability.

Oxidative Stress: It prompts an excessive generation of reactive oxygen species (ROS), leading to DNA damage, cell death, and compromised sperm function.

Hormonal Disruption: It modifies the levels of testosterone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH), affecting the process of spermatogenesis.

Genotoxic Effects: It triggers DNA fragmentation, chromosomal irregularities, and the formation of micronuclei, contributing to genomic instability and the potential onset of cancer.

IV. Genetic Damage: An Area of Continued Research

The possibility of EMF-induced genetic damage is a crucial area of investigation. While some studies suggest a link between EMF exposure and DNA alterations, further research is needed to establish a definitive cause-and-effect relationship. The long-term consequences of such alterations, if any, also require further exploration.

Points to Consider:

- The original text included a reference to the Bhopal Gas Tragedy, which is not directly related to EMF exposure.
- The specific dangers mentioned at 20 meters distance require further citations for credibility.
- The certainty regarding specific health effects (e.g., most disastrous) should be toned down to reflect the on-going research nature.

Table 1 shows the International Commission for Non-Ionizing Radiation Protection (ICNIRP) SAR limitations for 100 kHz to 10 GHz. These limitations are classified by occupational and public exposure. For occupational exposure, whole-body average SAR is restricted to 0.4 W/kg, head and trunk are 10 W/kg, and limbs are 20 W/kg. The whole-body average SAR for general public exposure is 0.08 W/kg, with localized SAR restrictions of 3 W/kg for the head and trunk and 4 W/kg for limbs. Remember that all SAR limitations are six-minute averages, and localized SAR is based on a 10g mass of contiguous tissues. These restrictions must be followed to reduce non-ionizing radiation health concerns.

Table 1.2: Basic SAR restrictions according to ICNIRP (1998)

Exposure characteristic	Frequency range	Whole-body average SAR(Wkg^{-1})	Local Head/Torso SAR(Wkg^{-1})	Local Limb SAR(Wkg^{-1})	Local S_{ab} (Wm^{-2})

Occupational	100 kHz to 6 GHz	0.4	10	20	NA
	>6 to 300 GHz	0.4	NA	NA	100
General public	100 kHz to 6 GHz	0.08	2	4	NA
	>6 to 300 GHz	0.08	NA	NA	20

Note:

1. "NA" signifies "not applicable" and does not need to be taken into account when determining compliance.

2. Whole-body average SAR is to be averaged over 30 min.

3. Local SAR and Sab exposures are to be averaged over 6 min.

4. Local SAR is to be averaged over a 10-g cubic mass.

5. Local Sab is to be averaged over a square 4-cm2 surface area of the body. Above 30 GHz, an additional constraint is imposed, such that exposure averaged over a square 1-cm2 surface area of the body is restricted to two times that of the 4-cm2 restriction.

History of mobile phone

In 1980, Nippon Telegraph and Telephone commercialized 1st generation wireless cellular network. 1G is created on analog signals based on Advance Mobile Phone Service along with multiplexing scheme of Frequency Division Multiple Access. Ten year later 2G was introduced in Finland with advantages such as GPRS (Global System for Mobile Access) to accesses internet and digital radio signal to offer more security over 1G spectrum. It is based on TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) to allow more user to connect at a time in a given frequency. In early 2000 telecommunication industry was accelerated with introduction of CDMA (Code Division Multiple Access) and WCDMA (Wideband Code Division Multiple Access) in Japan as 3G. In 2010, industry was further electrifying with the concept of OFDM (Orthogonal Frequency division multiplexing). Internet speed is reached up to 100 Mbps in 4G. Now mobile phone is an integral part of human life. It is also becoming a threat to human health as researchers found various health implications on human body due to excessive use Mobile phone being a vital piece of human life and also becoming a threat to human health as researchers found various health implications on human body due to excessive use. Effects of Radio wave (30KHz-300GHz) and Microwave radiation(300MHz-300GHz) emitted from mobile phones are mainly thermal and non-thermal effect which causes damages on biological tissues. The tissue temperature increases resulting from exposure to electromagnetic waves is referred to as 'thermal effect'. Heat generation depends on SAR (Specific absorption rate) value and the power density of the emitted radiation (Buccella, De Santis, and Feliziani 2007b) . As we know that cell phone is mostly exposed to the eyes compared to other part of our body and so chances of dioptric power variation which causes unclear vision after prolonged use. Not many investigations have been made with respect to visual changes in extra time mobile users (Rai et al. 2016).

Smartphones have become a part of life for every human being in the 21st century. However, the radiation emitted from smartphones causes many health hazards when used excessively, unfortunately, not many of us are aware of this fact. Mobile phones emit Radio wave, microwave radiation, and have thermal and non-thermal effects, which causes damage to biological tissues. The highly exposed area in our body to mobile phones is eyes compared to the other parts of the body and therefore the radiation impacts mainly the eyes compared to other organs (Buccella, De Santis, and Feliziani 2007).

Mobile Phones and Electromagnetic Waves

Mobile phones rely on electromagnetic waves, particularly in the form of radiofrequency (RF) waves, to transmit and receive data wirelessly. These waves, typically within the frequency range of 800 MHz to 3 GHz, facilitate voice calls, text messaging, internet access, and multimedia streaming. As mobile networks have evolved from 2G to 5G, the frequency bands have expanded, with newer generations like 5G utilizing millimeter waves (24-100 GHz) to deliver ultra-fast speeds and low latency. However, mobile phones emit RF radiation, raising concerns about potential health risks. Prolonged exposure to RF waves, although non-ionizing, can cause thermal effects by slightly heating tissues, especially with close and extended use. Regulatory frameworks monitor these exposures through Specific Absorption Rate (SAR) limits, ensuring radiation remains within safe levels. While studies have yet to conclusively link mobile phone radiation with serious health issues, researchers continue to explore long-term impacts, particularly on the brain and reproductive health. Advances in technology, such as beamforming in 5G, aim to enhance connectivity while minimizing unnecessary radiation exposure, ensuring safer mobile communication in an increasingly connected world.

Mobile Phone Radiation and Safety Standards

SAR Data for Popular Mobile Phones

Specific Absorption Rate (SAR) is a regulatory metric for mobile devices, ensuring that RF energy absorption in the body remains within safe limits. SAR values vary across phone models, depending on design and operational frequency. For example, SAR values in the head are typically capped at 1.6 W/kg in regions like the United States (per FCC guidelines) and 2.0 W/kg in Europe (per ICNIRP guidelines).

These limits aim to minimize thermal effects and prevent adverse health outcomes, but even within permissible SAR levels, user habits, such as holding devices close to the body for prolonged periods, can influence actual exposure. Awareness of SAR ratings, often available on manufacturer websites or regulatory databases, is crucial for informed mobile device use.

Table 1.3: Comparison of SAR value of selected mobile phone model available in market

Mobile Phone Model	SAR (Head) W/kg	SAR (Body) W/kg	Frequency Range	Notes
Apple iPhone 13	1.19	1.19	800 MHz-5 GHz	SAR values for both head and body fall under the safety limit in most regions.
Samsung Galaxy S21	1.24	1.25	800 MHz-5 GHz	Similar SAR values across different models within the same series.
Google Pixel 5	0.89	1.14	700 MHz - 5 GHz	Low SAR values for both head and body
One Plus 9 Pro	1.19	1.16	800 MHz – 3.5 GHz	Low SAR values for both head and body
Motorola Moto G Power	1.39	1.33	850 MHz – 2.4 GHz	SAR value slightly higher compared to premium models.
Sony Xperia 10 II	1.16	1.14	850 MHz – 2.5 GHz	Within acceptable SAR limits for public exposure.
Huawei P40 Pro	1.39	1.21	850 MHz – 2.5 GHz	SAR values vary depending on the version and region.
Samsung Galaxy Note 10+	1.17	1.16	800 MHz - 5 GHz	SAR values slightly higher than most recent devices.
Apple iPhone 12	1.36	1.22	700 MHz - 5 GHz	Same SAR value for head and body.
Xiaomi Mi 11	1.36	1.22	850 MHz - 5 GHz	SAR value higher for the body compared to the head.

SAR (Head) refers to the radiation absorption rate when the phone is held close to the head (e.g., during a phone call).

- SAR (Body) refers to the radiation absorption rate when the phone is used near the body (e.g., in a pocket).

-SAR Limits: Regulatory standards, such as those by the FCC (Federal Communications Commission) in the U.S. and ICNIRP (International Commission on Non-Ionizing Radiation Protection) in Europe, limit the SAR for mobile phones to 1.6 W/kg (for the head) and 2.0 W/kg (for the body), averaged over 1 gram of tissue (head) or 10 grams (body).

Frequency Bands Used in Mobile Communication

Mobile networks use a range of frequency bands, with lower frequencies used in 2G and 3G and higher frequencies in 4G and 5G. The shift to higher frequencies, especially in 5G (up to millimeter-wave bands of 24-100 GHz), enhances data speed but also concentrates RF exposure nearer the body's surface due to lower penetration depth. These frequencies require new safety measures and optimized infrastructure, like beamforming and small cells, to manage exposure and mitigate potential health risks.

While 2G-4G bands primarily operate below 3 GHz, 5G's millimetre waves necessitate more stringent SAR guidelines and engineering controls to ensure that energy exposure does not exceed safe limits for nearby users.

Health Implications of Mobile Phone Usage

RF radiation from mobile phones, while non-ionizing, has been studied for both thermal and non-thermal effects. Prolonged and frequent usage can lead to tissue heating, especially in high-water-content tissues like the brain and skin, causing localized temperature rises. While thermal effects are well-documented, non-thermal effects, such as potential impacts on gene expression, cellular stress response, and neurological effects, remain areas of active research.

The eye is particularly vulnerable due to its proximity to the phone during calls, with studies showing increased ocular temperature and tear film instability among heavy users. Visual acuity, eye strain, and even changes in the corneal curvature are documented among users exposed to RF radiation over long periods. These findings underscore the importance of adhering to SAR limits and adopting safer mobile phone habits to mitigate potential health risks.

A study with highly accurate model to estimate the Specific Absorption Rate (SAR) and temperature rise within the human eye region was conducted where a eye model incorporates a detailed representation of various eye tissues, including the lens, muscles, and the posterior chamber, which are often overlooked in traditional computational approaches. The research highlights the numerical techniques involved, particularly the use of a fine discretization grid with a cell size of 0.25 mm, ensuring precise and efficient simulations. To assess the thermal effects caused by handheld wireless transmitters, the investigation considered both simplified dipole antennas and actual handheld devices as sources of radiofrequency (RF) radiation. The findings reveal notable temperature increases in the eye due to RF exposure, which are scientifically significant but do not pose critical health risks in terms of acute thermal effects (Buccella, De Santis, and Feliziani 2007).

Here is a sample table showcasing the Specific Absorption Rate (SAR) values for various mobile phones. Please note that the actual SAR values may vary based on region, model, and testing conditions. The values mentioned below are commonly reported SAR ratings for popular mobile devices:

This section has highlighted the complexities of RF radiation interaction with human tissue, especially the eye, alongside the implications of mobile frequency use in modern communication. Distinguishing between ionizing and non-ionizing radiation is critical for understanding their health impacts and ensuring that SAR standards effectively protect users. Continued research and technological advancements will be essential to safely manage the growing RF exposure from mobile devices, especially as 5G networks proliferate and the demand for wireless connectivity rises.

1.4 Evolution of Mobile Networks and radiation: From 2G to 5G

The evolution of mobile networks from 2G to 5G has been driven by the need for faster communication, enhanced data capacity, and improved connectivity. Each generation introduced significant technological advancements that reshaped how people communicate and access information globally.

2G (Second Generation)

Launched in the early 1990s, 2G marked the shift from analog to digital communication. It used GSM (Global System for Mobile Communications) and CDMA technologies, enabling clearer voice calls, SMS (Short Message Service), and basic multimedia messaging. Operating within 900 MHz and 1800 MHz bands, 2G provided better security and call encryption but had limited data capabilities, with internet access restricted to slow speeds (~50 Kbps).

3G (Third Generation)

Introduced in the 2000s, 3G revolutionized mobile communication by enabling mobile broadband access. With UMTS (Universal Mobile Telecommunications System) and CDMA2000, 3G allowed smoother web browsing, video calls, and multimedia applications. Operating on frequencies like 900 MHz and 2100 MHz, 3G increased data speeds up to 2 Mbps and supported GPS-based services, expanding the use of mobile apps and social media.

4G (Fourth Generation)

The deployment of 4G in the 2010s brought about high-speed mobile broadband, with data rates reaching 100 Mbps to 1 Gbps. Technologies such as LTE (Long-Term Evolution) and WiMAX reduced latency, making seamless video streaming, online gaming, and real-time video conferencing possible. 4G operated across multiple frequency bands, including 700 MHz, 1800 MHz, and 2300 MHz, and introduced features like carrier aggregation, which enhanced network capacity by combining different frequency bands.

5G (Fifth Generation*)*

5G, launched in the late 2010s, represents a paradigm shift in mobile communication by offering ultra-fast speeds of up to 10 Gbps and ultra-low latency (as low as 1 ms). It operates across low-band, mid-band, and high-band frequencies:

- Low-band: Sub-1 GHz for long-range coverage.
- Mid-band: 3.5 GHz for a balance between speed and coverage.
- High-band: Millimeter waves (24-100 GHz) for extremely high speeds and dense urban connectivity.

5G's introduction of technologies like massive MIMO (Multiple Input Multiple Output) and beamforming allows the network to handle billions of connected devices, powering the Internet of Things (IoT), smart cities, autonomous vehicles, and remote surgeries.

The transformation from 2G to 5G reflects the growth of mobile networks from basic voice communication to high-speed data services. While 2G and 3G laid the foundation for mobile communication and internet access, 4G accelerated multimedia consumption and application development. 5G further transforms industries by delivering reliable, real-time connectivity and enabling advanced technologies. This change not only modified everyday communication but also shapes the future of healthcare, transportation, and smart infrastructure, pushing the boundaries of what mobile networks can achieve.

Future: 6^{th} G (Sixth Generation)

In 2020, the global rollout of the fifth generation (5G) of wireless communication networks marked a significant leap in technology. 5G introduced three main communication scenarios: massive machine-type communications (mMTC), ultra-reliable and low latency communications (uRLLC), and enhanced mobile broadband (eMBB). Compared to 4G, 5G brought a range of powerful features, including a peak data rate of up to 20 Gbps, 0.1 Gbps for user-experienced speeds, 1 ms end-to-end latency, support for 500 km/h mobility, a connection density of 1 million devices per square kilometer, an area traffic capacity of 10 Mbps per square meter, threefold spectrum efficiency, and 100-fold improvements in energy efficiency. To meet these goals, pivotal technologies such as millimeter-wave (mmWave), massive multiple-input multiple-output (MIMO), and ultra-dense networks (UDN) were developed and implemented.

Despite the transformative impact of 5G, research has already pivoted toward the next generation: 6G. The drive for 6G is propelled by an unprecedented rise in mobile data traffic anticipated by 2030, which will results even greater connectivity, speed, and reliability. The 6G vision promises a hundredfold increase in energy efficiency and a fivefold improvement in spectrum efficiency compared to 5G. Achieving these ambitious goals will require an overhaul of foundational wireless technologies.

Evaluating 6G mobile communications presents challenges, as the technology remains under development and lacks a standardized set of performance metrics. However, insights from previous generations guide an approach to 6G evaluation, encompassing several key aspects:

Key Performance Indicators (KPIs)

6G KPIs are expected to surpass those of 5G, potentially including:

- **Ultra-high data rates**: Moving towards Tbps speeds.
- **Ultra-low latency**: Targeting sub-millisecond latency for instantaneous responses.
- **Massive connectivity**: Supporting higher densities of connected devices.
- **Enhanced reliability and availability**: Creating a more resilient network infrastructure.
- **Improved energy efficiency**: Lowering energy consumption across networks and devices.
- **Extended coverage and range**: Expanding to hard-to-reach areas to enable diverse applications.

Enabling Technologies

To meet its performance goals, 6G will incorporate advanced technologies, such as:

- **Terahertz communication**: Leveraging higher frequencies to boost bandwidth.
- **Advanced antenna systems**: Utilizing massive MIMO, beamforming, and reconfigurable intelligent surfaces for optimized signal management.
- **Artificial intelligence (AI) and machine learning (ML)**: Enhancing network management, resource allocation, and service customization.
- **Network slicing and virtualization**: Creating customized virtual networks for specific applications.

Use Case Performance

Beyond KPIs, 6G evaluation will consider its effectiveness in supporting transformative use cases:

- **Holographic communication**: Enabling immersive 3D interactions.
- **Tactile Internet**: Allowing remote control of physical devices with real-time haptic feedback.
- **Extended reality and metaverse applications**: Facilitating virtual, interactive environments.
- **Industrial automation and smart factories**: Delivering low-latency, high-reliability networks for critical operations.

Challenges and Considerations

The shift to 6G presents significant challenges that must be addressed:

- **Technical feasibility**: Assessing the practicality and economic viability of 6G technologies.
- **Standardization**: Ensuring global standards for seamless interoperability and deployment.

- **Spectrum availability**: Securing adequate bandwidth to accommodate 6G's needs.
- **Security and privacy**: Addressing heightened security concerns in a hyper-connected digital landscape.

Comparative Analysis of SAR Values and Mobile Device Safety

The growing adoption of mobile devices has sparked concerns regarding exposure to electromagnetic radiation. The Specific Absorption Rate (SAR) is a critical measure of the amount of RF energy absorbed by the human body during mobile phone use.

Variation in SAR Values

SAR values differ significantly across mobile devices based on factors such as design, network provider, and user behavior (Zhang et al., 2019)(Chen et al. 2019). Regulatory standards ensure these values remain within permissible limits to protect public health. However, a study on university students revealed a gap between their awareness of mobile radiation risks and the protective behaviors they adopt (Gavrilas, Kotsis, and Papanikolaou 2022).

Table 1.4: Basic restrictions for electromagnetic field exposure from 100 kHz to 10 MHz, for peak spatial values, (ICNIRP,1998)

Exposure characteristic	Frequency range	Induced electrical field E_{ind} (V $^{m-1}$)
Occupational	100 kHz to 10 MHz	2.70 × 10−4f
General public	100 kHz to 10 MHz	1.35 × 10−4f

* f is frequency in Hz.

* Restriction values relate to any region of the body, and are to be averaged as root mean square (rms) values over 2 mm 2 mm 2 mm contiguous tissue (as specified in ICNIRP 2010).

Table 1.5: Basic Restrictions associated with SAR according to International Commission for Non-Ionizing Radiation Protection (ICNIRP 1998) (Data has been taken from ICNIRP portal with copyright permission)

Types of Exposure	Frequency range	Whole-body Average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
Occupational	100kHz -10MHz	0.4	10	20
	10MHz-10GHz	0.4	10	20
General public	100kHz -10MHz	0.08	2	4
	10MHz-10GHz	0.08	2	4

Note 1-f is the frequency in Hertz

Note 3- All SAR values are to be averaged over any 6-minute period.

Note 4- The localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.

It is thought that mobile phones produce RF energy of non-ionizing radiation, which is considered to be low for any effects on the tissues of the body, and to show similar effects on human health as produce by ionizing radiation.. The electromagnetic field is categorized into 2 classes and they are, extremely low frequencies (ELF; 3 to 3000Hz), including high-voltage transmission lines and in-house wiring; and the other one is radio frequencies (RF; 30 kHz to 300 GHz), which includes cell phones, smart electronics and devices, Wi-Fi, base stations and 5G advancements (Buccella, De Santis, and Feliziani 2007b), (Rai et al. 2016).

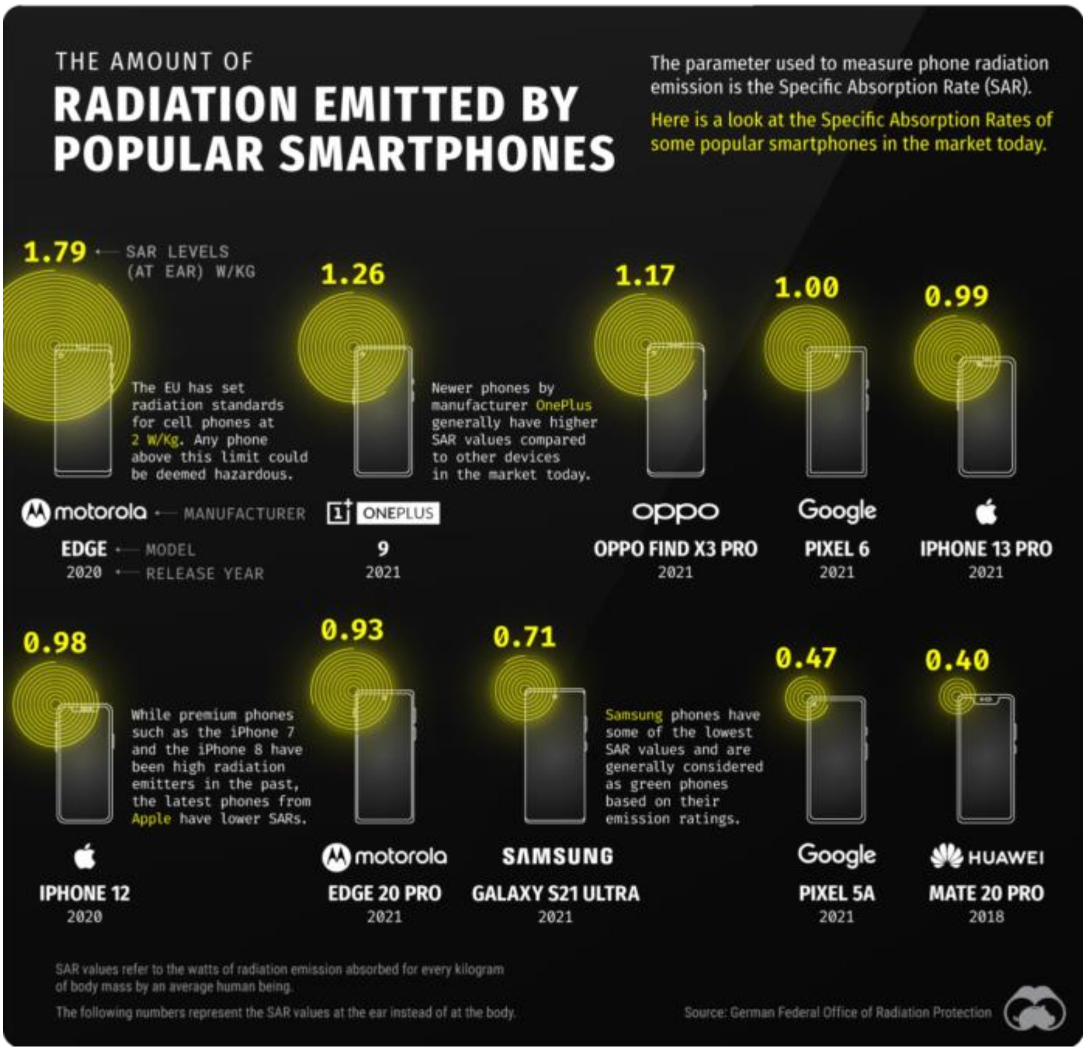


Fig 1.5: Different model of mobile phone with SAR value (Courtesy: Federal office for Radiation Protection)

The development of the mobile phone framework has enormously expanded the degree and extent of RF radiation exposure (RF). Thermal and non-thermal impacts are exerted from the RF radiation emitted from the cell phone and cell phone base stations. An antagonistic impact on people and animals is to be expected from the short-term and long-term exposure to RF radiation. In the year 2015, to demonstrate the effects of radio frequency(RF) radiation emitted from cell phones on human eye function, a study was done and it was found that there is significant changes in visual acuity. (Visual acuity, Refraction) (Siddig Tawer Kafi et al. 2015). A direct connection has been demonstrated by various research center investigations between exposure to RF radiation and biological impacts. Different types of cancers, chromosomal damages and DNA changes are known to be induced through RF radiation exposure (Verschaeve 2009). Whereas numerous studies show effects of RF radiation on the human body, literature related RF radiation effects on eyes with special consideration to dioptric power are scarce. Another study in 2023 found that When the eye is exposed to waves, the eye's temperature increases, and the antenna angle relative to the eye is effective in the rate of specific absorption. This study also found that without observing safety points, including maintaining distance, they can cause dangerous bodily complications Therefore, in our study, an effort has been made to know the effects of RF radiation on dioptric power in human eyes (Elder 2003). Cell phone conversations tend to artificially constrict the peripheral awareness as measured by a visual field. This suggests that cell phone use while driving can decrease the perceptual visual field, making the driver less aware of the surroundings and more susceptible to accident (Elder 2003). A study carried out in 2005 found that prolog use of mobile phone may cause blurring of vision, secretion of the eyes, inflammation in the eyes and lacrimation of the eyes (Küçer 2008)

In 2008, a survey of 229 university students in Kocaeli, Turkey, examined the relationship between mobile phone use and six ocular symptoms: blurring of vision, eye redness, vision disturbance, eye secretion, eye inflammation, and lachrymation. A Chi-square test with Yates correction was used to analyze the data. The study found a significant increase in the incidence of blurred vision among participants who had used mobile phones for over two years compared to those with less than two years of use. Additionally, women reported experiencing eye inflammation more frequently than men (Küçer 2008).

Unfortunately, there is a lack of long-term evidence about the negative impacts of 5G's microwave radiation on biological and environmental systems. There is a significant need for research that is both in-depth and comprehensive on the implications of 5G on human health. In order to ensure the safety of their citizens, telecom rules worldwide should be consistent. Everyone needs to be aware of something. It is important to prioritize their health above responding to compelled behaviour (Koivisto et al. 2000).

It is often assumed that mobile phones emit non-ionizing radio frequency (RF) radiation. In contrast to ionizing radiations like X-rays, the dose of radiation is too little to cause thermal damage to human tissues. An indicator of the potential biological harm caused by electromagnetic radiation, the Specific Absorption Rate (SAR) is defined as, where S is the electrical conductivity of the tissue, E is the electric field, and r is the mass density (Krause et al. 2000). The unit of measurement for this tissue's specific energy absorption rate is watts per kilogram (W/kg). The use of mobile phones has an impact on the dynamics of tear fluid (TBUT and S1T) and the thickness of the cornea in the eye. This can be attributed to the radiations and/or thermal effects emitted by mobile phones (Mittal et al. 2022).

Therefore, in our study, an effort has been made to know the effects of RF radiation on dioptric power in human eyes. So, there is a need for in depth study on this particular issue which will help to overcome problems resulting from excess use of cell phones. The fundamental target of this study will be to explore the visual changes (Dioptric power) among the people using excessive mobile phone. There is scope of more extensive study among the teenager as well as patient having symptoms of dry eye and accommodative anomalies for further evaluation of additional visual problems.

1.5. Human Eye

A comprehensive study of symptoms related to visual changes and visual discomfort associated with excessive use of smart phone may be helpful for clinician to guide and reduce the impact of visual discomfort.

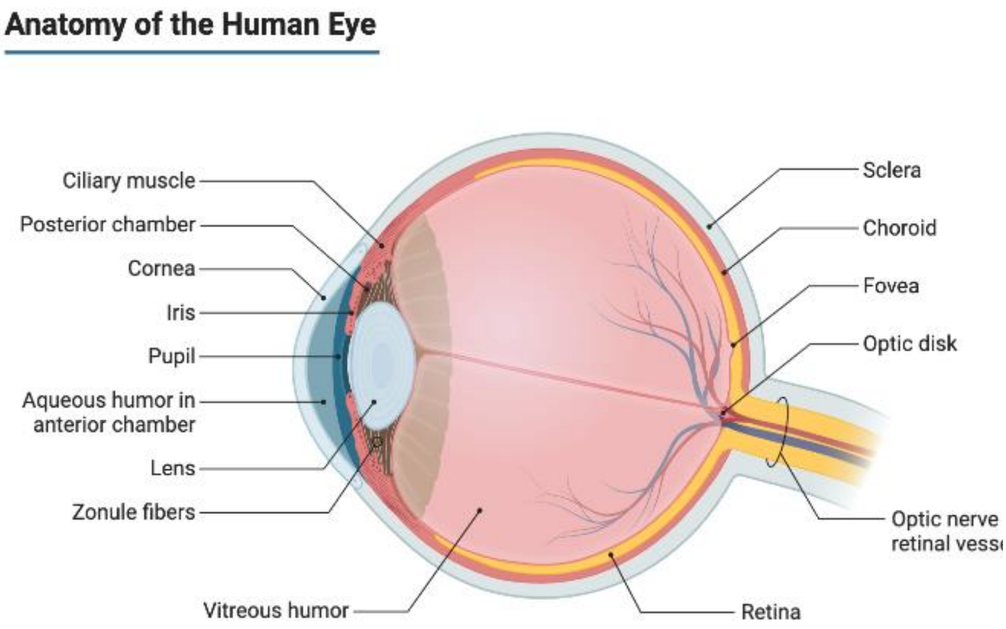


Figure 1.6: Schematic diagram of the Human Eye

Ocular Anatomy: The globe occupies approximately one-third (or less) of the volume of the orbit, with the other two-thirds of the volume composed of fat, muscles, nerves, and vasculature (Fig. 1.1). The wall of the eyeball (globe) consists of 3 primary layers:

1. The sclera, or outer layer, is the fibrous protective layer with the transparent cornea anteriorly; The sclera is the outer supporting layer of the globe and extends from the limbus at the margin of the cornea anteriorly to the optic nerve posteriorly, where it is contiguous with the dural sheath of the optic nerve.1

The cornea (Figure: 1.2) is the most anterior part of the eye, in front of the iris and pupil. It is the most densely innervated tissue of the body, and most corneal nerves are sensory nerves, derived from the ophthalmic branch of the trigeminal nerve (Müller et al. 2003). The cornea of an adult human eye has an average horizontal diameter of about 11.5 mm and a vertical diameter of 10.5 mm, and a curvature that remains rather constant throughout life (F, Schröder, and Erb 2005)

2. The uvea (uveal tract), or middle layer, having vascular and nutritive function, contains pigmented tissue consisting of the choroid, ciliary body, and iris;

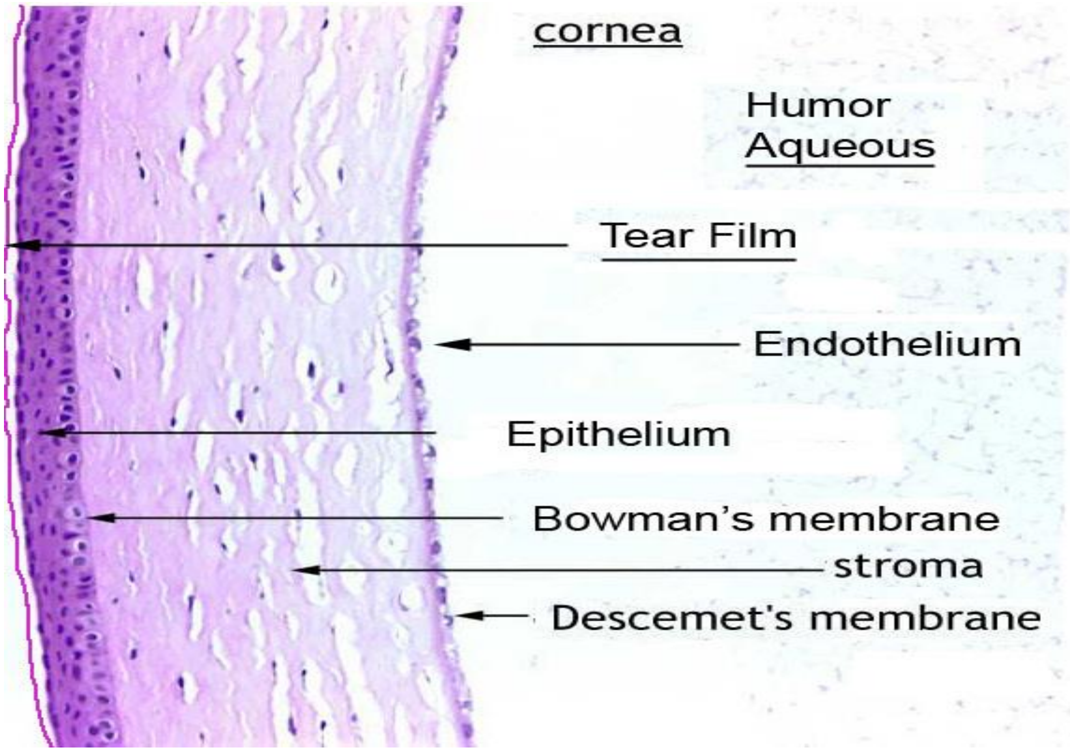


Figure 1.7: Schematic diagram of human corneal layer

The sclera is the outer supporting layer of the globe and extends from the limbus at the margin of the cornea anteriorly to the optic nerve posteriorly, where it is contiguous with the dural sheath of the optic nerve (Mafee et al. 1987).

The sclera acts as a protective layer, maintains intraocular pressure and serves as the attachment site for the extra ocular muscles.[4]

The retina **(**Figure 1.3**)** is the tissue that lines the inner surface of the eye, surrounding the vitreous cavity. The inner wall of the optic cup (surrounding the vitreous cavity) ultimately becomes the neural retina; the outer wall (surrounded by the choroid and sclera) becomes the retinal pigment epithelium (RPE) (Rizzo 2003). The retina is protected and held in the appropriate position by the surrounding sclera and cornea. The retina

receives its blood supply from two circulatory systems: the retinal and the choroidal blood vessels. Retinal function depends on several factors, including the region of the retina being illuminated, the wavelength and intensity of the light stimulus and the state of light adaptation.

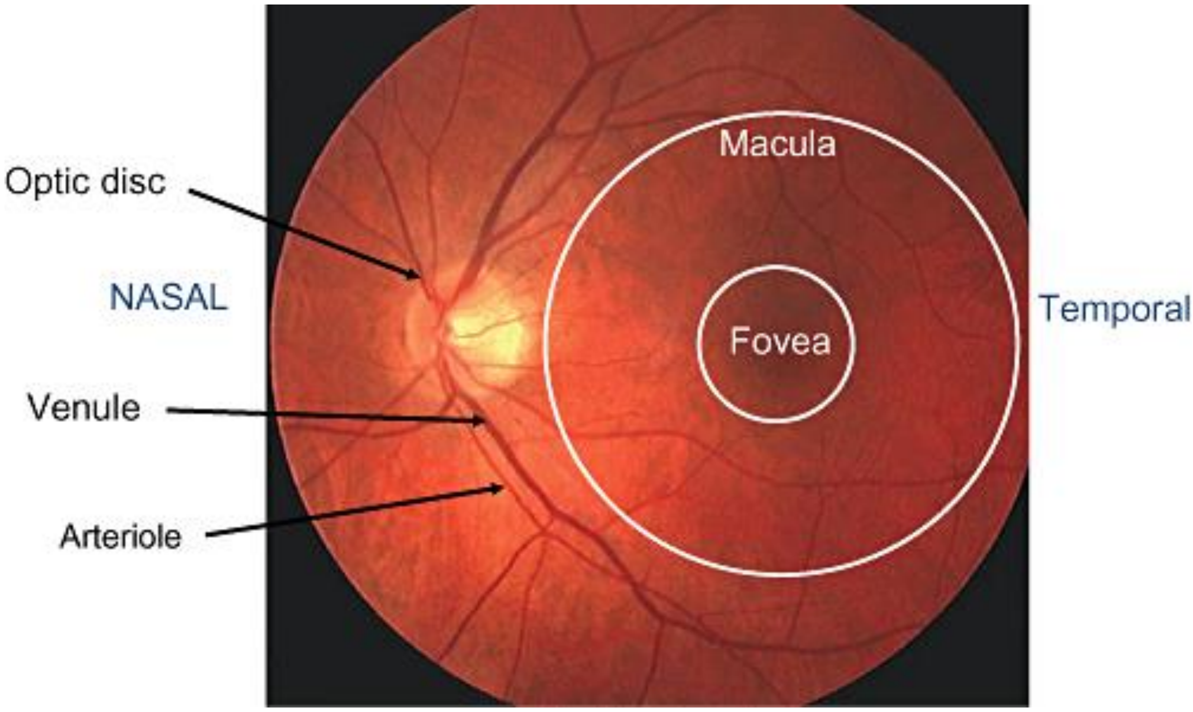


Figure 1.8: Structure of the retina

Myopia:

Myopia, or near-sightedness, is a refractive error where light focuses in front of the retina instead of directly on it. This occurs when the eyeball is too long or the cornea is too curved. As a result, distant objects appear blurry, while near vision remains clear. Myopia has become a global public health crisis, affecting a significant portion of the world's population. The prevalence of myopia has soared in recent decades, driven by changes in lifestyle and behaviour, particularly the reduction in outdoor activities and the increase in near-work activities (Vagge et al. 2018). Myopia is the leading cause of distance vision impairment globally, and its onset at younger ages is particularly concerning, as it can lead to more severe myopia and an increased risk of associated eye conditions.

The impact of myopia extends beyond just vision impairment. Myopia is linked to an increased risk of severe eye conditions, including myopic macular degeneration, retinal detachment, glaucoma, and cataracts, which can lead to visual impairment or blindness (Saw et al., 2005). The economic burden of myopia is significant, considering both the consequences of uncorrected refractive errors and the costs of treatment and management. The economic burden of myopia is also substantial, both in terms of the consequences of uncorrected refractive error and the costs of providing corrective devices, such as glasses and contact lenses.

Myopia, Hyperopia, and Astigmatism.

The prevalence of myopia, or near-sightedness, has been a growing public health concern in recent decades, with numerous studies documenting its alarming rise across various regions of the world. As the World Health Organization's "Vision 2020" initiative highlights, myopia is one of the five immediate priorities for addressing vision-related issues globally (Walline et al. 2013).

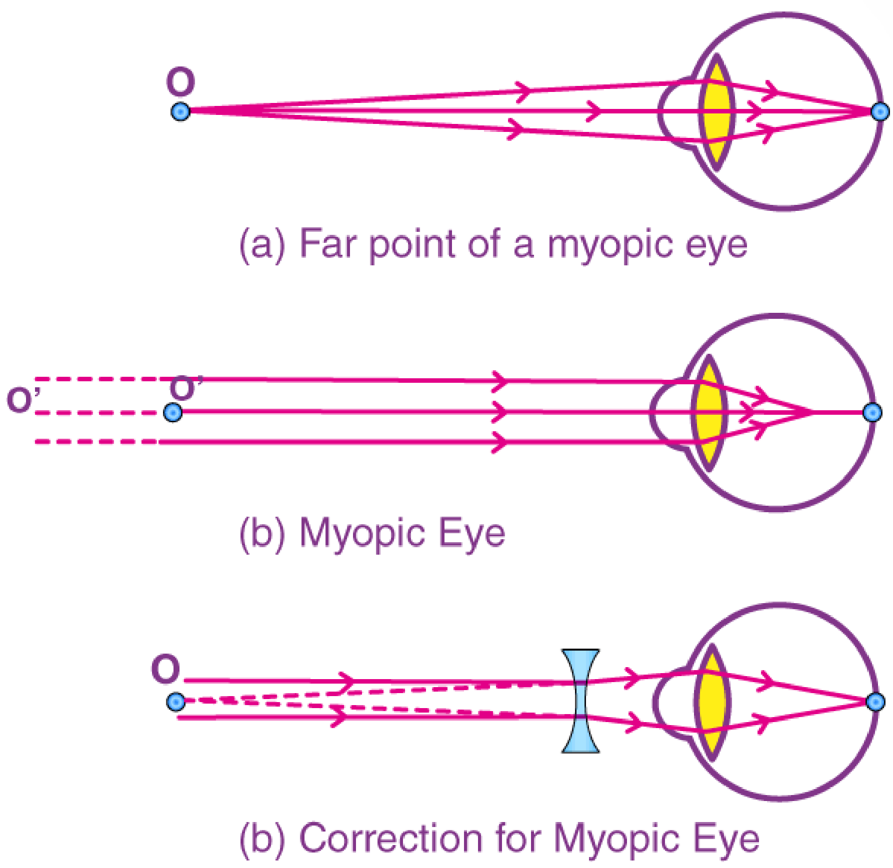


Figure 1.9: Schematic diagram of Myopia and its correction (Source: National Eye Institute)

The situation is particularly acute in Asia, where urban areas have seen myopia rates soar to 80-90% among young adults, with 10-20% experiencing high myopia. By 2050, it is estimated that five billion people will be myopic, and one billion will have high myopia (Ang and Wong 2019). This dramatic increase in myopia prevalence is not limited to Asia, as studies have shown that the prevalence of myopia has risen significantly in the United States as well, from approximately 25% in the early 1970s to 33% currently (Xiang and Zou 2020), (Walline et al. 2013).

Hyperopia:

Hyperopia, commonly known as farsightedness, is a refractive error of the eye that affects an individual's ability to focus on near objects. In individuals with hyperopia, the light entering the eye is focused behind the retina, making it difficult to see nearby objects clearly (Castagno et al. 2014). This condition is typically caused by the eyeball being too short or the cornea having insufficient curvature, resulting in the focal point of light falling behind the retina (Castagno et al. 2014), (Naidoo and Jaggernath 2012).

The prevalence of hyperopia varies across different populations and age groups. Presbyopia, a age-related form of hyperopia, is particularly common in individuals over the age of 50, affecting almost all persons in this age group (Krishnaiah et al. 2006). Hyperopia can be present from birth or develop later in life, and its severity can range from mild to severe.

Hyperopia can be diagnosed through a comprehensive eye examination, which may include measurements of the eye's refractive power, the shape of the cornea, and the length of the eyeball. Once diagnosed, hyperopia can be corrected using various methods, including the prescription of corrective lenses, such as eyeglasses or contact lenses, or refractive surgery.

Several factors, such as age, genetics, and environmental influences, can contribute to the development of hyperopia. Individuals with a family history of hyperopia or who engage in prolonged near-work activities may be at a higher risk of developing the condition (Zadnik et al. 2015).

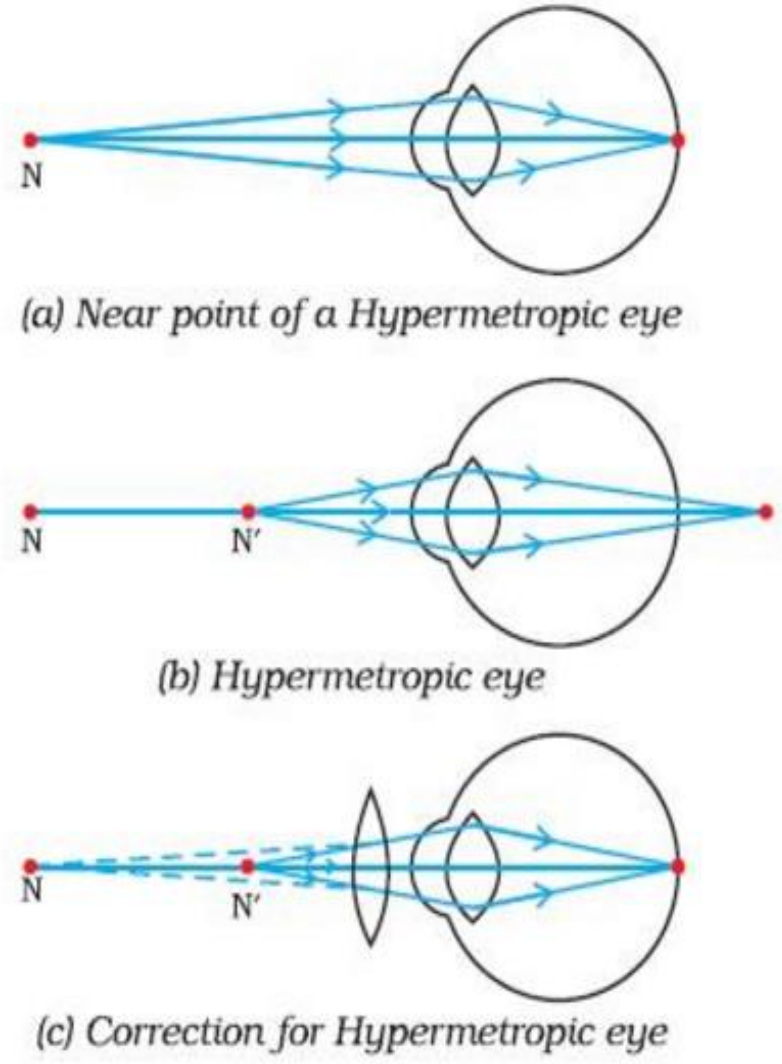


Figure 2.0: Schematic diagram of Hyperopia and its correction (Source: National Eye Institute)

Astigmatism:

Astigmatism is a common refractive error that affects the way light enters the eye, leading to blurred or distorted vision. This condition occurs when the cornea, the clear front part of the eye, is not evenly curved, causing light to focus at different points on the retina (Huang et al. 2021). Astigmatism can be present from birth or develop later in life, and it can have a variety of causes, including genetic factors, eye injuries, and certain medical conditions (Castagno et al. 2014).

One of the primary causes of astigmatism is the irregular shape of the cornea. The cornea is responsible for refracting the majority of the light entering the eye, and when its surface is not perfectly spherical, it can lead to astigmatism. Astigmatism can also be caused by the crystalline lens, the structure inside the eye that helps focus light, if it is not properly shaped (Huang et al. 2021).

Astigmatism can have a significant impact on an individual's vision, leading to blurred or distorted images, eye strain, and headaches. Fortunately, astigmatism can be corrected using various optical devices, such as glasses, contact lenses, or refractive surgery.

1.6. Objectives

- To investigate the possible effects of radiofrequency wave radiation emitted from smart phone and its impact on eye which leads to visual changes (dioptric power) among the selected group of people.
- To investigate the visual acuity variation among some selected group of people.
- To investigate the other possible relevant effects of radio frequency (RF) wave radiation emitted from smart phone along with the visual changes (dioptric power) among the selected group of people.

1.7. Problem undertaken:

Mobile phones, with their diverse configurations and features, vary significantly across manufacturers, resulting in differences in Specific Absorption Rate (SAR) values among models. SAR, which measures the rate at which the body absorbs electromagnetic radiation, plays a crucial role in assessing the potential health risks associated with mobile phone usage. Furthermore, the effects of radio wave and microwave radiation emitted by mobile phones are influenced by environmental lighting conditions, with variations observed between natural and artificial light exposure (Siddig et al., 2015).

Excessive focus on mobile screens, particularly at close distances, and the concurrent reduction in distant focus have been linked to changes in the dioptric power of the human eye, potentially leading to visual strain and other ophthalmological issues. This concern is particularly significant for children under five years of age, as their developing eyes are more susceptible to harm. Recognizing these risks, the World Health Organization (WHO) issued guidelines recommending that children in this age group should limit screen exposure to no more than one hour per day to mitigate potential adverse effects on visual health and overall development (WHO, 2019).

This thesis aims to investigate the implications of mobile phone use on human health, focusing on SAR variability, the differential effects of electromagnetic radiation under various lighting conditions, and the impact of prolonged screen exposure on eye health, particularly in young children.

REFERENCES

Aggarwal, Aakanksha, and Abhishek Gupta. 2011. "Effect of Electromagnetic Radiations on Humans: A Study." *TechSym 2011 - Proceedings of the 2011 IEEE Students' Technology Symposium*: 75–80. doi:10.1109/TECHSYM.2011.5783805.

Albanese, Richard, Richard Medina, and John Penn. 2003. "Mathematics and Electromagnetic Theory." In *Research Directions in Distributed Parameter Systems,* , 1–15. doi:10.1137/1.9780898717525.ch1.

Alorainy, Abdullah. 2003. "Recent Research on Mobile Phones Effects." *Health San Francisco* (October): 1–6.

Ang, Marcus, and Tien Y. Wong. 2019. "Updates on Myopia: A Clinical Perspective." *Updates on Myopia: A Clinical Perspective*: 1–305. doi:10.1007/978-981-13-8491-2.

Buccella, Concettina, Valerio De Santis, and Mauro Feliziani. 2007a. "Numerical Prediction of SAR and Thermal Elevation in a 0.25-Mm 3-D Model of the Human Eye Exposed to Handheld Transmitters." *IEEE International Symposium on Electromagnetic Compatibility* (July): 50–60. doi:10.1109/ISEMC.2007.77.

Buccella, Concettina, Valerio De Santis, and Mauro Feliziani. 2007b. "Prediction of Temperature Increase in Human Eyes Due to RF Sources." *IEEE Transactions on Electromagnetic Compatibility* 49(4): 825–33. doi:10.1109/TEMC.2007.909024.

Čáp, I., Čapová, K., Smetana, M., & Borik, Š. (2021). Electromagnetic and Acoustic Waves in Bioengineering Applications. In I. Čáp, K. Čapová, M. Smetana, & Š. Borik, IntechOpen eBooks. IntechOpen. https://doi.org/10.5772/intechopen.101655

Castagno, Victor Delpizzo, Anaclaudia Gastal Fassa, Maria Laura Vidal Carret, Manuel Augusto Pereira Vilela, and Rodrigo Dalke Meucci. 2014. "Hyperopia:

A Meta-Analysis of Prevalence and a Review of Associated Factors among School-Aged Children.” *BMC Ophthalmology* 14(1). doi:10.1186/1471-2415-14-163.

Chen, Honghui, Wenle Ma, Zhiyu Huang, Yi Zhang, Yi Huang, and Yongsheng Chen. 2019. “Graphene-Based Materials toward Microwave and Terahertz Absorbing Stealth Technologies.” *Advanced Optical Materials* 7(8): 1–16. doi:10.1002/adom.201801318.

Coggle, J. E. (2012). Biological effects of radiation. In J. E. Coggle, CRC Press eBooks (p. 27). Informa. https://doi.org/10.1201/b13379-5

Csanád, Máté. 2016. “Investigation of the Compton Effect.” : 18.

Elder, J. A. 2003. “Ocular Effects of Radiofrequency Energy.” *Bioelectromagnetics* 24(SUPPL. 6): 148–61. doi:10.1002/bem.10117.

F, Rüfer, Anke Schröder, and Carl Erb. 2005. “White-to-White Corneal Diameter Normal Values in Healthy Humans Obtained With the Orbscan II Topography System.” *Cornea* 24(3): 259–61. doi:10.1097/01.ico.0000148312.01805.53.

Gavrilas, Leonidas, Konstantinos T. Kotsis, and Marianna-Sotiria Papanikolaou. 2022. “Attitudes and Behaviors of University Students Towards Electromagnetic Radiation of Cell Phones and Wireless Networks.” *Aquademia* 6(2): ep22009. doi:10.30935/aquademia/12393.

Griffiths, David J. 2007. 1 *Introduction to Electrodynamics*. delhi: Pearson.

Huang, Lihua, Katrina L. Schmid, Jingyu Zhang, Gui You Yang, Jianbo Wu, Xiao Na Yin, Guanhao He, et al. 2021. “Association between Greater Residential Greenness and Decreased Risk of Preschool Myopia and Astigmatism.” *Environmental Research* 196(74): 110976. doi:10.1016/j.envres.2021.110976.

Ishino, Shotaro. 2018. “Novel Waveguide Technologies and Its Future System Applications.” *Surface Waves - New Trends and Developments*.

doi:10.5772/intechopen.72039.

Karaboytcheva, Miroslava. 2020. “Effects of 5G Wireless Communication on Human Health.” *Briefing of the European Parliament* (March).

Kesari, Kavindra Kumar, Ashok Agarwal, and Ralf Henkel. 2018. “Radiations and Male Fertility.” *Reproductive Biology and Endocrinology* 16(1): 1–16. doi:10.1186/s12958-018-0431-1.

Koivisto, Mika, Antti Revonsuo, Christina Krause, Christian Haarala, Lauri Sillanmäki, Matti Laine, and Heikki Hämäläinen. 2000. “Effects of 902 MHz Electromagnetic ®eld Emitted by Cellular Telephones on Response Times in Humans.” *NeuroReport* 11(2): 413–15.

Krause, Christina M., Lauri Sillanmäki, Mika Koivisto, Anna Häggqvist, Carina Saarela, Antti Revonsuo, Matti Laine, and Heikki Hämäläinen. 2000. “Effects of Electromagnetic Field Emitted by Cellular Phones on the EEG during a Memory Task.” *NeuroReport* 11(4): 761–64. doi:10.1097/00001756-200003200-00021.

Krishnaiah, Sannapaneni, Praveen K. Nirmalan, Bindiganavale R. Shamanna, Marmamula Srinivas, Gullapalli N. Rao, and Ravi Thomas. 2006. “Ocular Trauma in a Rural Population of Southern India. The Andhra Pradesh Eye Disease Study.” *Ophthalmology* 113(7): 1159–64. doi:10.1016/j.ophtha.2006.02.020.

Küçer, Nermin. 2008. “Some Ocular Symptoms Experienced by Users of Mobile Phones.” *Electromagnetic Biology and Medicine* 27(2): 205–9. doi:10.1080/15368370802072174.

Mafee, Mahmood F, Allen Putterman, Galdino E Valvassori, and Mario Campos. 1987. “Orbital Space-Occupying Lesions : Role of Computed Tomography and Magnetic Resonance Imaging.” *Radiologic Clinics of North America* 25(3): 8389.

Mittal, Sanjeev Kumar, Rimpi Rana, Athul Puthalath, Ajai Agrawal, Anupam, Neeti

Gupta, and Sunita Mittal. 2022. “Ocular Effects of Mobile Phone Radiation.” *Indian Journal of Clinical and Experimental Ophthalmology* 8(1): 66–71. doi:10.18231/j.ijceo.2022.013.

Müller, Linda J., Carl F. Marfurt, Friedrich Kruse, and Timo M.T. Tervo. 2003. “Corneal Nerves: Structure, Contents and Function.” *Experimental Eye Research* 76(5): 521–42. doi:10.1016/S0014-4835(03)00050-2.

Naidoo, Kovin S., and Jyoti Jaggernath. 2012. “Uncorrected Refractive Errors.” *Indian Journal of Ophthalmology* 60(5): 432–37. doi:10.4103/0301-4738.100543.

Rai, Shailesh, Satish Saroshe, A. Khatri, Suraj Sirohi, and Sanjay Dixit. 2016. “A Cross Sectional Study to Assess the Effects of Excessive Use of Smartphones among Professional College Going Students.” *International Journal of Community Medicine and Public Health* (January): 758–63. doi:10.18203/2394-6040.ijcmph20160647.

Rizzo, Joseph F. 2003. 46 Deutsche Zeitschrift fur Akupunktur *Embryology, Anatomy, and Physiology of the Afferent Visual Pathway*. 6th ed. Philadelphia, PA. doi:10.1078/0415-6412-00019.

Ross, P. A., and D. L. Webster. 1925. “Compton Effect.” *Proceedings of the National Academy of Sciences* 11(1): 61–64. doi:10.1073/pnas.11.1.61.

Saw, Seang Mei, Gus Gazzard, Edwin Chan Shin-Yen, and Wei Han Chua. 2005. “Myopia and Associated Pathological Complications.” *Ophthalmic and Physiological Optics* 25(5): 381–91. doi:10.1111/j.1475-1313.2005.00298.x.

Siddig Tawer Kafi, Abdalfattah Mohammed Ahmed, Bashir Algaily Ismail, Enas Ali Nayel, Asma Rashied Awad, and Esraa Alzobair Alhassan. 2015. “Effects of RF Radiation Emitted from Cellphones on Human Eye Function (Vision Acuity/Refraction).” *J. of Electrical Engineering* 3(3): 128–33. doi:10.17265/2328-2223/2015.03.003.

Vagge, Aldo, Lorenzo Ferro Desideri, Paolo Nucci, Massimiliano Serafino, Giuseppe Giannaccare, and Carlo E. Traverso. 2018. “Prevention of Progression in Myopia: A Systematic Review.” *Diseases* 6(4): 92. doi:10.3390/diseases6040092.

Verschaeve, Luc. 2009. “Genetic Damage in Subjects Exposed to Radiofrequency Radiation.” *Mutation Research - Reviews in Mutation Research* 681(2–3): 259–70. doi:10.1016/j.mrrev.2008.11.002.

Walline, Jeffrey J, Kristina Lindsley, Satyanarayana S Vedula, Susan A Cotter, O Donald, and J Daniel Twelker. 2013. “Commentary on ‘Interventions to Slow Progression of Myopia in Children.’” *Chinese Journal of Evidence-Based Medicine* 13(1): 2–4. doi:10.7507/1672-2531.20130003.

Webster, D. L., and P. A. Ross. 1925. “The Compton Effect [10].” *Nature* 115(2880): 51. doi:10.1038/115051a0.

Xiang, Zhao Yu, and Hai Dong Zou. 2020. “Recent Epidemiology Study Data of Myopia.” *Journal of Ophthalmology* 2020. doi:10.1155/2020/4395278.

Zadnik, Karla, Loraine T. Sinnott, Susan A. Cotter, Lisa A. Jones-Jordan, Robert N. Kleinstein, Ruth E. Manny, Donald O. Mutti, et al. 2015. “Prediction of Juvenile-Onset Myopia.” *JAMA Ophthalmology* 133(6): 683–89. doi:10.1001/jamaophthalmol.2015.0471.

Zastko, L., L. Makinistian, A. Tvarožná, F. L. Ferreyra, and I. Belyaev. 2021. “Mapping of Static Magnetic Fields near the Surface of Mobile Phones.” *Scientific Reports* 11(1): 1–10. doi:10.1038/s41598-021-98083-9.

Zhu, Jiang. 2023. “Theory and Application of Compton Scattering Experiment.” *Highlights in Science, Engineering and Technology* 64: 185–90. doi:10.54097/hset.v64i.11278.

CHAPTER- 2

LITERATURE REVIEW

This chapter contains the literature survey.

CHAPTER - 2

LITERATURE REVIEW

2.1 Introduction

The widespread adoption of mobile phones has revolutionized communication, but concerns about potential health risks have emerged, particularly from prolonged exposure to radiofrequency (RF) radiation emitted by these devices. Numerous studies have investigated the relationship between mobile phone usage and various health issues, including visual discomfort, neurological effects, and potential links to cancer. In particular, research has highlighted possible impacts on ocular health, such as eye strain, dry eye syndrome, and even oxidative stress in ocular tissues. This chapter reviews existing literature on the physiological and neurological impacts of mobile phone usage, with a focus on visual health. It aims to consolidate findings from global studies and explore the extent of these effects to provide a comprehensive understanding of mobile phone-related health risks.

2.2. LITERATURE REVIEW:

Research program on the implication of mobile phone used was carried out by number of countries. A Cohort study of 5,50,000 were completed in Denmark (2). In this review Cohort investigation, the incidence of Cancer in each of the 4, 20,095 users of mobile phone user during 1982 to 1995. Overall, 3391 cancers were found with 3825 expected (Rai et al. 2016). No expansion frequency was seen for malignant growths of the strain or nervous system of the salivary gland or leukemia cancer which were of a priority intern. In 2001 a large case control study of the danger of brain tumors according to utilization of cell phone in USA and the investigation does not show association of brain tumor danger and the use of cell phone (Johansen et al. 2001).

In 2010, Karampatzakis and Samaras developed a new 3D numerical model for heat transfer in the human eye that incorporates aqueous humor flow within the anterior chamber. Their study demonstrated that including this fluid dynamics aspect in calculations changes the temperature distribution on the corneal and lens surfaces, though without significantly altering absolute temperature values. Notably, the coolest region of the cornea shifts approximately 2 mm below its geometric center. The maximum fluid velocity in the anterior chamber was calculated to be $3.36 * 10^{-4}$, m/s. This displacement of the cool area on the corneal surface is counterbalanced by assuming anisotropic thermal conductivity. The model was further applied to cases with an artificial intraocular lens to illustrate the resulting temperature variations (Karampatzakis and Samaras 2010).

2.2: Health Implication of Mobile Phone Radiation

2.2.1: Neurological and Musculoskeletal Impacts

The proliferation of smartphones and digital devices has transformed daily life but has also brought about various health concerns, particularly regarding musculoskeletal issues and eye strain (Asadullah et al. 2022), Han et al., 2018; Lowry et al., 1951; Kim et al., 2016). Prolonged usage of these devices, often coupled with poor posture, has been associated with neck and shoulder pain. (S. Y. Kim and Koo 2016) investigated the effects of smartphone use duration on neck and shoulder discomfort in adults with forward head posture, a common postural issue among frequent smartphone users. Their findings indicate that prolonged smartphone use significantly correlates with increased muscle pain and fatigue in these areas. The study observed that adults using smartphones for over 30 minutes without a break reported the highest levels of pain and fatigue, supporting the recommendation for breaks every 20 minutes to mitigate these adverse effects.

Other studies echo these findings, highlighting the widespread prevalence of neck and shoulder pain among digital device users. According to Lowry et al. (1951), neck pain affects up to 45.5% of office workers annually, with poor posture contributing to these rates. Moreover, (Asadullah et al. 2022) defined heavy smartphone usage as exceeding four hours per day, noting that it leads to increased fatigue, reduced productivity, and diminished quality of life. These findings are particularly relevant in light of the COVID-19 pandemic, which has accelerated remote work and, consequently, extended device usage.

Research has also drawn attention to the ocular health implications of prolonged smartphone use. Kim et al. (2016) noted that digital eye strain is increasingly common among youth, often resulting in symptoms such as dry eyes and, in severe cases, contributing to myopia progression. Studies, including one by the Canadian Association of Optometrists and the Canadian Ophthalmological Society (2018), have documented musculoskeletal pain and visual discomfort in children using digital devices, underscoring the need for ergonomic interventions and awareness.

Furthermore, exposure to radiofrequency radiation emitted by mobile devices has raised concerns. Dodo and Muhammad (2024) conducted a study examining radiofrequency radiation levels near mobile phone antennas and found these levels were below international safety limits. However, the authors emphasized the necessity for ongoing research to fully understand long-term exposure effects, as some studies associate radiation exposure with headaches, fatigue, and sleep disturbances (Babadi-Akashe et al. 2014).

In addition to physical health issues, research suggests that heavy smartphone use may contribute to mental health challenges. Hussain et al. (2017) found that excessive smartphone usage correlates with increased anxiety and depression, stressing the importance of balanced technology use. Additionally, Lissak (2018) and Shrestha (2017) highlighted that extensive screen time and close-up work are associated with eye problems, including dry eyes and temporary eye misalignment, as well as the potential development of myopia.

Overall, current literature points to the multifaceted health impacts of prolonged smartphone use. Addressing these issues through education, ergonomic support, and the promotion of digital wellness practices is essential to safeguard users' physical and mental health.

2.2.2 Studies on Cancer and Radiation Exposure

In 2002 a study was performed to study the malignant melanoma in Denmark, but no evidence of increase number of ocular melanoma was detected. In 2002 in Sweden study was done among 1600 people with brain tumor of whom had used mobile for 10 yrs. It was discovered that cell phone dough's the danger of developing brain tumor on the side of head where phone is held. It was also found that the danger increased to more than thrice for mobile users in case of tumors of the auditory nerve (Rizzo 2003). In 2002 a study was done in Finland to demonstrate the effects of cell phone radiation on human cells rather than those to rats. Researcher found that exposit human cells to mobile phone radiation damaged the blood brain barrier and it's also demonstrated that mobile phones can affect cell without rectify them (INSKIP et al. 2001). Research on the effects of RF-EMF (Radio Frequency Electromagnetic Fields) radiation in India has largely focused on short-term impacts on various species, including frogs, honey bees, sparrows, bats, and humans. However, long-term studies across the country remain limited. Sivani and Sudarsanam suggest that even at lower intensities, RF-EMF radiation can cause notable changes in biological systems. These include alterations in cellular metabolism, such as calcium influx, changes in cell morphology, disruption of the blood-brain barrier, alterations in neurotransmitter activities, and variations in gene and protein expression in certain types of cells (Sivani and Sudarsanam 2012).

2.2.3 Ocular Effects of Radiofrequency (RF) Radiation

In 2015, a study was conducted to investigate the effects of Radio Frequency Radiation (RFR) emitted by cell phones on human eye function, including visual acuity and refraction. The research, which focused on the thermal effects of RFR, found that vision defects were common, regardless of which side of the head was used (right or left). This study was limited to the 3G generation of mobile phones (Karinen et al., 2008). In 2016, a cross-sectional study by the Department of Community Medicine at MGM Medical College, Indore, India, explored the impact of excessive cell phone use among professional college students. The study identified visual problems such as dry eyes, headaches, and disturbances in sleep as common issues among students who overused their phones. (Rai et al. 2016).

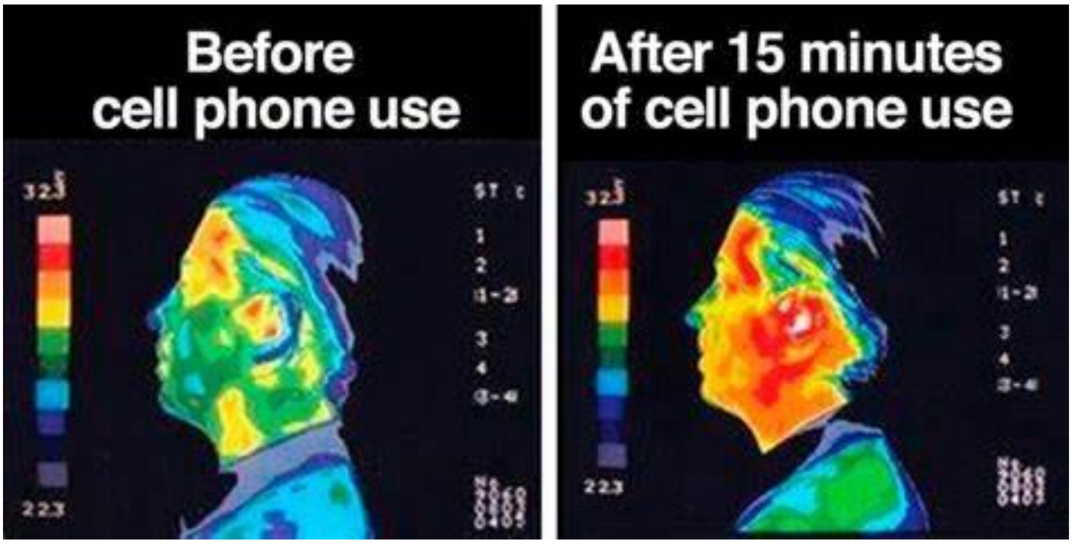


Figure 2.1: Hermographic image of the head without cell phone radiation. (Right) Thermographic image after a 15-minute call, showing yellow and red areas indicating heating that may impact health.

Earlier studies found physiological and biological impact on human life excessive exposure of cell phones. SAR value of cell phones needs to be limited to minimize level to control the risk of cell phone hazards. The ICNIRP guidelines should impose to limits the implication cause by cell phone to human body especially the visual system. There is a proof supporting the idea that visual display unit use decreases the blink rate and possibly reduces the stability of the pre-corneal tear film (Siddig Tawer Kafi et al. 2015). An enormous investigation of primary school students in Korea discovered dry eye symptoms were higher with cell phone use and decreases when phone use was stooped (Patel et al. 1991). Korean young people are reported to have more multiple times increased ocular discomfort and visual symptoms, when cell phone is used for more than two hours a day (Moon, Kim, and Moon 2016).

According to studies, already 0.50-1.00D of uncorrected simulated astigmatism has been established to cause a negative impact on subjective visual comfort, and 1.00-2.00D of astigmatic error may increase task errors by up to 370%

and reduce the productivity of digital device workers to a considerable extent (D. J. Kim et al. 2017).

Several studies have shown one hour of tablet or Smartphone use increases eye strain and blur in young adults. Smartphone and tablets are often used while multitasking with other activities. This requires the user to rapidly modify accommodation for distant objects to maintain distinct vision. By and large there is a dependable proof connecting asthenopia associated with Smartphone use to accommodative facility (Jaman and Tiwari 2021).

2.2.4 Impacts on Mental Health and Behavior

Davanipour et al. (2007) presented a case-control study explores the link betweenoccupational exposure to magnetic fields and the development of Alzheimer’s disease. The research highlights a heightened risk for neurodegenerative disorders among individuals working in environments with elevated electromagnetic fields (EMF). It underscores the potential role of ELF (extremely low-frequency) magnetic fields in accelerating neurodegenerative processes, which is significant for those in electrical or industrial occupations with high exposure levels (Davanipour et al. 2007).

Roosli et al. (2007) provide an extensive longitudinal study on Swiss railway employees, Roosli and colleagues observed increased mortality from neurodegenerative diseases, particularly Alzheimer’s, in correlation with long-term exposure to ELF magnetic fields. Their findings suggest that even low-intensity, chronic exposure to EMFs can have profound impacts on neurological health, offering insight into potential occupational hazards for workers frequently exposed to EMFs (Röösli et al. 2007).

Ahlbom & Feychting (2003) had investigated the link between occupational ELF magnetic field exposure and neurodegenerative diseases, emphasizing conditions like Alzheimer’s and Parkinson’s. Feychting and colleagues found that workers in certain industries faced a higher incidence of these diseases, suggesting that EMF exposure could exacerbate or accelerate neurodegenerative processes. This work reinforces the call for stricter occupational safety guidelines concerning EMF exposure (Ahlbom and Feychting 2003).

Qui et al. (2004) explore the relationship between occupational EMF exposure and Alzheimer's disease risk, focusing on long-term, cumulative exposure. Their findings indicate a dose-response relationship, with higher cumulative exposure correlating with an increased risk of developing Alzheimer's. This research highlights the importance of controlling and monitoring EMF levels in the workplace to minimize health risks (Qiu et al. 2004).

Garcia et al. (2008), explore a meta-analysis, Garcia and colleagues compile data on occupational ELF EMF exposure and its association with Alzheimer's disease. The analysis presents evidence supporting the hypothesis that long-term EMF exposure can contribute to neurodegeneration, providing a comprehensive overview of the potential occupational risks. Their work advocates for further epidemiological studies to refine exposure guidelines and mitigate EMF-related health risks .

Fragopoulou et al. (2010)synthesized research on the health effects of electromagnetic fields, stressing the urgent need for public health policies that reduce EMF exposure. The researchers highlight various physiological and cognitive impacts, including potential carcinogenic effects, supporting the argument for precautionary measures. Their work has been influential in raising awareness about the need for updated EMF safety standards (Fragopoulou et al. 2010).

Sonmez et al. (2010) was focusing on cellular-level impacts, Sonmez and colleagues found that exposure to 900 MHz EMR reduced the number of Purkinje cells in the cerebellums of rats. Given Purkinje cells' role in motor control, this study suggests that prolonged EMR exposure may affect motor functions and coordination. Their findings underline the potential neurological risks posed by high-frequency EMR exposure, relevant for mobile phone users and other EMR-exposed populations (Sonmez et al. 2010).

Avendano et al. (2012) investigates the effects of Wi-Fi exposure on sperm quality, identifying a decline in sperm motility and increased DNA fragmentation in sperm cells exposed to Wi-Fi radiation. This research points to reproductive risks associated with EMF exposure, particularly in environments with high Wi-Fi usage, suggesting a need for caution and further exploration into EMF's impact on reproductive health (Avendaño et al. 2012).

Li et al. (2017) examined magnetic field exposure during pregnancy and its association with miscarriage. Their findings indicate a significant correlation between high magnetic field exposure and increased miscarriage risk, highlighting potential reproductive and developmental dangers of EMF exposure. This study has contributed to growing concerns over EMF safety, especially for vulnerable populations such as pregnant women (Li et al. 2017).

Falcioni et al. (2018) presents conclusive results from long-term exposure of rats to RF radiation, reporting an increased incidence of tumors, especially heart tumors. The findings provide strong evidence of the carcinogenic potential of RF radiation, particularly with prolonged, high-level exposure. This research supports the need for revised RF exposure limits to reduce cancer risk, especially as RF sources become more prevalent in modern environments (Falcioni et al. 2018).

Magda Havas emphasizes the increasing health risks associated with electromagnetic pollution, including dirty electricity, ground currents, and radio-frequency radiation from wireless devices. These forms of pollution are linked to rising cases of asthma, diabetes, multiple sclerosis, chronic fatigue, and fibromyalgia (Havas, 2006). Further research is needed to understand the connection between electromagnetic pollution and these disorders and to determine the percentage of the population affected. Epidemiological studies and in vivo experiments have shown that exposure to non-ionizing radiation ranging from extremely low to microwave frequency electromagnetic fields at intensities well below international safety limits can increase anxiety, depression, and physiological stress, while impairing cognitive functions. Prolonged exposure to NIR is also associated with neurodegenerative diseases, such as dementia, Alzheimer's disease, multiple sclerosis, Parkinson's disease, and amyotrophic lateral sclerosis, as well as developmental and behavioral disorders like ADHD and autism spectrum disorder. Moreover, individuals already affected by electromagnetic exposure are more susceptible to environments heavily contaminated with "electro smog," compounding their health risks (Havas, 2019).

Guidelines	Power Density (microW/cm²)	Exposure Times	Limit Based on	Reference
Most of Western Europe	1,000	30 min	thermal/heating	IEEE C95.1-1999 & ICNIRP
USA	1,000	30 min	thermal/heating	(FCC) IEEE C95.1-1999 & ICNIRP
Canada	439	6 min	thermal/heating	Safety Code 6, Table 5 (2015)
Russia, China, Italy, Most of Eastern Europe	10	3 hours plus	biological effects	Sanitary Norms
Switzerland	10	long term	precautionary	Ordinance on Protection from Non-ionizing radiation
Toronto, Canada	10	long term	precautionary	Toronto Board of Health, Proposed 1999
BioInitiative Report	0.1	long term	biological & precautionary	BioInitiative Report Recommendations 2007
Salzburg Resolution	0.1	long term	precautionary	Preventive Public Health Protection, Salzburg, 2000
European Parliament	0.010 6	long term	precautionary	Resolution 1815, Strasburg, 2011
Germany (sleeping areas)	0.000 01	long term	precautionary	Building Biology Guidelines; level of no biological concern
Exposures	**Power Density (microW/cm²)**	**Exposure Times**	**Exposure**	**Reference**
Average indoor urban exposure Toronto, Canada	0.02 – 0.5	–	urban	Safe Living Technologies, Inc. 2011
Cell Phone Operation Requirements	0.000 000 1	–	cell phone requirements	
Natural Cosmic Radiation	0.000 000 000 1	long term	natural	MAES 2000

Table 2.1: Guideline for mobile exposure time

Several studies have linked RF radiation exposure to oxidative stress in the eye.Oxidative stress in the eye results from an imbalance between the production of reactive oxygen species (ROS) and the body's ability to defuse them. Excessive ROS can damage cellular structures, including the lens of the eye. Barnes and Greenenbaum found that RF radiation from mobile phones can induce oxidative stress, potentially leading to eye damage.These findings suggest that long-term exposure to RF radiation may increase the risk of cataracts and other eye conditions (Barnes and Greenebaum 2016).

In addition to oxidative stress, RF radiation has been implicated in disrupting the function of the retina. Balmorí (2009) reported that RF radiation from phone masts can cause aversive behavioral responses in animals, such as sparrows, suggesting potential neurological effects. While the exact mechanisms underlying these effects are not fully understood, it is possible that RF radiation can interfere with the electrical signaling in the retina, leading to visual disturbances (Balmori 2009).

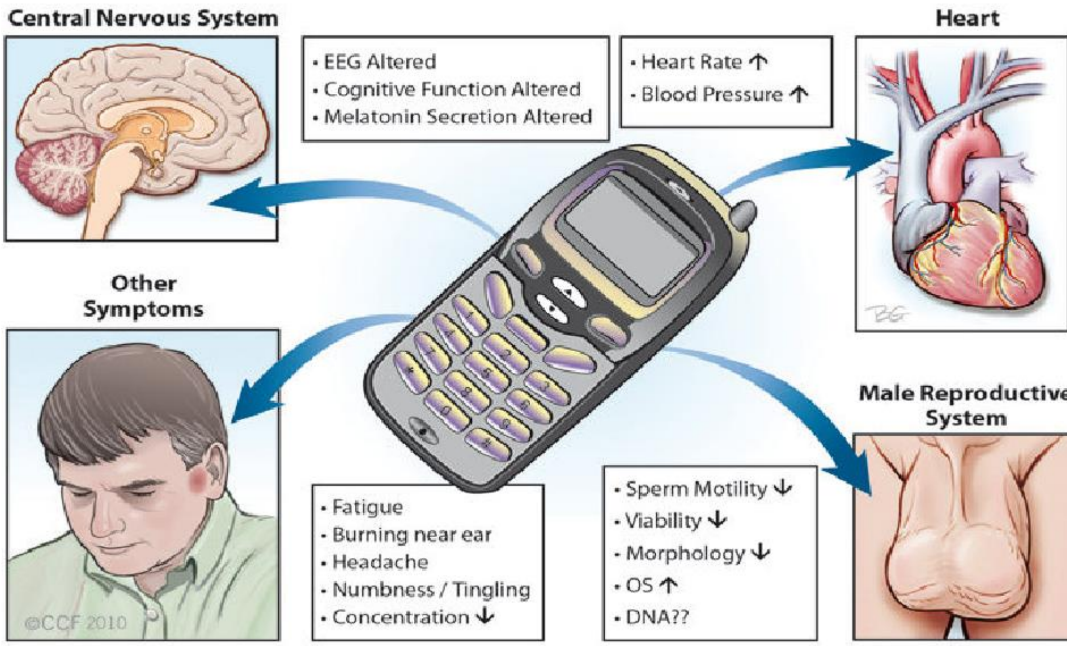


Figure 2.2: Effects of Cellular Phone Use on the Human Body: Cell phone use can affect the central nervous, cardiovascular, and male reproductive systems (Agarwal et al. 2011).

So, there is a need for in depth study on this particular issue which will help to overcome problems resulting from excess use of cell phones. The fundamental target of this study will be to explore the visual changes (Dioptric power) among the people using excessive mobile phone

There is scope of more extensive study among the teenager as well as patient having symptoms of dry eye and accommodative anomalies for further evaluation of additional visual problems.

A comprehensive study of symptoms related to visual changes and visual discomfort associated with excessive use of smart phone may be helpful for clinician to guide and reduce the impact of visual discomfort.

Tissue	The Amplitude of Pulse at a Frequency of 0.9 GHz in Different Exposure Periods in V/m				
	30 min	45 min	1h	1.5 h	2h
Sclera	55	28.21	46.6	53.55	65.13
Cornea	47.68	102.4	37.02	142.8	53.81
Lens	48.78	82.48	31.32	110	41.54
Nerve	41.26	58.52	12.84	59	79.34
Brain	30.59	55.4	77.97	80.95	42.77

Table 2.2: Amplitude of pulse at a frequency in a multilayered human eye model exposed to RF radiation at 0.9 GHz (Shadidi et al. 2024)

Al Shadidi et al, (2024) uses a Finite-Difference Time-Domain (FDTD) method to calculate Specific Absorption Rate (SAR) values in a multilayered human eye model exposed to RF radiation at 0.9 GHz and 1.8 GHz frequencies, representing common emissions from mobile phones. The researchers observed that prolonged exposure significantly increased SAR values, especially in the cornea, where SAR reached 19.44 W/kg after 1.5 hours of exposure at 0.9 GHz, far exceeding FCC safety standards. The results emphasize the potential health risks of extended mobile phone use near the eye, advocating for limited exposure to mitigate thermal effects on ocular tissues (Shadidi et al. 2024).

Tissue	The Power Density of the Eye Tissue Model at a Frequency of 0.9 GHz in Different Exposure Periods in W/m^3				
	30 min	45 min	1h	1.5h	2h
Sclera	1846	4740	2798	4560	6057
Cornea	2905	9692	3788	2.041×10^4	6673
Lens	2192	5338	2123	8595	6432
Nerve	1025	2309	2722	6436	7780
Brain	1513	1758	3129	6020	2.35×10^4

Table 2.3: Power density of the eye tissue in a multilayered human eye model exposed to RF radiation at 0.9 GHz (Shadidi et al. 2024)

2.3. Conclusion

In summary, the current body of research presents compelling evidence of the potential adverse effects of prolonged mobile phone use on human health. Studies indicate a strong association between RF radiation exposure and visual symptoms, including eye strain and oxidative stress, which may increase the risk of cataracts and other ocular issues. Additionally, there are indications of neurological effects, such as cognitive fatigue and impaired memory, stemming from RF exposure. Although no definitive causal relationships have been established for more severe health conditions like cancer, the need for continued research is clear. By better understanding these risks, clinicians can guide patients in adopting healthier mobile phone habits, potentially mitigating the impact on visual and neurological health. Future research should focus on long-term studies to elucidate these effects further and to inform safe mobile phone usage guidelines.

REFERENCES

Agarwal, Ashok, Aspinder Singh, Alaa Hamada, and Kavindra Kesari. 2011. "Cell Phones and Male Infertility: A Review of Recent Innovations in Technology and Consequences." *International Braz J Urol* 37(4): 432–54. doi:10.1590/S1677-55382011000400002.

Ahlbom, Anders, and Maria Feychting. 2003. "Electromagnetic Radiation." *British Medical Bulletin* 68: 157–65. doi:10.1093/bmb/ldg030.

Asadullah, G. M., Hazrat Ali, Kotaro Hashikura, Md Abdus Samad Kamal, and Kou Yamada. 2022. "Development of an Automatic Air-Driven 3D-Printed Spinal Posture Corrector." *Actuators* 11(7): 1–16. doi:10.3390/act11070184.

Avendaño, Conrado, Ariela Mata, César A. Sanchez Sarmiento, and Gustavo F. Doncel. 2012. "Use of Laptop Computers Connected to Internet through Wi-Fi Decreases Human Sperm Motility and Increases Sperm DNA Fragmentation." *Fertility and Sterility* 97(1). doi:10.1016/j.fertnstert.2011.10.012.

Babadi-Akashe, Zahra, Bibi Eshrat Zamani, Yasamin Abedini, Hojaetolah Akbari, and Nasim Hedayati. 2014. "The Relationship between Mental Health and Addiction to Mobile Phones among University Students of Shahrekord, Iran." *Addiction & health* 6(3–4): 93–99. http://www.ncbi.nlm.nih.gov/pubmed/25984275%0Ahttp://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC4354213.

Balmori, Alfonso. 2009. "Electromagnetic Pollution from Phone Masts. Effects on Wildlife." *Pathophysiology* 16(2–3): 191–99. doi:10.1016/j.pathophys.2009.01.007.

Barnes, Frank, and Ben Greenebaum. 2016. "Some Effects of Weak Magnetic Fields on Biological Systems: RF Fields Can Change Radical Concentrations and Cancer Cell Growth Rates." *IEEE Power Electronics Magazine* 3(1): 60–68. doi:10.1109/MPEL.2015.2508699.

Davanipour, Zoreh, Chiu Chen Tseng, Pey Jiuan Lee, and Eugene Sobel. 2007. "A Case-Control Study of Occupational Magnetic Field Exposure and Alzheimer's Disease: Results from the California Alzheimer's Disease Diagnosis and Treatment Centers." *BMC Neurology* 7: 1–10. doi:10.1186/1471-2377-7-13.

Falcioni, L., L. Bua, E. Tibaldi, M. Lauriola, L. De Angelis, F. Gnudi, D. Mandrioli, et al. 2018. "Report of Final Results Regarding Brain and Heart Tumors in Sprague-Dawley Rats Exposed from Prenatal Life until Natural Death to Mobile Phone Radiofrequency Field Representative of a 1.8 GHz GSM Base Station Environmental Emission." *Environmental Research* 165(December 2017): 496–503. doi:10.1016/j.envres.2018.01.037.

Fragopoulou, Adamantia, Yuri Grigoriev, Olle Johansson, Lukas H. Margaritis, Lloyd Morgan, Elihu Richter, and Cindy Sage. 2010. "Scientific Panel on Electromagnetic Field Health Risks: Consensus Points, Recommendations, and Rationales." *Reviews on Environmental Health* 25(4): 307–17.

Havas, Magda. 2006. "Electromagnetic Hypersensitivity: Biological Effects of Dirty Electricity with Emphasis on Diabetes and Multiple Sclerosis." *Electromagnetic Biology and Medicine* 25(4): 259–68. doi:10.1080/15368370601044192.

Havas, Magda. 2019. "Review Article Electrohypersensitivity (EHS) Is an Environmentally-Induced Disability That Requires Immediate Attention." *Citation: J Sci Discov* 3(1): 18020. doi:10.24262/jsd.3.1.18020.

INSKIP, PETER D., R OBERT E. TARONE, E LIZABETH E. H ATCH, T IMOTHY C. W ILCOSKY, W ILLIAM R. S HAPIRO, R OBERT G. S ELKER, H OWARD A. F INE, et al. 2001. "CELLULAR-TELEPHONE USE AND BRAIN TUMORS." *The New England Journal of Medicine* 344(2): 79–86.

Jaman, Firdoos, and Ramesh Chandra Tiwari. 2021. "Environmental and Biological Effects of Cell Phone Radiation: A Review." *Design Engineering* 9(November): 300–311.

Johansen, Christoffer, John D. Boice, Joseph K. McLaughlin, and Jørgen H. Olsen. 2001. "Cellular Telephones and Cancer - A Nationwide Cohort Study in Denmark." *Journal of the National Cancer Institute* 93(3): 203–7. doi:10.1093/jnci/93.3.203.

Karampatzakis, Andreas, and Theodoros Samaras. 2010. "Numerical Model of Heat Transfer in the Human Eye with Consideration of Fluid Dynamics of the Aqueous Humour." *Physics in Medicine and Biology* 55(19): 5653–65. doi:10.1088/0031-9155/55/19/003.

Karinen, Anu, Sirpa Heinävaara, Reetta Nylund, and Dariusz Leszczynski. 2008. “Mobile Phone Radiation Might Alter Protein Expression in Human Skin.” *BMC Genomics* 9: 1–5. doi:10.1186/1471-2164-9-77.

Kim, Dong Ju, Chi-Yeon Lim, Namyi Gu, and Choul Yong Park. 2017. “Visual Fatigue Induced by Viewing a Tablet Computer with a High-Resolution Display.” *Korean Journal of Ophthalmology* 31(5): 388. doi:10.3341/kjo.2016.0095.

Kim, Seong Yeol, and Sung Ja Koo. 2016. “Effect of Duration of Smartphone Use on Muscle Fatigue and Pain Caused by Forward Head Posture in Adults.” *Journal of Physical Therapy Science* 28(6): 1669–72. doi:10.1589/jpts.28.1669.

Li, De Kun, Hong Chen, Jeannette R. Ferber, Roxana Odouli, and Charles Quesenberry. 2017. “Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study.” *Scientific Reports* 7(1): 1–7. doi:10.1038/s41598-017-16623-8.

Moon, Jun Hyung, Kyoung Woo Kim, and Nam Ju Moon. 2016. “Smartphone Use Is a Risk Factor for Pediatric Dry Eye Disease According to Region and Age: A Case Control Study Pediatrics and Strabismus.” *BMC Ophthalmology* 16(1): 1–7. doi:10.1186/s12886-016-0364-4.

Patel, S., R. Henderson, L. Bradley, B. Galloway, and L. Hunter. 1991. “Effect of Visual Display Unit Use on Blink and Tear Stability.” *Optometry and vision science* 68(11): 888–92.

Qiu, C., M. Kivipelto, H. Agüero-Torres, B. Winblad, and L. Fratiglioni. 2004. “Risk and Protective Effects of the APOE Gene towards Alzheimer’s Disease in the Kungsholmen Project: Variation by Age and Sex.” *Journal of Neurology, Neurosurgery and Psychiatry* 75(6): 828–33. doi:10.1136/jnnp.2003.021493.

Rai, Shailesh, Satish Saroshe, A. Khatri, Suraj Sirohi, and Sanjay Dixit. 2016. “A Cross Sectional Study to Assess the Effects of Excessive Use of Smartphones among Professional College Going Students.” *International Journal of Community Medicine and Public Health* (January): 758–63. doi:10.18203/2394-6040.ijcmph20160647.

Rizzo, Joseph F. 2003. 46 Deutsche Zeitschrift fur Akupunktur *Embryology, Anatomy, and Physiology of the Afferent Visual Pathway*. 6th ed. Philadelphia, PA. doi:10.1078/0415-6412-00019.

Röösli, Martin, Manfred Lörtscher, Matthias Egger, Dominik Pfluger, Nadja Schreier, Emanuel Lörtscher, Peter Locher, Adrian Spoerri, and Christoph Minder. 2007. “Mortality from Neurodegenerative Disease and Exposure to Extremely Low-Frequency Magnetic Fields: 31 Years of Observations on Swiss Railway Employees.” *Neuroepidemiology* 28(4): 197–206. doi:10.1159/000108111.

Shadidi, Zina Al, Ahmad Falih, Zina A Al Shadidi, Ahmed Kadum Falih, and Zainab Raheem Muslim. 2024. “Specific Absorption Rate in Human Eye Model Exposed to Mobile Phone Radiation : A FDTD Study Specific Absorption Rate in Human Eye Model Exposed to Mobile Phone Radiation : A FDTD Study.”

Siddig Tawer Kafi, Abdalfattah Mohammed Ahmed, Bashir Algaily Ismail, Enas Ali Nayel, Asma Rashied Awad, and Esraa Alzobair Alhassan. 2015. “Effects of RF Radiation Emitted from Cellphones on Human Eye Function (Vision Acuity/Refraction).” *J. of Electrical Engineering* 3(3): 128–33. doi:10.17265/2328-2223/2015.03.003.

Sivani, S., and D. Sudarsanam. 2012. “Impacts of Radio-Frequency Electromagnetic Field (RF-EMF) from Cell Phone Towers Andwireless Devices on Biosystem and Ecosystem-a Review.” *Biology and Medicine* 4(4): 202–16.

Sonmez, Osman Fikret, Ersan Odaci, Orhan Bas, and Süleyman Kaplan. 2010. “Purkinje Cell Number Decreases in the Adult Female Rat Cerebellum Following Exposure to 900 MHz Electromagnetic Field.” *Brain Research* 1356: 95–101. doi:10.1016/j.brainres.2010.07.103.

CHAPTER- 3

EXPERIMENTAL TECHNIQUES

This chapter deals with the details of the experimental procedures relevant to the current.

CHAPTER - 3

EXPERIMENTAL TECHNIQUES

3.1 Introduction

This chapter outlines the experimental techniques employed to assess visual acuity and refractive errors using various instruments. Among these, the Snellen chart serves as the primary tool for evaluating distant vision, while modern devices such as autorefractometers and retinoscopes allow for precise measurement of refractive errors. The methodology aims to establish a standardized approach to visual function assessment, enabling accurate diagnosis of common visual impairments and providing valuable data for clinical and research purposes.

3.2 Methodology

The study examining the effects of electromagnetic radiation from mobile phones has been conducted, and the results are compiled in the following data sheet. The data represents a sample size from various age groups within Aizawl City. This investigation aims to analyse how exposure to electromagnetic radiation may impact individuals across different demographics, considering factors such as age and duration of mobile phone usage. The findings will provide insights into potential health implications and contribute to a broader understanding of mobile phone radiation effects on the population of Mizoram.

3.2.1. General Work Up Forms (Part I, II, III):

Effective patient history-taking is an essential part of the eye examination process, as it provides valuable insights into a patient's symptoms and underlying health conditions (Craenen et al. 2004). Through careful questioning, eye care professionals can assess the severity, onset, and progression of the condition, allowing for a tailored diagnosis and treatment plan.

Importance of Communication in History Taking

To establish a rapport with the patient and gather accurate information, it's essential to use simple, clear language, actively listen, and show empathy. Research indicates that building a positive communication environment encourages patients to describe their symptoms more thoroughly (Andrews, Whiteside, and Buettner 1996). This includes maintaining eye contact and using a mix of open and closed questions to clarify the patient's concerns.

Key Information to Collect

During history taking, several aspects should be addressed:

1. **Personal and General Information**: Asking about the patient's job, daily activities, and lifestyle choices helps to understand their vision needs and any symptoms that may arise from occupational hazards.
2. **History of Present Complaint**: Documenting the symptoms in the patient's own words provides a clearer understanding of their experience. Key questions should address the onset (sudden or gradual), duration, and any previous occurrences of similar symptoms (Johnson et al. 2016).
3. **Past Eye and Medical History**: It is vital to ask about any previous eye conditions, surgeries, or general health conditions such as diabetes or hypertension, as these can impact ocular health (Craenen et al., 2004)(Craenen et al. 2004).
4. **Medication and Allergy History**: Certain medications can have ocular side effects. Asking about allergies and current medications helps in understanding the patient's treatment history and potential adverse effects (Andrews, Whiteside, and Buettner 1996).

Symptom-Specific Inquiries

Eye health professionals should tailor questions to specific symptoms:

- **Red Eyes**: Could indicate conjunctivitis or uveitis.
- **Pain or Soreness**: May be a sign of trauma or infection.
- **Difficulty Reading**: May suggest issues with refraction or presbyopia.

Gathering information on these symptoms, including their severity and duration, is essential to forming a diagnosis (Greenwald 2003).

Introduction of the Work Up Form:

A General Eye Work Up Form is a crucial tool in ophthalmology, acting as a roadmap for comprehensive eye examinations. It ensures a systematic approach to gathering patient information, conducting tests, and documenting findings. Here's why it's so important:

1. Standardized Data Collection:

The form provides a structured format for collecting essential patient information, including:

- **Medical and Ocular History:** This section records pre-existing conditions, medications, allergies, and previous eye problems, which are crucial for understanding potential risk factors and guiding the examination.
- **Visual Acuity and Refraction:** Measurements of visual acuity (clarity of vision) and refractive errors (Myopia, Hyperopia, astigmatism) are documented, forming the basis for prescribing corrective lenses if needed.
- **Ocular Motility and Alignment:** Assessment of eye movements and coordination helps identify any issues with muscle control or alignment that may affect binocular vision.

- **Anterior and Posterior Segment Examination:** Detailed examination of the front (cornea, iris, and lens) and back (retina, optic nerve) of the eye helps detect any abnormalities or diseases.

2. Enhanced Accuracy and Efficiency:

- **Reduced Errors:** Pre-defined sections and prompts minimize the risk of overlooking crucial details during the examination, leading to more accurate diagnoses.
- **Time Optimization:** The structured format streamlines the examination process, allowing eye care professionals to focus on patient interaction and complex procedures.

3. Effective Communication and Collaboration:

- **Standardized Language:** The form uses consistent terminology and abbreviations, facilitating clear communication among eye care professionals.
- **Comprehensive Documentation:** Detailed documentation of findings, diagnoses, and treatment plans ensures continuity of care, especially when multiple providers are involved.

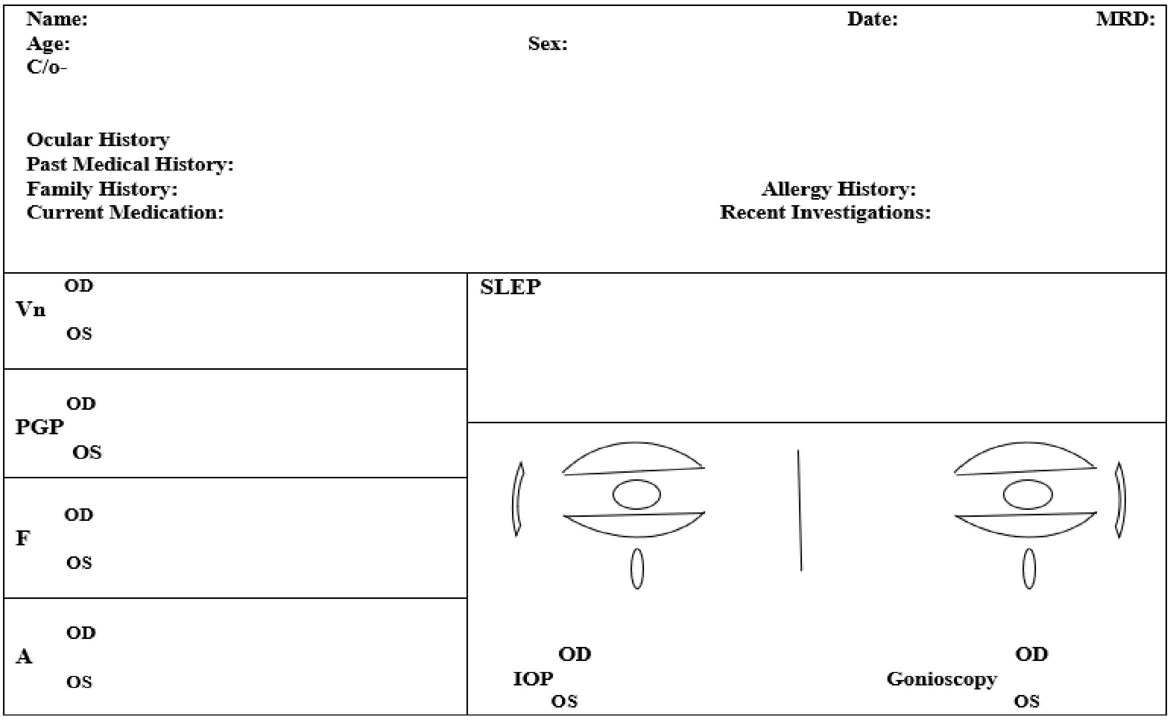

Name:
Date:
MRD:
Age:
Sex:
C/o-
Ocular History
Past Medical History:
Family History:
Allergy History:
Current Medication:
Recent Investigations:
Vn OD OS
SLEP
PGP OD OS
F OD OS
A OD OS
IOP OD OS
Gonioscopy OD OS

Figure 3.1: General work up form (Part I)

4. Facilitation of Research and Analysis:

- **Data Aggregation:** Standardized forms allow for easy compilation and analysis of patient data, contributing to epidemiological studies and clinical research.
- **Treatment Outcome Evaluation:** Longitudinal data collected through these forms helps track treatment effectiveness and identify areas for improvement in eye care practices.

5. Improved Patient Care:

- **Personalized Treatment:** Information gathered through the form enables eye care professionals to tailor treatment plans to individual patient needs.

- **Early Detection and Intervention:** Regular eye examinations using a standardized form facilitate the early detection of eye conditions, leading to timely intervention and better outcomes.

K **OD** **OS**	**TBUT/ Schirmer's Test/Blink Rate: OD OS** **Syringing: OD OS** **ROPLAS: OD OS** **Fundus: OD OS** 
Cover test: **NPC:** **EOM:** **WFDT: D** **N** **Pupillary Evaluation:** **Other Evaluation:**	**Diagnosis:** **Investigation Planned:** **Treatment:**

Figure 3.2: General work form (Part II)

The General Eye work up Form is not just a form, but a cornerstone of quality eye care. It ensures comprehensive assessments, accurate diagnoses, effective communication, and ultimately, better vision and eye health for patients.

For this study this form was utilized and the particular required data was collected using parameters such as, visual acuity, Keratometry, Autorefractometry and refraction by retinoscope.

General workup

Posting: **Date:** **MRD:**
Age:

Ocular History:

Past Medical History:

Family History:

Birth History: **Allergy History:**

Current Medication: **Recent Investigations:**

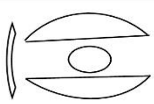
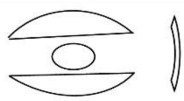
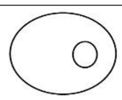
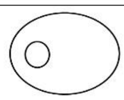
	OD	OS
Vision (aided/Unaided)		
Previous Glass Prescription		
Flash		
Acceptance		
Keratometry		
EOM		
Cover Test		
NPC		
Pupillary Evaluation		
Other evaluation		
Slit Lamp Examination		
Gonioscopy		
IOP (mmHg)		
TBUT/ Schirmer's Test/Blink Rate		
Syringing/ ROPLAS		
		
Diagnosis		
Investigation Planned		
Learning		

Figure 3.3: General work form (Part III)

3.2.2 Instruments

Visual acuity, a fundamental measure of visual function, is the eye's ability to discern fine details and distinguish between small objects at a distance. Measuring distant visual acuity is a vital component in assessing and monitoring various eye conditions and treatments.

The standard procedure for measuring distant visual acuity involves the use of a Snellen chart, which consists of rows of letters or symbols that gradually decrease in size from top to bottom. This test is typically conducted at a distance of 6 meters (20 feet) from the chart, where the patient reads the smallest line of letters or symbols they can clearly identify.

If the patient cannot read the smallest line at 6 meters, the test distance may be reduced to 4 meters or even 1 meter as necessary to determine the patient's visual acuity (Beck et al., 2007). In cases where the patient cannot recognize symbols from a 1-meter distance, finger counting or hand movement detection close to the face may be performed. The same procedure is repeated for the other eye. If the patient cannot recognize hand movement, tests for light perception and projection of rays are conducted. This approach allows for a more accurate assessment of visual function, particularly in cases of severe visual impairment. The patient needs to occlude one eye while checking the visual acuity.

While the Snellen chart remains the most widely used tool for measuring distant visual acuity, advancements in technology have led to the development of computerized alternatives, such as the ETDRS chart. These digital charts provide a standardized and consistent testing method, while also allowing for more effective recording and analysis of results.

The steps for Snellen's visual acuity assessment typically include:

1. Prepare the testing environment: Ensure adequate lighting, a quiet and distraction-free setting, and a standardized testing distance (6 meters for distance vision, 40 cm for near vision).
2. Position the patient: The patient should be seated or standing at the appropriate testing distance, with the eyes positioned at the same level as the chart.

Assessing distant visual acuity is a crucial component in diagnosing and managing a wide range of eye conditions, from refractive errors to retinal diseases.

Visual acuity charts (Distant vision): Visual acuity is the resolving power of the eye. By using this chart, we have estimated the distant vision of the volunteer. Snellen chart kept at a distance of 6 m can determine distant visual acuity. The Snellen chart has well documented limitations, including inconsistent progression in letter size from 1 line to the next, large gaps between visual acuity levels at the lower end of the chart. (Figure 1.2)

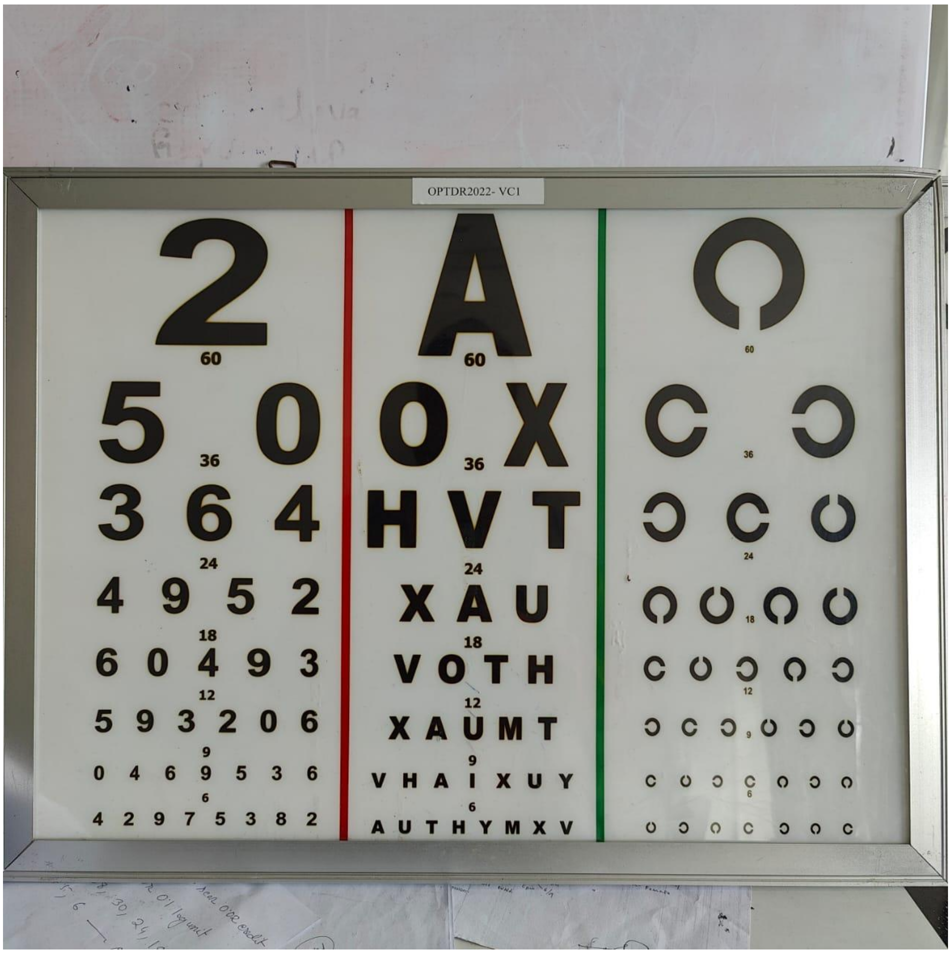


Figure 3.4: Snellen Chart

Key features of the Snellen Vision Chart:

The Snellen chart, named after the Dutch ophthalmologist Hermann Snellen, is a widely recognized and extensively used tool in the assessment of visual acuity. This standardized chart is designed to measure an individual's ability to distinguish letters or symbols at a specific distance, providing a reliable indicator of their visual function. (Colenbrander 2005).

One of the key advantages of the Snellen chart is its ability to be adapted for use with different populations, including young children and illiterate adults.

Researchers have developed modified versions of the chart, such as the Arabic letter distance visual acuity test chart, to cater to the needs of individuals who may not be familiar with the Latin alphabet. These adaptations have been particularly useful in regions where Arabic is the predominant language, ensuring that the assessment of visual acuity is accessible and meaningful for the target population.

The design of the Snellen chart, with its carefully calibrated letter sizes and spacing, plays a crucial role in its effectiveness. The inter-letter and inter-row spacing are crucial factors that contribute to the chart's ability to accurately measure visual acuity. The precise dimensions of the letters and the spacing between them ensure that the chart can be used at a specific distance, typically 6 meters (20 feet), to provide a reliable assessment of an individual's visual function.

Letter Gradation: The chart typically uses uppercase letters of the alphabet, with each row representing a different size. The letters in each row are of equal size, and as you go down the chart, the letters become smaller.

Distance Measurement: The standard distance at which the chart is viewed is 20 feet (or 6 meters). The test subject stands at this distance and covers one eye while reading the letters aloud or identifying the symbols.

Visual Acuity Measurement: Visual acuity is expressed as a fraction, with the numerator indicating the distance at which the chart is viewed (20 feet), and the denominator representing the distance at which a person with normal vision could read the same line. For example, if someone can read the 20/20 line, it means they can see at 20 feet what a person with normal vision sees at that distance.

Standardized Testing: The Snellen chart provides a standardized and quantitative measure of visual acuity, making it a valuable tool for eye examinations. It is commonly used in eye clinics, optometrists' offices, and ophthalmology practices.

Limitations: While the Snellen chart is a widely accepted method for assessing visual acuity, it has some limitations. It primarily measures central vision and may not fully represent the overall visual function, especially in cases of peripheral vision issues or other visual abnormalities.

Variations: There are variations of the Snellen chart, including the Tumbling E chart, which uses the letter 'E' rotated in different directions, allowing the test to be conducted for individuals who may have difficulty with letter recognition.

In conclusion, Snellen's Vision Chart remains a fundamental tool in eye examinations for assessing visual acuity. It provides valuable information about an individual's ability to see clearly at a standard distance and serves as a baseline for further examination and diagnosis of visual impairments. The Snellen chart, is commonly used visual acuity chart which is simple to perform and is sensitive to the most common sources of visual impairment, such as uncorrected refractive error, cataract, macular disease, and amblyopia.

Autorefractometer:

The Nidek AR-360A is an autorefractometer which objectively measures refractive errors using a super luminescent diode (SLD). The device is a conventional tabletop AR, and it uses a closed-field format. The measurement beams are projected onto the fundus of the eye, and the computation of the refractive error is performed by capturing the reflected beam as a ring image. The measurements of refraction are analysed from a 4-mm cross-sectional area of the pupil to obtain data that is aimed to be close to the subjective refraction. The minimum measurable pupil size is 2 mm. Subjective refraction can also be performed using the built-in charts and corrective lenses, but only the spherical component can be changed, not the power or axis of the cylindrical correction.

The measurement range of Nidek AR-360A is from −30 D to +25 D for sphere and 0 D to 12 D for cylinder. The auto tracking mechanism enables the device to follow small losses of fixation, and after alignment, the measurement starts automatically. An auto fogging mechanism is used to relax accommodation. The refractive error is estimated by averaging three successive readings. An estimation of near vision measurement, that is presbyopic correction (add), is also provided.

Examination Techniques and Procedures

Nidek Autorefractometer: This device uses light rays to measure refractive error. The procedure involves aligning the instrument with the patient’s eye and analyzing the light reflex, offering reliable data on refractive abnormalities (Greenwald 2003).

Factors Affecting Visual Acuity: Provide A Comprehensive Analysis

II. **Physiological Factors**

A. **Retinal Factors**

1. **Photoreceptor density and distribution:**

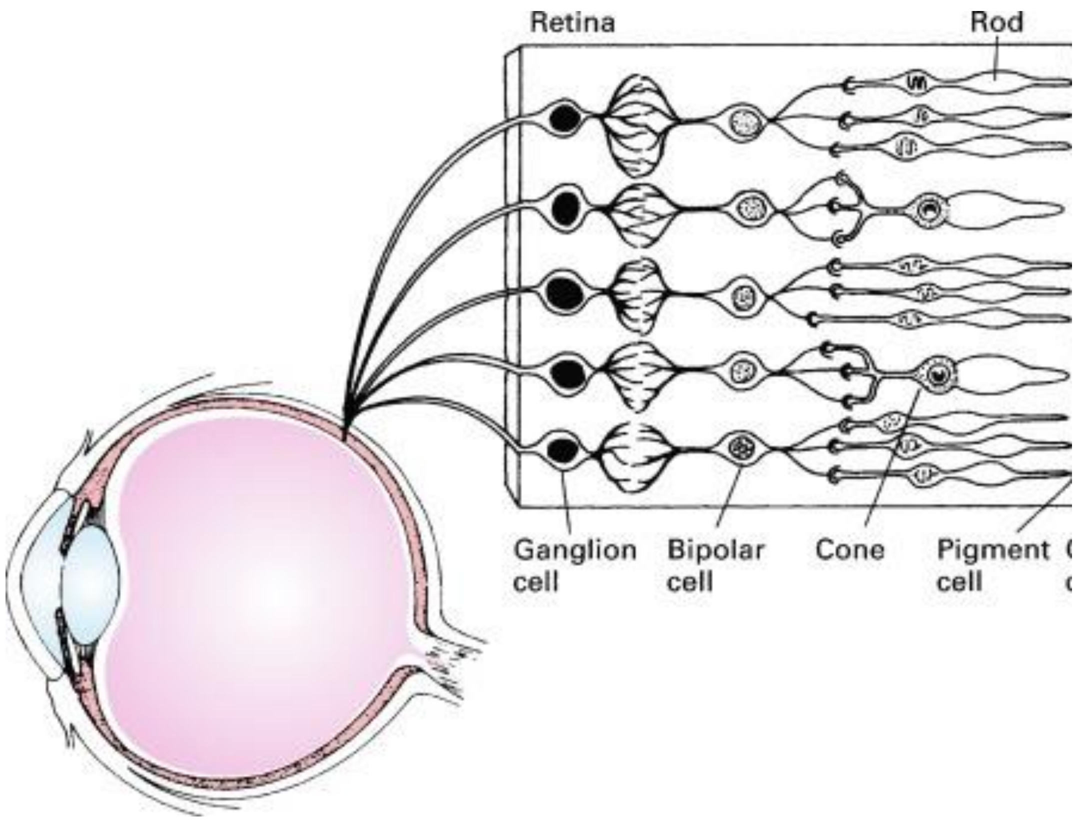


Figure 3.5: Photoreceptor density and distribution (Panayotakis 2013)

The density and distribution of photoreceptors, particularly cones in the fovea, play a crucial role in visual acuity. The fovea centralis, which occupies about 1.5 degrees of visual angle, contains the highest density of cones (approximately 160,000 cones/mm²) and is responsible for our sharpest vision. This density decreases rapidly outside the fovea, leading to reduced acuity in peripheral vision (Curcio et al. 1990).

Research by Curcio et al., has shown that the peak cone density can vary significantly between individuals (100,000 to 324,000 cones/mm^2), which may partly explain individual differences in visual acuity. Furthermore, the spacing between cones, known as cone mosaic, influences the spatial sampling of the retinal image and thus affects acuity (Rossi and Roorda 2009).

2. **Neural processing in the retina:**

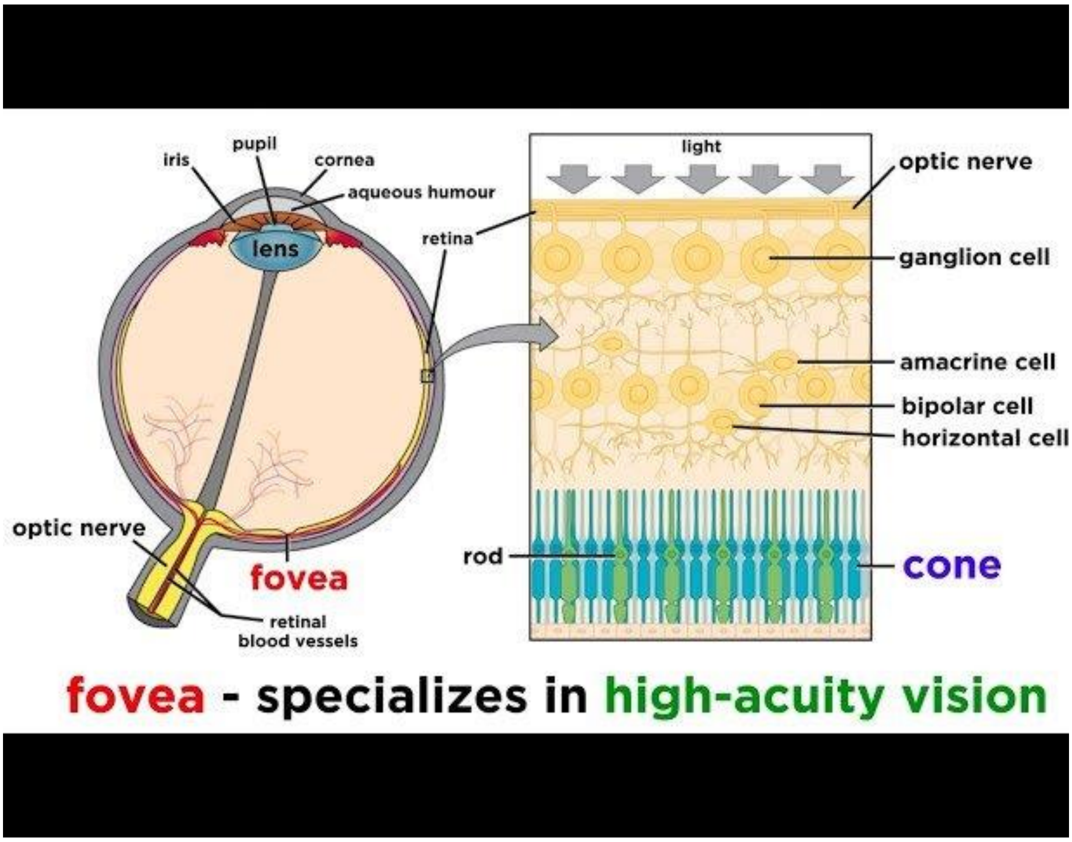


Figure 3.6: Neural processing in the retina (Wakshull et al. 2017)

Beyond photoreceptor density, the neural circuitry within the retina significantly impacts visual acuity. The convergence and divergence of signals from photoreceptors to bipolar and ganglion cells create receptive fields that influence spatial resolution (Wässle 2004).

Of particular importance is the midget pathway, where a one-to-one relationship between cones, midget bipolar cells, and midget ganglion cells in the fovea allows for high-resolution sampling of the visual scene. This pathway is crucial for maintaining high acuity and is less prominent in peripheral retina, contributing to reduced acuity outside the foveal region (Kolb 2003). Recent research using adaptive optics has revealed that neural factors in the retina may limit visual acuity even when optical factors are optimized (Rossi and Roorda 2009).

B. **Optical Factors**

1. **Pupil size and diffraction:**

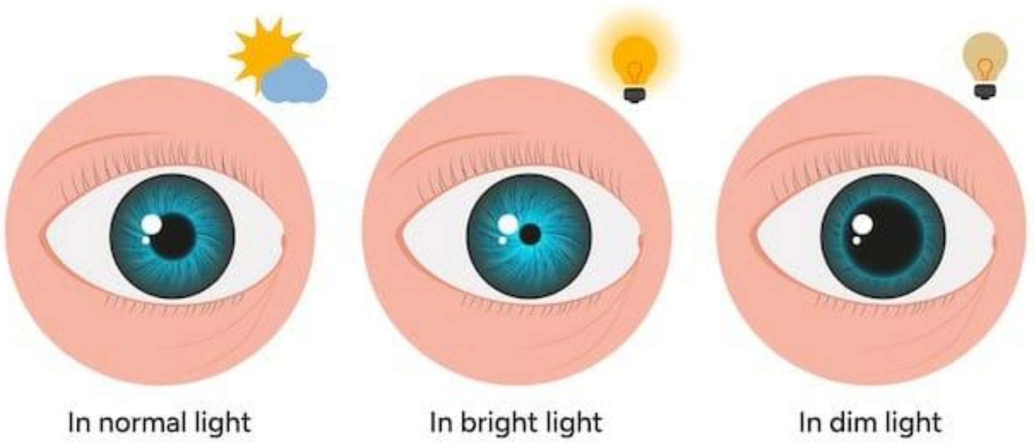


Figure 3.7: Schematic diagram of Pupil size with different light intensity

Pupil size affects visual acuity through its influence on diffraction and aberrations. A smaller pupil reduces the impact of optical aberrations but increases diffraction effects. Conversely, a larger pupil reduces diffraction but increases aberrations. The optimal pupil size for maximizing visual acuity is typically between 2-4 mm, depending on illumination conditions and individual eye characteristics (Campbel and Gregory 1960).

2. **Ocular aberrations:**

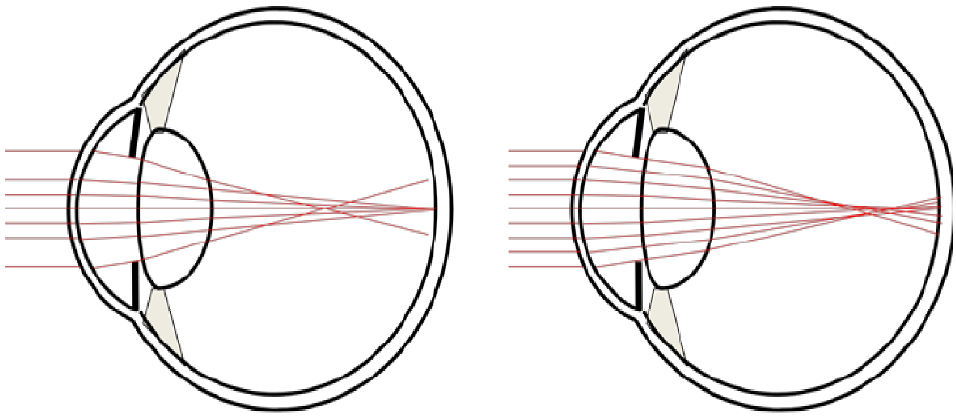


Figure 3.8: Ocular aberrations, Reference-

Higher-order aberrations, such as spherical aberration, coma, and trefoil, can significantly impact visual acuity. These aberrations are not corrected by traditional refractive corrections (glasses or standard contact lenses) and can limit the potential improvement in visual acuity even after correcting lower-order aberrations (Liang, Williams, and Miller 1997).

Advanced wavefront-guided corrections and adaptive optics systems have demonstrated the potential to correct these higher-order aberrations, potentially improving visual acuity beyond the standard 20/20 level (Liang, Williams, and Miller 1997); (Yoon and Williams 2002)).

3. **Accommodation:**

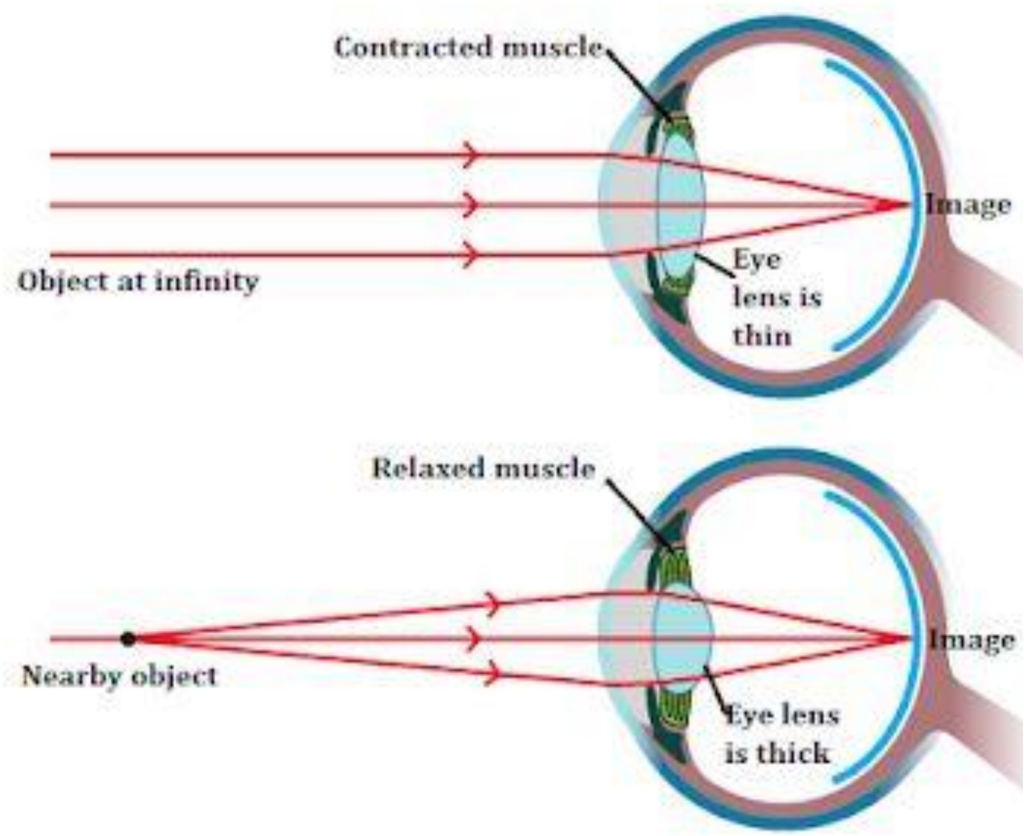


Figure 3.9: Accommodation of the eye, Reference-Pinterest-

The eye's ability to change focus for different viewing distances directly affects visual acuity. Accurate accommodation is crucial for maintaining clear vision at various distances. Factors such as accommodative lag (where accommodation falls short of the ideal) can reduce visual acuity, particularly for near tasks (Charman 1999).

Age-related changes in accommodation (presbyopia) significantly impact near visual acuity and are a major area of ongoing research in vision science and ophthalmology (GLASSER and CAMPBELL 1998).

C. Cortical Factors

1. **Visual cortex organization:**

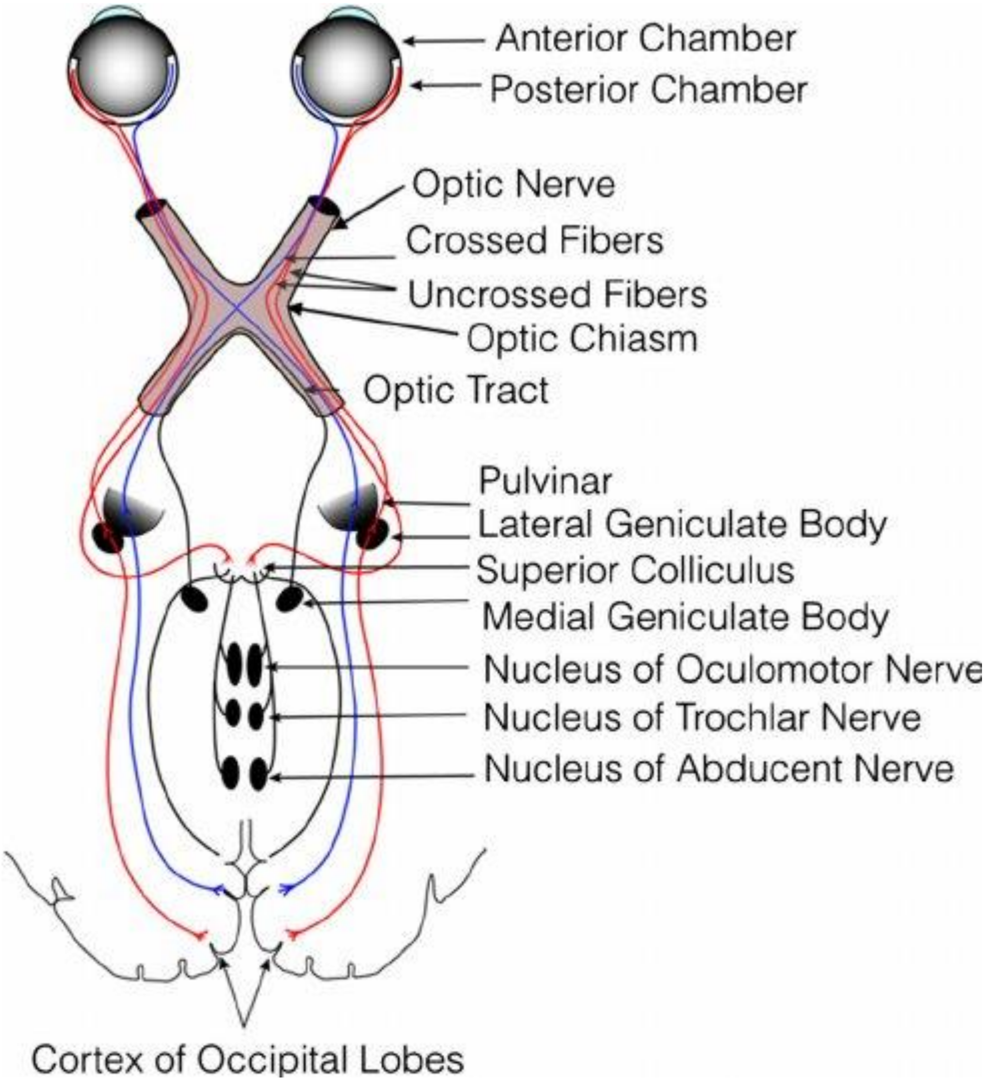


Figure 3.10: Visual pathway and visual cortex organization (Başgöze, Mackey, and Cooper 2018)-

The organization and function of the primary visual cortex (V1) and higher visual areas play a critical role in visual acuity. The magnification factor in V1, which describes how much cortical space is devoted to processing a given region of the visual field, is highest for the foveal region, corresponding to our highest acuity vision (Horton and William 2015).

Research using functional MRI has shown that the size of V1 and its degree of activation correlate with individual differences in visual acuity (Duncan, Boynton, and Jolla 2003).

2. Neural plasticity and visual learning:

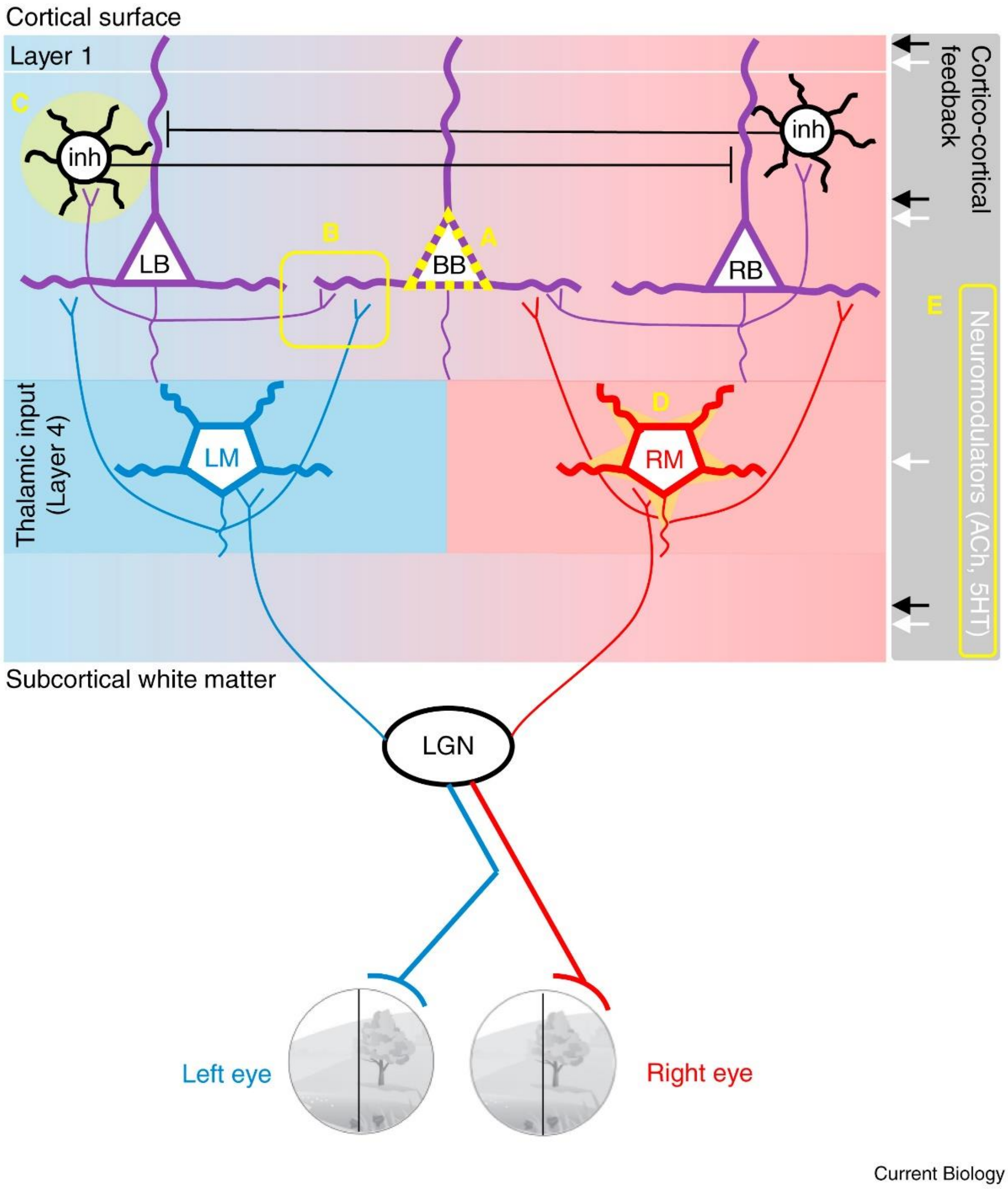


Figure 3.11: Neural plasticity and visual learning (Başgöze, Mackey, and Cooper 2018)-

The adult visual system retains a degree of plasticity, allowing for improvement in visual acuity through perceptual learning. Studies have demonstrated that training can lead to improvements in various aspects of vision, including visual acuity, particularly in individuals with amblyopia or other visual impairments (Levi & Li, 2009 (Levi and Li 2020); Polat et al., 2004 (Polat et al. 2004)).

Understanding the neural mechanisms underlying this plasticity is an active area of research, with implications for developing new therapies to improve visual acuity in various clinical populations (Gilbert & Li, 2012)(Gilbert and L 2012) .

Autorefractometer:

Figure 3.12: Image of Autorefractometer -

Autorefractometers have become an essential tool in the field of optometry and ophthalmology, playing a crucial role in the assessment and management of refractive errors. One of the primary benefits of autorefractometers is their ability to provide an objective and automated measurement of refractive errors, including myopia, hyperopia, and astigmatism (Ang et al. 2009)

Nidek ARK (Auto Refractometer Keratometer)

It is a sophisticated optical instrument designed for eye care professionals to obtain accurate and objective measurements of a patient's refractive error and corneal curvature. This device combines auto refraction and keratometry functions, streamlining the process of determining the prescription for corrective lenses and assessing the shape of the cornea. Nidek, a prominent manufacturer of ophthalmic equipment, is known for producing advanced and reliable devices, and the Nidek ARK is no exception.

Heine Streak Retinoscopy: A diagnostic tool for assessing refractive errors like myopia or hyperopia by observing the movement of the retinal light reflex. It is a non-invasive and objective method widely accepted in clinical practice (Greenwald, 2003).

Key features of the Nidek ARK Autorefractometer:

Auto Refraction: The autorefractometer function of the Nidek ARK allows for quick and precise measurement of a patient's refractive error. It uses an automated process to analyze how light is focused within the eye, providing objective data on the patient's prescription for eyeglasses or contact lenses.

Keratometry: In addition to measuring refractive error, the ARK includes a keratometer to assess the curvature of the cornea. This is crucial information for fitting contact lenses and diagnosing conditions such as astigmatism.

Objective Measurements: One of the key advantages of the Nidek ARK is its ability to obtain objective measurements without significant input from the patient. This is particularly useful in cases where patient cooperation may be challenging, such as with young children or individuals with communication difficulties.

User-Friendly Interface: The device typically features a user-friendly interface, making it easy for eye care professionals to operate. The intuitive design helps streamline the examination process, saving time and improving overall efficiency in the clinic.

Integration with Other Instruments: Nidek ARK devices are often designed to seamlessly integrate with other diagnostic instruments, electronic health record systems, or practice management software. This integration enhances the overall workflow in eye care practices.

Accuracy and Reliability: Nidek is renowned for producing high-quality ophthalmic equipment, and the ARK Autorefractometer is no exception. The device is engineered to provide accurate and reliable measurements, contributing to the precision of eye care prescriptions and diagnoses.

Versatility: The Nidek ARK may come in various models, offering additional features such as pupillometry, accommodation testing, and compatibility with wavefront technology for more comprehensive assessments of visual function.

In summary, the Nidek ARK Autorefractometer is a valuable tool for eye care professionals, combining auto refraction and keratometry functions in a single device. Its advanced features, user-friendly interface, and accuracy make it an asset in the diagnosis and treatment of refractive errors and corneal conditions. Autorefractometer is a computer-based device to know the refractive condition of the eye whether it is myopic, hyperopic or astigmatic with eye dioptric power as well as axis. In addition, the radius of corneal curvature and inter pupillary distance can be observed. Two infrared light sources illuminate the retina through a small aperture and reflect image onto a photodetector. Moving the position of the aperture varies the image focus, and its position for the sharpest image gives the measure of refractive error. The different meridians are measured by a coupled rotation of the illumination and the electronic detection system. (Figure3)

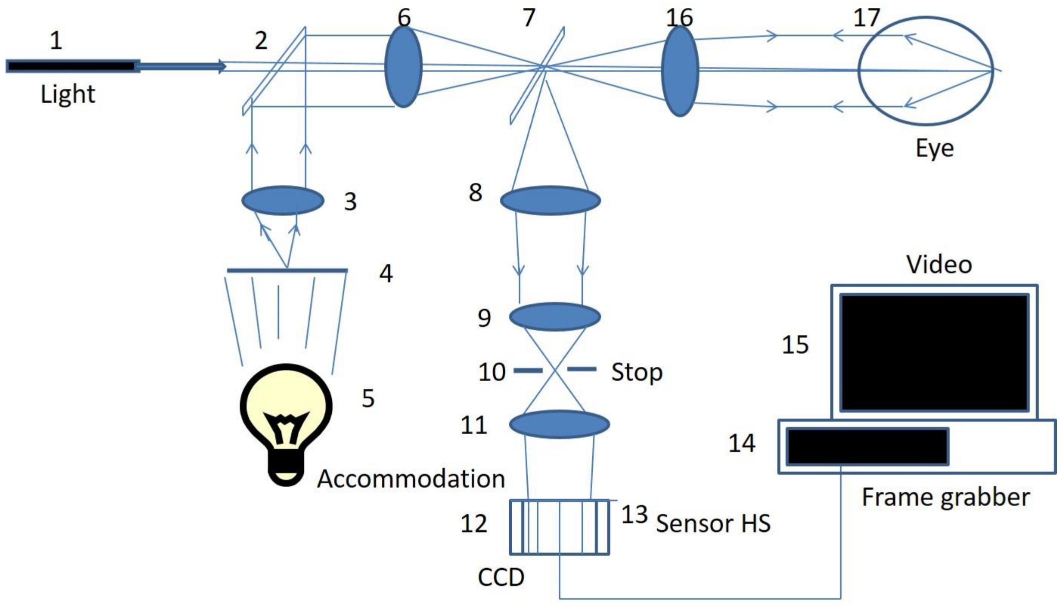


Figure 3.13: Schematic diagram of Autorefractometer

Autorefraction produces a fast, repeatable measurement of refractive error which helps clinician to examine the patient eye in a limited period of time. Autorefractometer have the potential to play a crucial role in the early detection and management of refractive errors, especially in resource-poor areas where access to skilled practitioners may be limited

Retinoscope:

Figure 3.14: Image of Heine Retinoscope,

Retinoscope is an instrument to know the refractive error of the eye whether it is nearsighted, hyperopic or astigmatic with powers as well as axis The HEINE Retinoscope is a high-quality ophthalmic instrument used by eye care professionals, particularly in optometry and ophthalmology, for assessing and measuring refractive errors of the eye. HEINE Optotechnik, a German company with a long-standing reputation for producing precision medical instruments, manufactures the HEINE Retinoscope. This device plays a crucial role in the objective determination of a patient's refractive status, aiding in the prescription of corrective lenses.

Key features of the HEINE Retinoscope:

Illumination Technology: The HEINE Retinoscope employs advanced illumination technology to provide a bright and consistent light source. The quality of illumination is crucial for obtaining accurate and reliable results during retinoscopy, where the examiner observes the movement and characteristics of the retinal reflex.

Retinoscopic Reflex: The instrument is designed to project a beam of light into the patient's eye, creating a retinoscopic reflex. The examiner observes the movement, brightness, and characteristics of this reflex to determine the patient's refractive error, including the presence of hyperopia, myopia, astigmatism, and presbyopia.

Versatility: HEINE Retinoscopes are often available in various models, including both streak and spot retinoscopy options. The streak retinoscope produces a streak of light, while the spot retinoscope projects a circular spot. The choice between these models depends on the preferences and techniques of the eye care professional.

Build Quality: HEINE is known for the exceptional build quality of its medical instruments, and the Retinoscope is no exception. Constructed with durable materials and precision engineering, these instruments are designed for longevity and consistent performance over time.

User-Friendly Design: The design of the HEINE Retinoscope is typically user-friendly, featuring ergonomic handles and controls that facilitate ease of use. This is especially important during prolonged examinations, ensuring comfort for the examiner and minimizing fatigue.

Compatibility: HEINE Retinoscopes are often compatible with various power sources, including traditional handles with rechargeable or disposable batteries. This versatility allows the instrument to be used in different clinical settings.

Integration with Other Instruments: HEINE instruments, including the Retinoscope, are often designed to integrate seamlessly with other diagnostic equipment and technologies, enhancing the overall diagnostic capabilities of eye care professionals.

In summary, the HEINE Retinoscope is a reliable and high-performance instrument that aids eye care professionals in objectively assessing and measuring refractive errors. With its advanced illumination technology, build quality, and user-friendly design, the HEINE Retinoscope is a valuable tool in the accurate determination of prescriptions for corrective lenses, contributing to the overall quality of eye care examinations.

Retinoscopy depends on the way that when light is reflected from a mirror into the eye, the bearing wherein the light will traverse the understudy will rely on the refractive condition of the eye. Retinoscopy is an objective method of refraction in which the patient does not need to tell the practitioner how they see. If instead they ask the patient questions about how she/ he sees, that is called subjective refraction. (Figure 3.15).

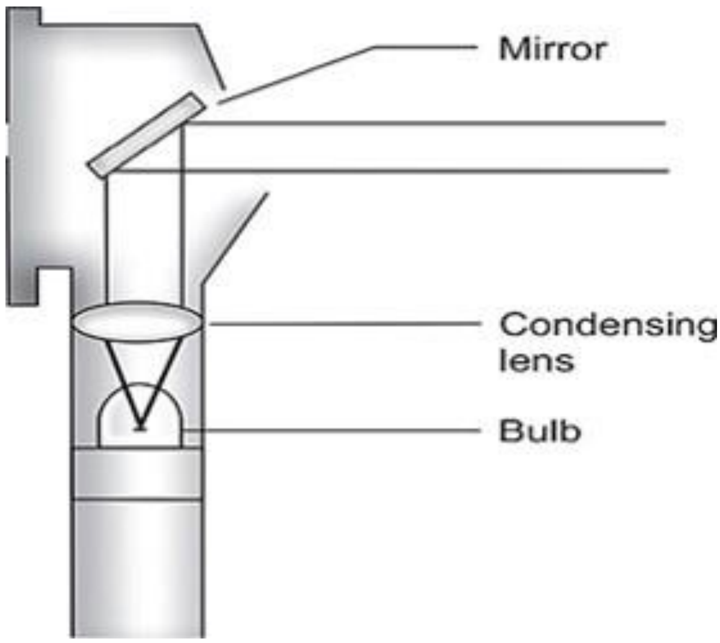


Figure 3.15: Schematic diagram of Retinoscope

When the practitioner shines the light of a retinoscope into an eye, they see the light reflected from the retina. This reflected light is called the retinoscopic reflex. It looks like a red light inside the pupil. Depending on the person's refractive error, when the practitioner moves the retinoscope, the ret reflex will move in a certain way inside the pupil.

Keratometer:

The results of keratometry examinations are crucial for diagnosing and managing various corneal conditions, such as keratoconus, a progressive, non-inflammatory thinning and distortion of the cornea (Loukovitis et al., 2018). Keratometry is also essential in determining the appropriate lens power for cataract surgery, refractive surgery, and specialty contact lens fittings (Kaya et al., 2015; Pobelle-Frasson et al., 2004; Ameerh et al., 2012).

Keratoconus is a relatively common bilateral condition characterized by the thinning and protrusion of the cornea, resulting in a conical shape (Loukovitis et al., 2018). It can lead to a variety of refractive errors, including myopia and irregular astigmatism, as well as vision distortion and sensitivity to light (Loukovitis et al., 2018). Although the exact causes of the biomechanical changes in keratoconus are not fully understood, a growing body of evidence indicates that genetic factors may play an important role.

Bausch & Lomb Keratometers use horizontal and vertical prisms that move along the instrument's axis, differing from Sutcliffe's design, which employs perpendicular cylindrical lenses that decenter transversely to the axis. This configuration produces a variable doubling effect in perpendicular directions, improving measurement precision. (Rabbetts, 2007).

While the fundamental design and principles of the keratometer have remained consistent, several modifications have been introduced over the years to address focusing challenges. For instance, as previously noted, the Bausch & Lomb keratometer uses the Scheiner disk principle to enhance focusing accuracy and testing distance adjustment (Rabbetts, 2007). Another innovation is the use of collimated mires in the Zeiss telecentric ophthalmometer, which eliminates magnification changes that could otherwise accompany testing distance errors.

A keratometer is a diagnostic tool used in optometry and ophthalmology to measure the curvature of the cornea, providing essential information for contact lens fitting and assessing corneal astigmatism. Bausch + Lomb, as a trusted name in the eye care industry, has produced keratometers designed to meet the needs of eye care professionals.

Key features associated with Bausch + Lomb keratometers:

Accurate Corneal Measurements: Bausch and Lomb keratometers are designed to provide accurate and precise measurements of corneal curvature. This information is crucial for determining the appropriate parameters for contact lenses and understanding the refractive characteristics of the eye.

Ease of Use: These keratometers are typically user-friendly, with intuitive interfaces that make them accessible to eye care professionals. The ease of use is important for efficient and accurate measurements during eye examinations.

Versatility: Bausch and Lomb keratometers are often versatile instruments that can be used in various clinical settings. They may offer different measurement options and modes to accommodate different patient needs.

Quality Optics: The accuracy of keratometric measurements relies on the quality of the optics within the instrument. Bausch and Lomb is known for producing instruments with high-quality optics, ensuring reliable and consistent results.

Durability: Instruments manufactured by Bausch and Lomb are generally built with durability in mind. This ensures that the keratometer can withstand the demands of a busy clinical environment and maintain its accuracy over time.

Integration with Other Instruments: Bausch and Lomb keratometers may be designed to integrate seamlessly with other diagnostic equipment, providing eye care professionals with a comprehensive set of tools for assessing eye health.

Brand Reputation: Bausch & Lomb has a long-standing reputation for excellence in the field of eye care. Eye care professionals often trust the brand for its commitment to producing high-quality products.

A device uses the refractive properties of the cornea to measure the radius of curvature and power of different meridians of the cornea. By measuring the size of the image, formed by reflection from the cornea, an object of known size and position, a measurement of the radius can be measured (figure 5).

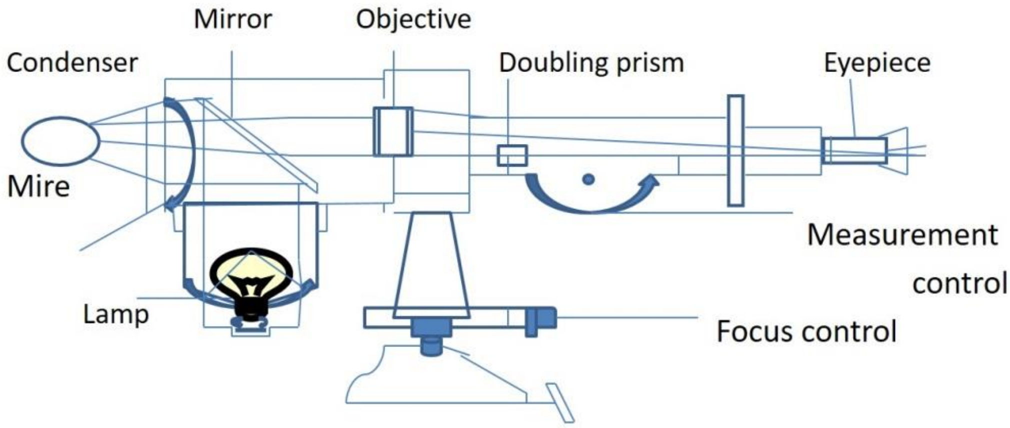


Figure 3.16: Schematic diagram of Keatometer

A keratometer is a vital instrument used to measure the central anterior curvature of the cornea, typically covering an area of 2-3 millimeters. This measurement is crucial for accurately prescribing contact lenses and determining the base curve required for optimal fit. The device operates on the principle that the cornea's anterior surface acts as a convex mirror, with the size of the reflected image varying according to the corneal curvature. By analyzing these reflections, the keratometer precisely calculates the radius of curvature of the cornea.

Trail lenses:

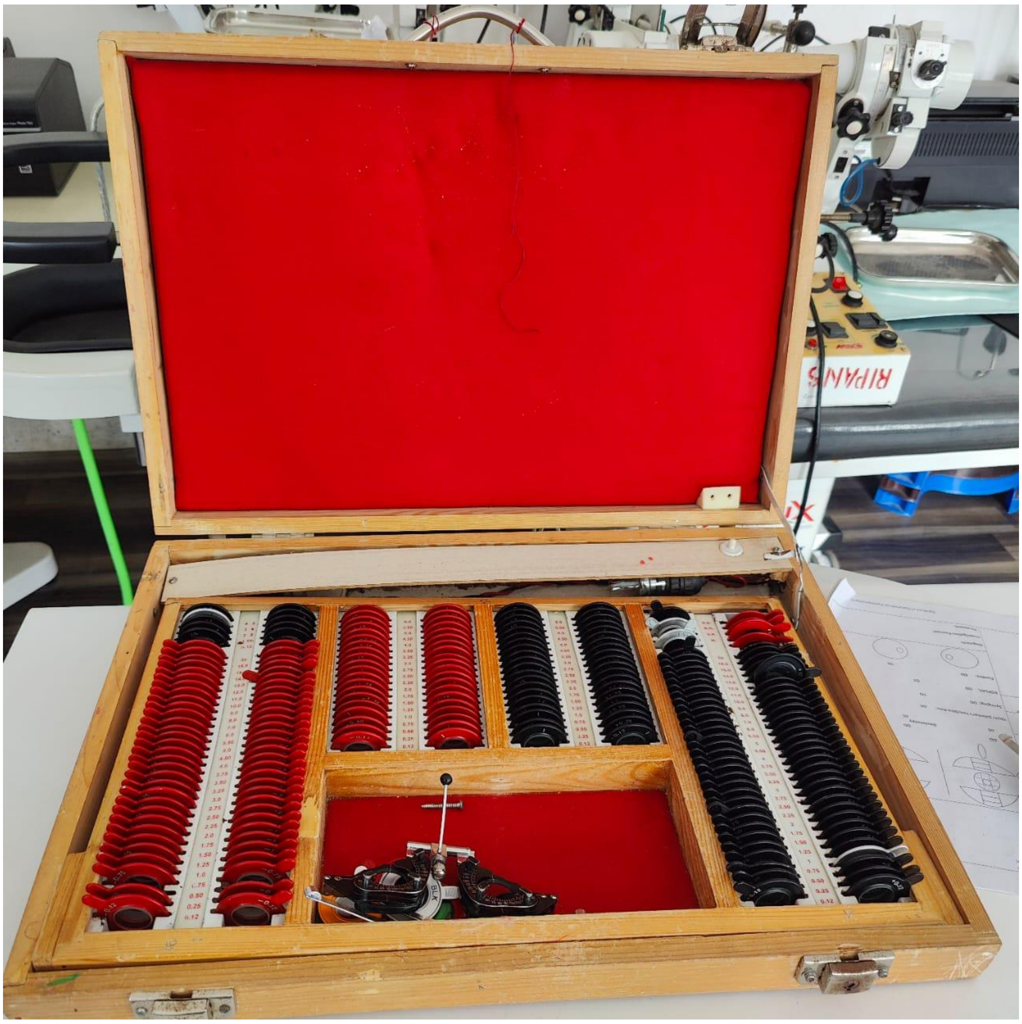


Figure 3.17: Image of Trial lenses

The trail lenses are the combination of sets of spherical, cylindrical and prism. It is a comprehensive set of lenses that enables optometrists to systematically test and determine the best corrective lens prescription for their patients. By methodically testing different lens powers and types, optometrists can identify the optimal combination that addresses the patient's specific visual needs, whether it's near-sightedness, far-sightedness, or astigmatism

A spherical lens comprises of series of convex and concave lenses which start with every quarter of a dioptre to 4 dioptre and every half to 6 dioptres, thereafter every dioptre to14 dioptre and every 2 dioptres to 20 dioptres. The cylindrical lenses have every quarter to 2 dioptre and every half to 6 dioptres.

Trail frames

A trail frame is used to carry test lenses during retinoscopy or during subjective examination of refraction procedure. The trail frame should be light and readily adaptable and allowing adjustments for each eye separately. It has four compartment to keep the lenses. It must be ensured that the dial indicating the orientation of the frame is truly positioned.

Figure 3.18: Image of Trial frame

In this present study a total of 320 subjects were screened for the parameters required for the study. The subjects were thoroughly informed about the entire procedure. After collecting demographic and other relevant data, the subjects' data was accumulated using appropriate instrumentation to obtain the initial parameter measurements. The subjects were then advised to return after 30 days for the final parameter recording. Visual acuity, keratometry, and retinoscopy tests in accordance with the study objectives.

3.3. Conclusion:

In summary, the experimental techniques described in this chapter highlight the critical role of standardized tools, such as the Snellen chart and autorefractometers, in evaluating visual acuity and refractive errors. The general work up form shown here is the complete format, the required parameters has been used as per as the data required. These instruments, while possessing certain limitations, provide reliable assessments that form the foundation for diagnosing and managing various visual impairments. The use of advanced technologies ensures precise measurements and enhances the accuracy of eye examinations, contributing to improved patient care and outcomes in ophthalmology.

REFERENCES

Andrews, James R., James A. Whiteside, and Craig M. Buettner. 1996. “Clinical Evaluation of the Elbow in Throwers.” *Operative Techniques in Sports Medicine* 4(2): 77–83. doi:10.1016/S1060-1872(96)80052-9.

Ang, Eng K., Terry Couper, Mohamed Dirani, Rasik B. Vajpayee, and Paul N. Baird. 2009. “Outcomes of Laser Refractive Surgery for Myopia.” *Journal of Cataract and Refractive Surgery* 35(5): 921–33. doi:10.1016/j.jcrs.2009.02.013.

Başgöze, Zeynep, Allyson P. Mackey, and Emily A. Cooper. 2018. “Plasticity and Adaptation in Adult Binocular Vision.” *Current Biology* 28(24): R1406–13. doi:10.1016/j.cub.2018.10.024.

Campbel, F W, and A H Gregory. 1960. “Effect of Size of Pupil on Visual Acuity.” *Nature* 187: 1121–23.

Charman, W N. 1999. “Near Vision , Lags of Accommodation and Myopia.” *Ophthal. Physiol. Opt.* 19(2): 126–33.

Colenbrander, August. 2005. “Reading Acuity — an Important Parameter of Reading Performance.” *International Congress Series* 1282: 487–91. doi:10.1016/j.ics.2005.05.003.

Craenen, Geert, Sandra M. Brown, Kenn A. Freedman, Thomas R. Windisch, and Jorge Corona. 2004. “Rapid, Painless Unilateral Vision Loss in a 37-Year-Old Healthy Woman.” *Survey of Ophthalmology* 49(3): 343–48. doi:10.1016/j.survophthal.2004.02.012.

Curcio, Christine A, Kenneth R Sloan, Robert E Kalina, and Anita E Hendrickson. 1990. “Human Photoreceptor Topography.” *THE JOURNAL OF COMPARATIVE NEUROLOGY* 523: 497–523.

Duncan, Robert O, Geoffrey M Boynton, and La Jolla. 2003. “Cortical Magnification within Human Primary Visual Cortex Correlates with Acuity Thresholds The Salk Institute for Biological Studies.” *Neuron* 38: 659–71.

Gilbert, Charles D., and Wu L. 2012. “Adult Visual Cortical Plasticity.” *Neuron*:

250–63. doi:10.1016/j.neuron.2012.06.030.

GLASSER, ADRIAN, and MELANIE C. W. CAMPBELL. 1998. “Presbyopia and the Optical Changes in the Human Crystalline Lens with Age.” *Vision Research* 38(2): 209–29.

Greenwald, Mark J. 2003. “Refractive Abnormalities in Childhood.” *Pediatric Clinics of North America* 50(1): 197–212. doi:10.1016/S0031-3955(02)00105-0.

Horton, Jonathan C, and F William. 2015. “The Representation of the Visual Field in Human Striate Cortex A Revision of the Classic Holmes.” *ARCH Ophthalmol* 109: 816–17.

Johnson, Craig W., Ronald Johnson, Michael Steigman, Chioma Odo, Suvendra Vijayan, and Devadatta V. Tata. 2016. “Appropriately Targeting Group Interventions for Academic Success Adopting the Clinical Model and PAR Profiles.” *Educational Researcher* 45(5): 312–23. doi:10.3102/0013189X16656939.

Kolb, Helga. 2003. “How the Retina Works.” *American Scientist* 91: 28–35.

Levi, Dennis M, and Roger W Li. 2020. “Perceptual Learning as a Potential Treatment for Amblyopia : A Mini-Review.” *Vision Research* 49(21): 2535–49. doi:10.1016/j.visres.2009.02.010.

Liang, Junzhong, David R Williams, and Donald T Miller. 1997. “Supernormal Vision and High-Resolution Retinal Imaging through Adaptive Optics.” *J. Opt. Soc. Am. A* 14(11): 2884–92.

Panayotakis, Stelios. 2013. “Optics.” In *In Complementary Science; Physics in Biology and Medicine*, ed. Paul Davidovits. , 225–31. doi:10.1515/9783110214130.225.

Polat, Uri, Tova Ma-naim, Michael Belkin, and Dov Sagi. 2004. “Improving Vision in Adult Amblyopia by Perceptual Learning.” *PNAS* 101(17): 6692–97.

Rossi, Ethan A, and Austin Roorda. 2009. “The Relationship between Visual Resolution and Cone Spacing in the Human Fovea.” *Nature Neuroscience* 13(2): 156–57. doi:10.1038/nn.2465.

Wakshull, Eric, Valerie Quarmby, Hanns Christian Mahler, Hongwen Rivers, Dhananjay Jere, Meg Ramos, Piotr Szczesny, et al. 2017. “Advancements in Understanding Immunogenicity of Biotherapeutics in the Intraocular Space.” *AAPS Journal* 19(6): 1656–68. doi:10.1208/s12248-017-0128-y.

Wässle, Heinz. 2004. “PARALLEL PROCESSING IN THE MAMMALIAN RETINA.” *NATURE REVIEWS* 5(October): 1–11. doi:10.1038/nrn1497.

Yoon, Geun-young, and David R Williams. 2002. “Visual Performance after Correcting the Monochromatic and Chromatic Aberrations of the Eye.” *J. Opt. Soc. Am. A* 19(2): 266–75.

CHAPTER- 4

A POPULATION BASED ANALYSIS OF THE EFFECT OF RADIOFREQUENCY RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE

This chapter deals with the effect of RF frequency on Dioptric power of the eye

CHAPTER - 4

RESULT AND DISCUSSION

A POPULATION BASED ANALYSIS OF THE EFFECT OF RADIOFREQUENCY RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE

4.1 Introduction

Smartphones have become a part of everyone's life in the 21st century. However, the radiation emitted from smartphones causes many health hazards when used excessively, unfortunately, not many of us are aware of this fact (Moon 2020). Mobile phones emit Radio wave, microwave radiation, and. It has thermal and non-thermal effects, which causes damage to biological tissues. The highly exposed area in our body to mobile phones is eyes compared to the other parts of the body and therefore the radiation impacts mainly the eyes compared to other organs (Moon 2020).

It is believed that mobile phones produce RF energy of non-ionizing radiation, which is too low to heat the tissues of the body, and hence is unlikely to have the same impact on human health as those produced by ionizing radiations such as X-rays.The electromagnetic field is categorized into 2 classes and they are, extremely low frequencies (ELF; 3 to 3000Hz), including high-voltage transmission lines and in-house wiring; and the another is radio frequencies (RF; 30 kHz to 300 GHz), which includes cell phones, smart electronics and devices, Wi-Fi, base stations and 5G advancements (Moon 2020), (Singh et al. 2019). The advancement of the mobile phone framework has enormously expanded the degree and extent of RF radiation exposure (RF). Cell phone and base station radiofrequency (RF) radiation can have both thermal and non-thermal effects on the human body. An antagonistic impact on people and animals is to be expected from the short-term and prolong exposure to RF radiation. In 2015 study investigated the potential influence of radiofrequency radiation emitted by mobile phones on human visual function. The research reported statistically significant alterations in visual acuity (Visual acuity, Refraction) (Siddig Tawer Kafi et al. 2015). Several research investigations have reported associations between exposure to radiofrequency (RF) radiation and biological effects. Different types of cancers, chromosomal damages and DNA changes are known to be induced through RF radiation exposure (Naeem 2014). Whereas numerous studies show effects of RF radiation on the human organs, literature related RF radiation effects on eyes with special consideration to dioptric power are scarce. Another study in 2023 found that the eye's temperature increases as it is exposed to waves and the antenna angle relative to the eye is effective in the rate of specific absorption. This study also found that without observing safety points, including maintaining distance, they can cause dangerous bodily complications Therefore, in our study; an effort has been made to know the effects of RF radiation on dioptric power in human eyes (Bozorgmanesh and Kowkabi 2020). Engaging in cell phone conversations may narrow a driver's peripheral visual field, potentially reducing their awareness of surrounding traffic and increasing the risk of accidents. Cell phone conversations tend to artificially constrict the peripheral awareness as measured by a visual field which recommends that cell phone use while driving can decrease the perceptual visual field, making the driver less aware of the surroundings and more susceptible to accident (Maples et al. 2008). A study carried out in 2005 found that prolog use of mobile phone may cause blurring of vision, secretion of the eyes, inflammation in the eyes and watering of the eyes (Balik et al. 2005).

Mobile phones use has an impact on the dynamics of tear fluid (TBUT and S1T) and the thickness of the cornea in the eye. This can be attributed to the radiations and/or thermal effects emitted by mobile phones (Mittal et al. 2022). Therefore, in our study, an effort has been made to know the effects of RF radiation on dioptric power in human eyes.

4.2. RESULTS AND DISCUSSION

The study has found that the use of smartphones has a significant effect on the eyes due to emission of radiation in the patients who were avid users only. The study recorded the several parameters (visual acuity, retinoscopic findings, refraction findings and keratometer) during each patient’s first visit. Again, the follow up study was done where we recorded the same parameters for the same patients.

Visual acuity of OD and OS has been represented in Table 4.1 and Table 4.2 respectively. In our study 50 persons underwent a visual acuity test before and 30 days after using a mobile phone. The results suggest that the visual acuity of the participants decreased after using the mobile phones. The mean percentage of visual acuity OD of 6/6 before using the mobile phone was 25.33±1.15%, while the mean percentage of visual acuity after using the mobile phone in OD was 15.33±1.15%. The result suggests that there was a significant decreased in 6/6 visual acuity in OD. Similar results could be observed in visual acuity 6/6(P) and 6/9(P) in OD. However, % of visual acuity is increased in OD were 6/9, 6/12, 6/12(P),6/18, 6/18(P),6/24, 6/36 and 6/60. The increased percentage of visual acuity % may be due to the shifting of visual acuity from lower higher. There are some evidences to suggest that prolonged mobile phone use may have a negative impact on visual acuity (Issa et al. 2021). However, the extent of this impact can vary depending on a number of factors, including the duration and frequency of mobile phone use, as well as the individual's overall eye health. Prolonged exposure to the blue light emitted by mobile phone screens can cause eyestrain, fatigue, and headaches (Kim et al. 2017). Additionally, some studies have suggested that the blue light exposure may contribute to the development of age-related macular degeneration and other vision problems over time (Jaman and Tiwari 2021). Similarly, changes in visual acuity were observed in OS among the population under study.

Table 4.1 Visual Acuity, right Eye (OD) of the subjects

Visual Acuity	Initial (OD) (%)	After (OD) (%)	P-value
6/6	25.33±1.15	15.33±1.15	<0.0004
6/6(P)	20±1.15	16.66±1.15	0.02
6/9	4±1.15	23.33±1.15	<0.0001
6/9(P)	10.66±1.15	6.66±1.15	0.013
6/12	0.66±0.15	13.33±1.15	<0.0001
6/12(P)	2±0.75	2.66±1.15	0.45
6/18	4±1.35	9.33±1.15	<0.0001
6/18(P)	0±0	0.66±1.15	-
6/24	0±0	2±0	-
6/24(P)	2±0	0±0	-
6/36	0±0	4±0	-
6/36(P)	2.66±0	0±0	-
6/60	2±1.3	6±1.75	<0.0001
6/60(P)	2±0	0±0	
	Data are represented as Mean±SD; significance was taken at P≤0.05.		

The study showed a change in dioptric power of participants during the follow up. The distribution of this change for each participant is represented in figure 4.1. The boxplot diagram figure 4.2 shows the various parameters like minimum, maximum, standard deviation (SD) a mean of the changes in Dioptric Power in each case (Both the eyes, left eye and right eye). The changes in Dioptric Power after usage of smartphones were found in several participants.

Table 4.2 Visual Acuity, left eye (OS) of the subjects

Visual Acuity	Initial (OS) (%)	After (OS) (%)	P-value
6/6	16.66±1.15	7.14±2.31	0.003
6/6(P)	15.33±1.15	5.69±2.31	0.003
6/9	23.33±1.15	14.83±2.31	0.0047
6/9(P)	6.66±1.15	23.45±2.31	<0.0004
6/12	13.33±1.15	13±1.15	0.74
6/12(P)	2.66±1.15	11.33±1.15	0.0008
6/18	10±1.15	12.5±1.15	0.056
6/18(P)	0±0	10.85±1.15	-
6/24	2±0	1±0	-
6/24(P)	0±0	0.4±0	-
6/36	4±0	0.5±0	-
6/36(P)	0±0	3±0	-
6/60	6±0	0±0	-
6/60(P)	0±0	6±0	-
Data are represented as Mean±SD; significance was taken at P≤0.05.			

Table 4.3 represents the retinoscopic readings of the subjects in both eyes. Retinoscopy is an objective test used to evaluate the refractive error of the eye, which includes the spherical and cylindrical power (Adyanthaya and Abhilash 2020). The given data suggests that there is a change in the average spherical power of the eye after 30 days of mobile phone exposure. The initial average spherical power of the eye in the OD is -0.51±0.71, which means that the mean spherical power is slightly nearsighted, with a range of ±0.71 diopters (D) around the mean. After 30 days of mobile phone exposure, the average spherical power in the OS increased to -0.80±0.90, indicating a greater degree of nearsightedness compared to the initial

measurement. The range also increased to ±0.90 D, suggesting a wider distribution of refractive errors.

Table 4.3 Retinoscopy readings, Right eye (OD)

	Initial (OD)	After (OD)	P-value
Spherical	-0.51±0.71	-0.80±0.90	0.07
Cyllinder	-0.39±0.49	-0.38±0.66	0.93
	Initial (OS)	**After (OS)**	
Spherical	-0.57±0.57	-0.86±0.85	0.047
Cyllinder	-0.5±0.28	-0.54±0.27	0.47

Data are represented as Mean ± SD; significance was taken at P ≤ 0.05.

Based on the given data, the average cylindrical powers of the OD of the 50 subjects were -0.39 ± 0.49 before mobile phone exposure, and -0.38±0.66 after 30 days of exposure. The small changes in cylinder powers between the initial and post-exposure measurements are within the range of normal variability and could be due to measurement error or other factors unrelated to mobile phone use.

The results suggest that there was a statistically significant change in the spherical power of the OS after 30 days of mobile phone exposure. The average spherical power of the OS increased from -0.57 ± 0.57 to -0.86 ± 0.85. This means that, on average, the participants had a more nearsighted (myopic) refraction after 30 days of mobile phone exposure.

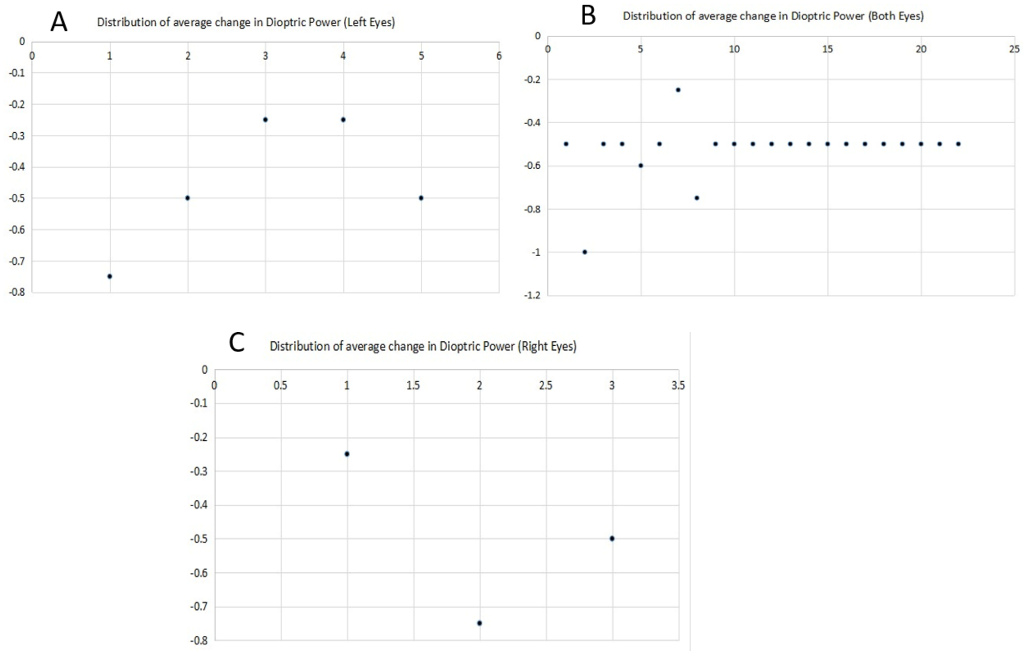


Figure 4.1: (a) Distribution of average change in Dioptric Power (Left Eye) (b) Distribution of average change in Dioptric Power (Both Eye) (c) Distribution of average change in Dioptric Power (Right Eye)

However, it is important to note that the magnitude of the change in spherical power was relatively small, with an average increase of only 0.29 diopters. The results of the retinoscopic reading of 50 subjects in average, shows that the average cylinder power of the eye in initial (OS) was -0.5±0.28 and after 30 days of mobile phone exposure, it was -0.54±0.27. This difference of 0.04 diopters in cylinder power between the initial reading and after mobile phone exposure may not be clinically significant, as it falls within the range of measurement error or variability of the technique used. The standard deviation of the readings is relatively low, which suggests that the measurements were consistent.

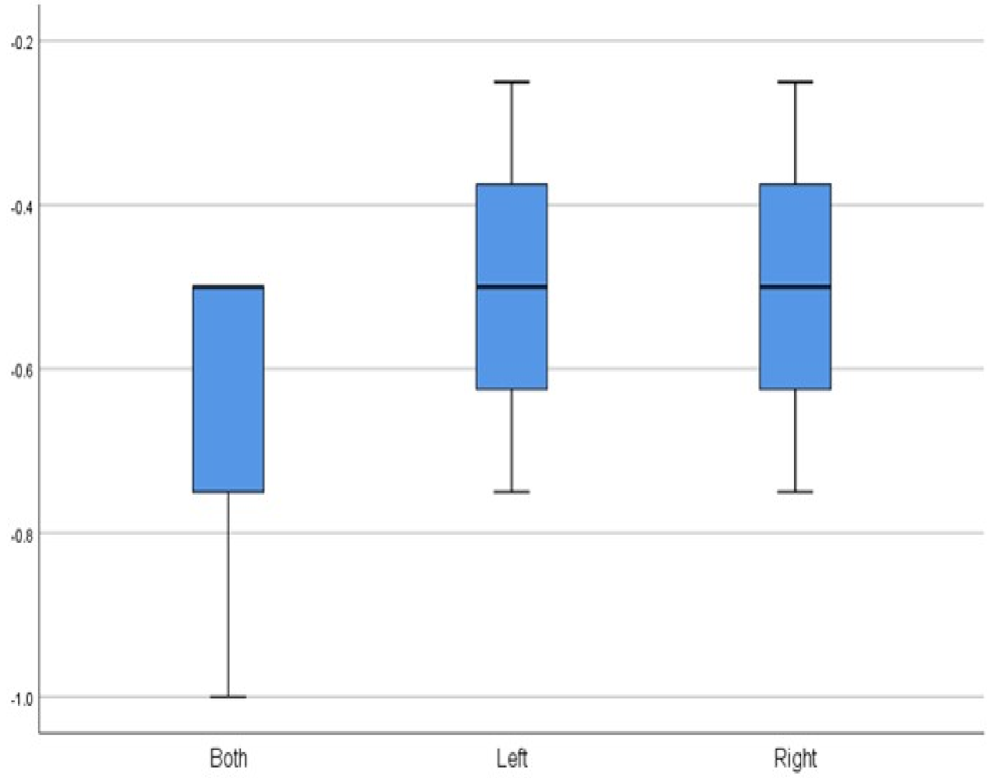


Figure 4.2: Distribution of changes of Dioptric power in left, right and both the eyes after usage of smartphone (exposure of radiation)

It is well-established that blue light emitted from electronic devices, such as mobile phones, can have a negative impact on ocular health, including the development of myopia. The increase in the degree of nearsightedness observed in the study is likely due to the prolonged exposure from mobile phones (Zhao et al. 2018).

Table 4.4 represents the keratometry readings**.** Keratometry readings are used to measure the curvature of the cornea, which is the clear, outermost layer of the eye**.** From the given data, we can see that the average K1 reading of 50 subjects in the OD eye initially was 7**.**7 ± 0**.**20, and after 30 days of mobile phone exposure, the K1 reading was 7**.**71 ± 0**.**21**.** The difference between these two measurements is very small, and it is within the range of measurement error**.** Therefore, it is not likely that mobile phone exposure has caused a significant change in the corneal curvature of these subjects. However, it is important to note that this study only considers the K1 readings in the OD eye, and it is possible that mobile phone exposure could have had an effect on other aspects of the eye's physiology. Additionally, this study only looks at short-term exposure to mobile phones, and it is possible that long-term exposure could have more significant effects. In the given scenario, the K2 reading of 50 subjects in average in the right eye (OD) before and after 30 days of mobile phone exposure are provided. The mean K2 reading before exposure is 7.6 ± 0.18, while the mean K2 reading after exposure is 7.6 ± 0.21. Here, the value 7.6 is the mean K2 reading, and the values 0.18 and 0.21 are the standard deviations of the measurements. Since the mean K2 reading is the same before and after exposure, it suggests that there is no significant change in the curvature of the cornea due to mobile phone exposure. The study evaluated the changes in the K1 readings of 50 subjects after 30 days of mobile phone exposure in the left eye (OS). The average K1 reading in OS initially was 7.71 ± 0.20, and after 30 days of mobile phone exposure, it was 7.69 ± 0.19. The difference between the two means is very small, only 0.02, and the standard deviation of each measurement is also small, 0.20 and 0.19, respectively. This indicates that there was not a significant change in the K1 readings after 30 days of mobile phone exposure in the left eye.

Table 4.4 Keratometer readings Right(OD) eye and Left eye(OS)

Keratometer readings (OD)			
	Initial (OD)(mm)	After (OD)	P- Value
K1 (mm)	7.7±0.20	7.71±.21	0.809
K2(mm)	7.6±0.18	7.6±0.21	>0.999
Keratometer readings (OS)			
	Initial	After	
K1 (mm)	7.71±0.20	7.69±0.19	0.90
K2(mm)	7.60±0.16	7.58±0.16	0.88

Data are represented as Mean ± SD; significance was taken at P≤0.05.

RF radiation exposure may have benign or adverse biological impacts due to the heating of cells and tissues. Thermal damage from both confines and entire body heating varies. The central nervous system, testis and lens of the eye seem to be especially delicate, because of a restricted ability to disperse heat eyes are more susceptible to heat-induced damage (Volkow et al. 2011), (Ahlbom et al. 2004) . Thermal effects from microwave radiation have been reported to cause cataract and have adverse effects for the cornea, retina and other ocular systems, but effects of non-thermal radiations are not well understood (Bormusov et al. 2008). Investigations on non-thermal impacts of RF radiation from cell phones are moderate, and analysis has suggested further investigation of consequences for the eye lens and lens epithelial cells (Gultekin and Moeller 2013). Electromagnetic fields from microwave radiation adversely affect the eyes. One review warned that high recurrence microwave electromagnetic radiation from cell phones and other present-day gadgets has potential harmful effects on eye tissues, however, its impact on the lens epithelium is still unidentified (Bormusov et al. 2008)]. Many researchers demonstrated that the lens of the eye is highly sensitive to heat, and damage can occur even from a solitary intense exposure. Consequently, there is a possible system for RF to prompt cataract incidence (Van Norren and Vos 2016). Epidemiological exploration has been limited, particularly to exposure evaluation. Exposure of electromagnetic radiation from smartphones is on rise as there is the advent of new generation devices and signals, due to which the hazard is also more than before in terms of damage to the environment and human body, especially when the legal emission values are not maintained (Ahlbom et al. 2004). In our study, after exposure of mobile phone for 30 days the average population % shows changes in visual acuity in both eyes. There were significant changes in average retinoscopic reading in the population indicates that the harmful effects in eyes. However, there was no significant change in keratometry reading which indicates thew there was no such harmful effects on curvature of the cornea.

4.4 Findings from a Physics Perspective

The study examines the effects of radiofrequency (RF) radiation emitted from smartphones on the dioptric power of the eye. Here's a detailed analysis of the findings from a physics perspective:

1. **Nature of RF Radiation and Interaction with Biological Tissue**

- RF radiation is categorized as non-ionizing, meaning it lacks the energy to remove tightly bound electrons from atoms but can still induce thermal effects through energy absorption.

- When RF waves interact with tissues like the eye, they cause molecular vibrations, leading to localized heating. The study shows that such thermal effects, even in non-ionizing radiation, can have measurable biological impacts.

2. **Impact on Visual Acuity**

- The results revealed a statistically significant decrease in visual acuity after 30 days of smartphone use. This finding correlates with RF radiation's impact on ocular tissues, potentially disrupting tear film dynamics and inducing fatigue or strain.

- The blue light emitted by screens further exacerbates visual strain, contributing to symptoms such as blurring and reduced focus. Blue light has shorter wavelengths and higher energy, leading to greater scattering and potential disruption of retinal cells.

3. **Changes in Dioptric Power**

- Spherical Power: There was a notable increase in near-sightedness (myopia), as evidenced by changes in spherical power. This reflects how prolonged smartphone exposure affects the focusing ability of the eye, potentially through thermal effects or structural changes at the cellular level.

- Cylindrical Power: Variations in cylindrical power were within measurement error, suggesting no significant correlation with RF exposure.

From a physics standpoint, these changes can be attributed to localized heating and stress on the lens and corneal layers, which alter their refractive properties.

4. **Keratometry Findings**

- Keratometry readings, which measure corneal curvature, showed no significant changes after RF exposure. This indicates that the corneal structure's resilience minimizes deformation under the exposure conditions studied.

- The lack of keratometric changes implies that short-term exposure affects functional, rather than structural, ocular parameters.

5. **Mechanisms of RF Radiation Effects**

- Thermal Effects: Heat generation due to energy absorption impacts sensitive ocular tissues, including the lens and retina, which are poorly equipped to dissipate heat.

- Non-Thermal Effects: Although less understood, non-thermal mechanisms, such as electromagnetic interference with cellular processes, could contribute to visual changes. For instance, RF radiation may influence ionic movements and cellular signalling pathways, subtly altering ocular function.

6. **Implications of Findings**

- The statistically significant reduction in visual acuity and increase in myopia suggest that smartphone-induced RF radiation can influence eye health over time.

- The study aligns with the broader understanding of electromagnetic wave interactions with matter, emphasizing the importance of SAR (Specific Absorption Rate) compliance to minimize health risks.

7. **Future Considerations**

- Expanding this study with a larger sample size and longer duration could yield more insights into the cumulative effects of RF radiation on the eye.

- Investigating the combined effects of blue light and RF radiation could further clarify their roles in visual health deterioration.

The study highlights how RF radiation, while non-ionizing, can significantly impact ocular health, primarily through thermal effects and prolonged exposure. From a physics perspective, this emphasizes the need to understand and mitigate electromagnetic wave interactions with biological systems. The findings call for stricter safety guidelines and public awareness regarding smartphone usage.

4.4. CONCLUSION

Smartphone usage by almost all ages has increased substantially. Due to demands of increased speed and efficiency, the strength of RF signals has been on the rise, hence, more effects on eyes health. Current study has shown that avid users of smartphones have experienced more occurrences of ophthalmologic abnormalities. The study has evaluated the findings of visual acuity, refraction, retinoscopy and keratometer. All these parameters have been shown to deviate except keratometry readings during the follow-up study. The study contained 50 participants and this does not represent the entire population. Therefore, we suggest that a large-scale future study with advance technology is required to get more data to compare the results and make more awareness among the population about the impact of RF on eyes. The study also concludes that there are significant effects on the ophthalmologic parameters such as dioptric power after usage of smartphones. Hence it is essential to choose a good quality smartphone with legally compliant SAR value. Therefore, this study brought forward an essential finding which needs to be addressed by the smartphone manufacturers and the governments.

REFERENCES

Adyanthaya, Sinchana, and B Abhilash. 2020. "A Comparison between Retinoscopy and Autorefraction in Acceptance of Subjective Correction in School Age Children." *Indian Journal of Clinical and Experimental Ophthalmology* 6(3): 418–21.

Ahlbom, Anders, Adele Green, Leeka Kheifets, David Savitz, and Anthony Swerdlow. 2004. "Epidemiology of Health Effects of Radiofrequency Exposure." *Environmental Health Perspectives* 112(17): 1741–54. doi:10.1289/ehp.7306.

Balik, Hasan H., Dilek Turgut-Balik, Kemal Balikci, and I. Cem Özcan. 2005. "Some Ocular Symptoms and Sensations Experienced by Long Term Users of Mobile Phones." *Pathologie Biologie* 53(2): 88–91. doi:10.1016/j.patbio.2004.03.012.

Bormusov, Elvira, Usha P. Andley, Naomi Sharon, Levi Schachter, Assaf Lahav, and Ahuva Dovrat. 2008. "Non-Thermal Electromagnetic Radiation Damage to Lens Epithelium." *The Open Ophthalmology Journal* 2(1): 102–6. doi:10.2174/1874364100802010102.

Bozorgmanesh, Mohammad Amin, and Fatemeh Kowkabi. 2020. "The Effect of Mobile Phone Electromagnetic Waves on Honey Bee." In *SSRN Electronic Journal*, , 1–8. doi:10.2139/ssrn.4439490.

Gultekin, David H, and Lothar Moeller. 2013. "NMR Imaging of Cell Phone Radiation Absorption in Brain Tissue." *PNAS* 110(1): 1–10. doi:10.1073/pnas.1205598109.

Issa, Lotfi F., Khaled A. Alqurashi, Talal Althomali, Talal A. Alzahrani, Abdullah S. Aljuaid, and Tariq M. Alharthi. 2021. "Smartphone Use and Its Impact on Ocular Health among University Students in Saudi Arabia." *International Journal of Preventive Medicine* 12(149): 1–7. doi:10.4103/ijpvm.IJPVM.

Jaman, Firdoos, and Ramesh Chandra Tiwari. 2021. "Environmental and Biological Effects of Cell Phone Radiation: A Review." *Design Engineering* 9(November): 300–311.

Kim, Dong Ju, Chi-Yeon Lim, Namyi Gu, and Choul Yong Park. 2017. “Visual Fatigue Induced by Viewing a Tablet Computer with a High-Resolution Display.” *Korean Journal of Ophthalmology* 31(5): 388. doi:10.3341/kjo.2016.0095.

Küçer, Nermin. 2008. “Some Ocular Symptoms Experienced by Users of Mobile Phones.” *Electromagnetic Biology and Medicine* 27(2): 205–9. doi:10.1080/15368370802072174.

Maples, W. C., Wes DeRosier, Richard Hoenes, Rodney Bendure, and Sherl Moore. 2008. “The Effects of Cell Phone Use on Peripheral Vision.” *Optometry* 79(1): 36–42. doi:10.1016/j.optm.2007.04.102.

Mittal, Sanjeev Kumar, Rimpi Rana, Athul Puthalath, Ajai Agrawal, Anupam, Neeti Gupta, and Sunita Mittal. 2022. “Ocular Effects of Mobile Phone Radiation.” *Indian Journal of Clinical and Experimental Ophthalmology* 8(1): 66–71. doi:10.18231/j.ijceo.2022.013.

Moon, Jin-hwa. 2020. “Health Effects of Electromagnetic Fields on Children.” *Clin Exp Pediatr* 63(11): 422–28.

Naeem, Zahid. 2014. “Health Risks Associated with Mobile Phones Use.” *International Journal of Health Sciences* 8(4): 1–2.

Van Norren, D., and J. J. Vos. 2016. “Light Damage to the Retina: An Historical Approach.” *Eye (Basingstoke)* 30(2): 169–72. doi:10.1038/eye.2015.218.

Siddig Tawer Kafi, Abdalfattah Mohammed Ahmed, Bashir Algaily Ismail, Enas Ali Nayel, Asma Rashied Awad, and Esraa Alzobair Alhassan. 2015. “Effects of RF Radiation Emitted from Cellphones on Human Eye Function (Vision Acuity/Refraction).” *J. of Electrical Engineering* 3(3). doi:10.17265/2328-2223/2015.03.003.

Singh, Rajeev, Ravindra Nath, Ajit Kumar Mathur, and Radhey Shyam Sharma. 2019. “Effect of Radiofrequency Radiation on Reproductive Health.” *Indian J Med Res* 148(December 2018): 92–99. doi:10.4103/ijmr.IJMR.

Volkow, Nora D, Paul Vaska, Joanna S Fowler, Frank Telang, Dave Alexoff, Jean Logan, and Christopher Wong. 2011. “Effects of Cell Phone Radiofrequency Signal Exposure on Brain Glucose Metabolism.” *jama* 305(8).

Zhao, Zhi-chun, Ying Zhou, Gang Tan, and Juan Li. 2018. “Research Progress about the Effect and Prevention of Blue Light on Eyes." *International Journal of Ophthalmology* 11(12): 1999–2003. doi:10.18240/ijo.2018.12.20.

https://www.who.int/news-room/fact-sheets/detail/electromagnetic-fields-and-public-health-mobile-phones Accessed on May, 2023.

CHAPTER- 5

INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMITTED FROM SMART PHONES ON VISUAL ACUITY AND CORNEAL CURVATURE OF THE EYE

This chapter deals with the effect of *RF* frequency on visual equity and corneal curvature of the eye.

CHAPTER- 5

RESULTS AND DISCUSSION (II)

INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMITTED FROM SMART PHONES ON VISUAL ACUITY AND CORNEAL CURVATURE OF THE EYE

5.1 Introduction:

Mobile phones have become an integral aspect of human life, yet they pose a potential threat to human health, as researchers have identified various health implications associated with their excessive use. The emitted Radio waves and Microwave radiation from mobile phones primarily induce thermal and non-thermal effects, leading to damage to biological tissues. Given that mobile phones are predominantly exposed to the eyes compared to other parts of the body, there is an increased likelihood of dioptric power variation, resulting in unclear vision after prolonged use. Despite limited studies on visual changes in long-term mobile phone users, there is a pressing need for an in-depth investigation into this specific issue to address problems arising from excessive mobile phone usage. The main aim of this study is to investigate the changes in visual acuity for distance vision and corneal curvature of the eye among individuals who extensively use mobile phones.

In current century, smartphones have seamlessly integrated into the daily lives of individuals. Unfortunately, the excessive use of smartphones poses significant health hazards due to the radiation they emit, a fact that often goes unnoticed by many. The emission of Radio waves and microwave radiation from mobile phones results in both thermal and non-thermal effects, leading to harm to biological tissues. Despite the widespread usage of smartphones, awareness about Mobile phones operates within the microwave spectrum, utilizing non-ionizing electromagnetic radiation (EMR) and radiofrequency radiation (RFR). The heat generated during their use has raised concerns about potential health risks associated with extended exposure to these waves, particularly during phone conversations (Sri Nageswari 2015). The potential health risks associated with their radiation remains limited."

In 2008, a survey was carried out with 229 university students in Kocaeli, Turkey, utilizing a questionnaire to examine six ocular symptoms associated with mobile phone usage. To analyses the data, a chi-square test with Yates correction was employed. The investigated symptoms included blurred vision, eye redness, visual disturbances and eye inflammation. The results revealed a significant rise in the frequency of blurring of vision among mobile phone users who possessed their devices for more than two years, in comparison to those with possession for less than two years. Moreover, women reported a higher frequency of inflammation in the eyes compared to men (Küçer 2008). In 2015, a research investigation aimed to illustrate the impact of radiofrequency radiation (RF)emitted by cell phones on human eye function. The research identified notable alterations in visual acuity and refraction (Siddig Tawer Kafi et al. 2015) . Adverse effects on both humans and animals are anticipated with both short-term and prolonged exposure to RF radiation.

Numerous research center studies have unequivocally established a direct correlation between RF radiation exposure and biological impacts. This includes the induction of various types of cancers, chromosomal damage, and alterations to DNA caused by exposure to RF radiation (Naeem 2014).

A numerical study explores diverse RF sources' impact on SAR and maximum temperature in the human eye across frequencies. Using a high-resolution head model, it distinguishes eye tissues, deriving new values for blood perfusion and metabolic rate. Findings reveal frequency and source-dependent SAR and temperature distributions, with significant temperature increases (approx. X°C for general exposure, 1.5°C for occupational exposure) in critical near-field scenarios meeting SAR guidelines (Buccella, De Santis, and Feliziani 2007).

5.2 Results and Discussion

We included 320 patients in this study with a mean age of 25.1+5.4 years of which 121 (60%) were males. The study analysed the visual acuity of individuals before and after exposure the RF Radiation in the form of mobile phone (Table 5.1). The initial visual acuity was 0.631, with a range of 0.1 to 1. After the exposure, the mean was slightly lower at 0.619. Both datasets showed variability in visual acuity, with negative skewness and negative kurtosis. The t-test results showed no statistically significant difference between the initial and after visual acuity, suggesting the observed difference may be due to random variability

Table 5.1 Comparison of Right Eye (OD) Visual Acuity

Initial VA OD		***After VA OD***	
Column1		*Column1*	
Mean	0.6307625	Mean	0.6192875
Standard Error	0.015050475	Standard Error	0.016065679
Median	0.667	Median	0.667
Mode	0.667	Mode	0.667
Standard Deviation	0.269231077	Standard Deviation	0.287391607
Sample Variance	0.072485373	Sample Variance	0.082593936
Kurtosis	-0.787510773	Kurtosis	-1.08065572
Skewness	-0.153991866	Skewness	-0.130637628
Range	0.9	Range	0.9
Minimum	0.1	Minimum	0.1
Maximum	1	Maximum	1
Sum	201.844	Sum	198.172
Count	320	Count	320
Confidence Level(95.0%)	0.02961073	Confidence Level(95.0%)	0.031608072
	t-test 0.6023		

In the left eye (Table 5.2) the study found no significant difference in the mean visual acuity of the left eye after the visual acuity

Table 5.2: Comparison of Left Eye (OS) Visual Acuity

Initial VA OS			**After VA OS**	
Column1			*Column1*	
Mean	0.624525		Mean	0.624525
Standard Error	0.015586451		Standard Error	0.015586451
Median	0.667		Median	0.667
Mode	0.667		Mode	0.667
Standard Deviation	0.278818914		Standard Deviation	0.278818914
Sample Variance	0.077739987		Sample Variance	0.077739987
Kurtosis	-0.916608621		Kurtosis	-0.916608621
Skewness	-0.186871716		Skewness	-0.186871716
Range	0.9		Range	0.9
Minimum	0.1		Minimum	0.1
Maximum	1		Maximum	1
Sum	199.848		Sum	199.848
Count	320		Count	320
Confidence Level(95.0%)	0.030665225		Confidence Level(95.0%)	0.030665225
	t-test	0.2379		

OS exposure, with a t-test result of 0.2379. The data showed a range of 0.1 to 1. The mean visual acuity remained constant after the exposure, with a slight tail towards higher values. Further investigation or consideration of clinical relevance is recommended to interpret the practical significance of the observed visual acuity stability in the left eye.

The Table 5.3 provides statistical data on mean values, sample sizes (N), and standard deviations (Std. Deviation) for various measurements (InitialODk1, InitialODk2, AfterODk1, AfterODk2, InitialOSk1, InitialOSk2, AfterOSk1, AfterOSk2) across three different age groups (20-29, 30-39, 40-50), and a total aggregate of these age groups. Here's a detailed analysis of the data:

Table 5.3: Initial and after keratometric readings of Right & Left eye respectively

Age group		InKeratoODk1	InKeratoODk2	AfKeratoODk1	AfKeratoODk2	InKeratoOSk1	InKeratoOSk2	AfKeratoOSk1	AfKeratoOSk2
20-29	Mean	7.4175	7.4204	7.4243	7.4311	7.4186	7.4175	7.4171	7.4171
	N	112	112	112	112	112	112	112	112
	Std. Deviation	0.03578	0.04761	0.02704	0.04222	0.04318	0.04769	0.04353	0.04319
30-39	Mean	7.4253	7.4206	7.4118	7.4041	7.4318	7.4259	7.4306	7.4312
	N	136	136	136	136	136	136	136	136
	Std. Deviation	0.03241	0.03059	0.03868	0.03365	0.03743	0.03693	0.03050	0.03087
40-50	Mean	7.4083	7.4128	7.4217	7.4283	7.4122	7.4111	7.4067	7.4000
	N	72	72	72	72	72	72	72	72
	Std. Deviation	0.04606	0.04649	0.03619	0.03394	0.04146	0.04310	0.04794	0.04138
Total	Mean	7.4188	7.4188	7.4184	7.4190	7.4228	7.4196	7.4205	7.4193
	N	320	320	320	320	320	320	320	320
	Std. Dev	0.03749	0.04094	0.03482	0.03900	0.04111	0.04262	0.04068	0.03974

Analysis by Age Group

20-29 Age Group

- The mean values for this age group show a slight increase from InitialODk1 (7.4175) to AfterODk2 (7.4311), indicating a small upward trend.
- InitialOSk measurements (7.4186, 7.4175) remain relatively stable, with very slight fluctuations observed after treatment (7.4171 for both AfterOSk1 and AfterOSk2).
- Standard deviations show some variability, with the highest being 0.04769 for InitialOSk2 and the lowest 0.02704 for AfterODk1.

30-39 Age Group

- The mean values for InitialODk measurements decrease from 7.4253 (InitialODk1) to 7.4041 (AfterODk2).
- InitialOSk values start at 7.4318 and show slight variation, ending at 7.4312 (AfterOSk2).
- Standard deviations in this group range from 0.03050 (AfterOSk1) to 0.03868 (AfterODk1), showing that variability is relatively low across measurements.

40-50 Age Group

- The mean values increase slightly from 7.4083 (InitialODk1) to 7.4283 (AfterODk2).
- InitialOSk measurements show a slight decrease from 7.4122 (InitialOSk1) to 7.4000 (AfterOSk2).
- Standard deviations range from 0.03394 (AfterODk2) to 0.04794 (AfterOSk1), indicating moderate variability within this group.

Total (All Age Groups Combined)

- The overall mean values across all groups are very stable, ranging from 7.4184 to 7.4228.

- Standard deviations for the total group are relatively low, ranging from 0.03482 to 0.04262, suggesting a consistent pattern across all measurements.

Key Observations

1. **Consistency Across Measurements**: The mean values do not show significant changes across the different phases (InitialODk, AfterODk, InitialOSk, AfterOSk) within each age group, indicating consistency in measurements.
2. **Slight Variations**: There are minor variations in mean values and standard deviations, but these are not substantial, suggesting that any changes in measurements due to the conditions studied are minimal.
3. **Standard Deviation**: The standard deviations indicate some variability within each group, but no extreme outliers or inconsistencies are observed.
4. **Age Group Comparisons**: There is no significant difference in trends when comparing different age groups, indicating a similar response pattern across age demographics.

Overall, the data suggests stability and consistency in the measurements across different phases and age groups. Any observed changes are minor and likely within the expected range of variability for the studied conditions.

The study recorded the parameters (visual acuity and keratometer) during each patient's first visit. Again, the follow up study was done where we recorded the same parameters for the same patients.

Standard Deviation: The standard deviations indicate some variability within each group, but no extreme outliers or inconsistencies are observed.
Age Group Comparisons: There is no significant difference in trends when comparing different age groups, indicating a similar response pattern across age demographics.

Overall, the data indicates stability and consistency in the measurements across different phases and age groups. The observed changes are not high and likely fall within the expected range of variability for the conditions studied.

Examination by Age Group: Age Group 20–29

• There is a little rising trend in the mean values for this age group, from InitialODk1 (7.4175) to AfterODk2 (7.4311).

• Following treatment, very modest changes are noted (7.4171 for both AfterOSk1 and AfterOSk2), but initial OSk values (7.4186, 7.4175) remain quite steady.

• There is some variation in the standard deviations; for InitialOSk2, the greatest is 0.04769, and for AfterODk1, the lowest is 0.02704.

30-39 Age Group • The mean InitialODk values drop to 7.4041 (AfterODk2) from 7.4253 (InitialODk1).

• The initial OSk values finish at 7.4312 (AfterOSk2) after varying slightly from 7.4318 to 7.4312.

• This group's standard deviations, which vary from 0.03050 (AfterOSk1) to 0.03868 (AfterODk1), indicate that measurement variability is generally minimal.

40–50 Age Range

• The mean values go from 7.4083 (InitialODk1) to 7.4283 (AfterODk2), a little rise.

• The 7.4122 (InitialOSk1) to 7.4000 (AfterOSk2) initialOSk readings indicate a small drop.

• The standard deviations show substantial variation, ranging from 0.03394 (AfterODk2) to 0.04794 (AfterOSk1).

Total (Combining All Age Groups)

• The mean values, which range from 7.4184 to 7.4228, are generally extremely steady for all groups.

• The group as a whole has relatively low standard deviations, which range from 0.03482 to 0.04262, indicating a similar pattern throughout all measurements.

We can understand the differences from the following sub group plot graphics.

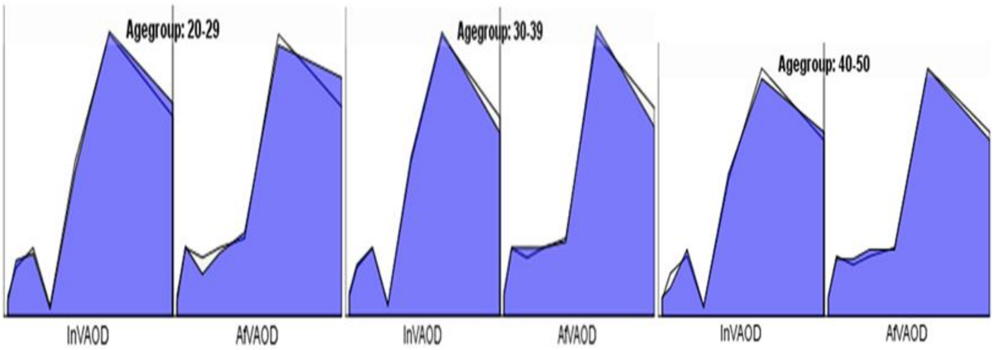


Figure:5.1 Differences Between Initial and after visual acuity in Right eye (OD) in the age group of 20-29,30-39,40-50.

In age group 20-29, both panels of sub group plot exhibit a steep rise followed by a decline, indicating similar overall patterns in the datasets. The visual acuity in the Right eye (OD) after the exposure of Radiofrequency (RF) radiation decline or changes is noted in the age group of 20 to 29 years than the others groups.

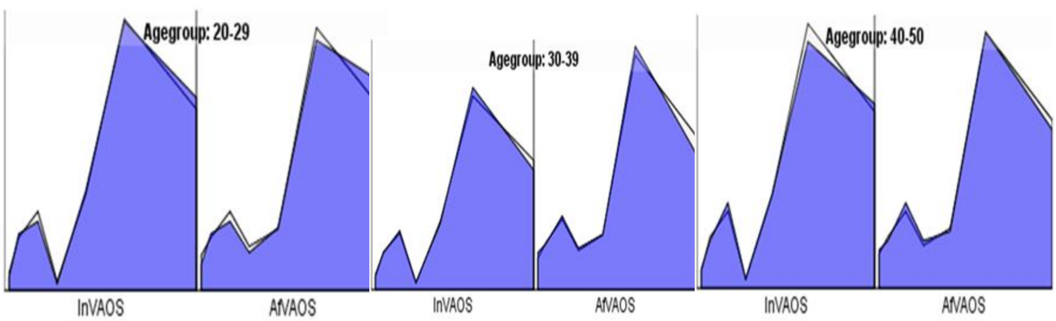


Figure: 5.2 Differences Between Initial and after visual acuity in Left eye (OS) in the age group of

20-29,30-39,40-50.

In age group 20-29, both panels of sub group plot exhibit a steep rise and then a decline.

Here may be a change in the Left eye (OS) after the exposure from Radiofrequency (RF) Radiation leading to slightly changes and smoother values compared to before the exposure. The 20-29 age group after the exposure indicate slight rise in the graph compared to the other two age groups.

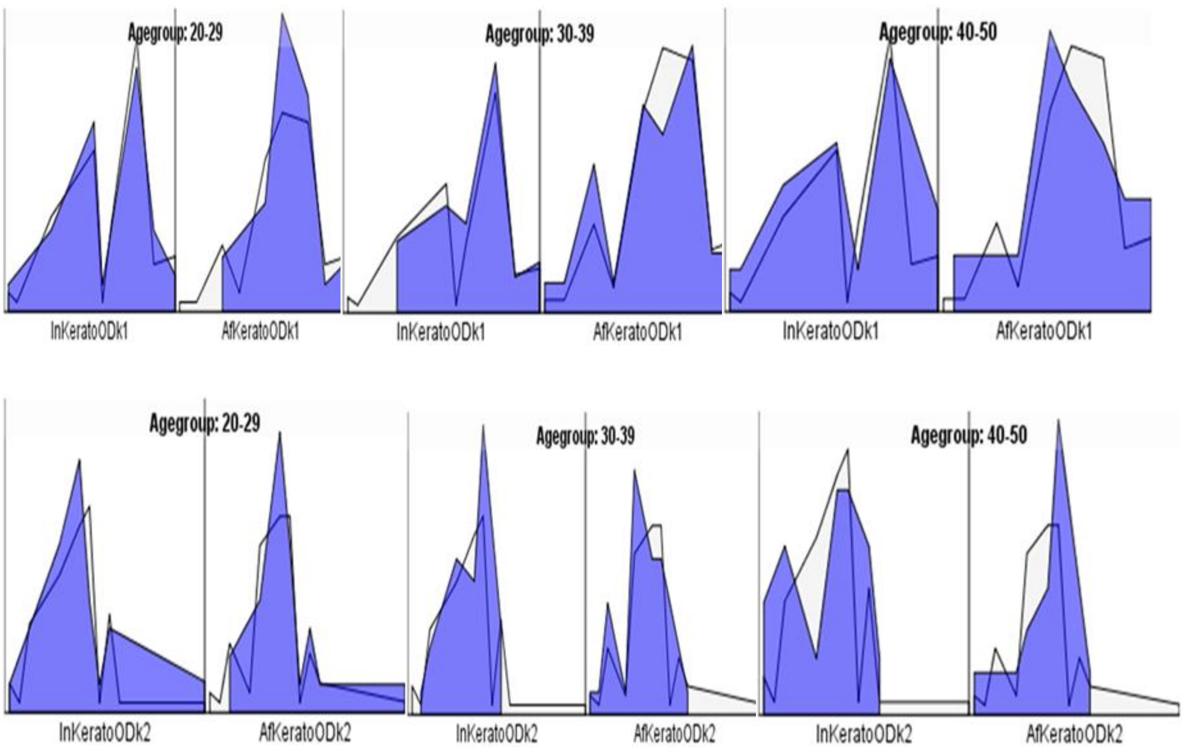


Figure:5.3 Differences Between Initial and after keratometry reading where K1 represent horizontal meridian and k2 represent vertical meridian in Right eye (OD) in the age group of 20-29,30-39,40-50.

The change in distribution pattern of the sub group plot suggests a shift in the measured of right eye horizontal keratometry (OD K1) reading parameter in the age group of 20-29 and 40-50.

In right eye vertical meridian, the image compares two sets of data (OD K2) for people aged 20-29 and 40-50 group, showing how their values are distributed. The shapes of the graphs suggest that the two datasets have some differences.

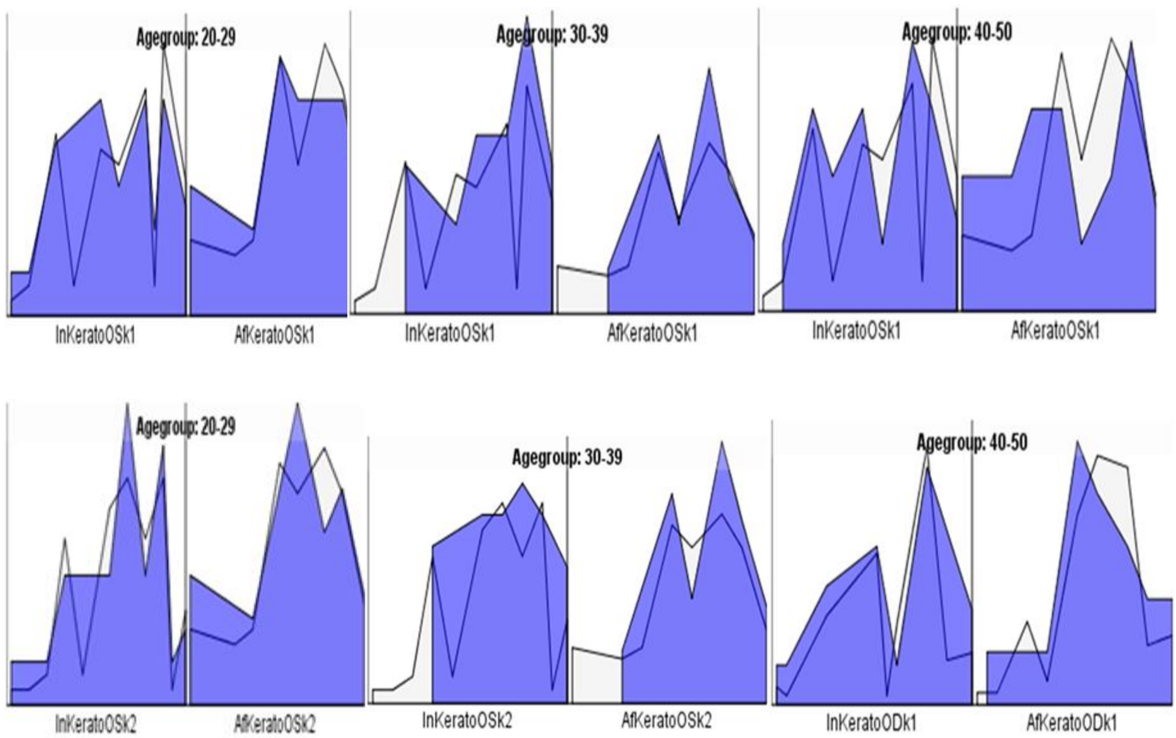


Figure:5.4 Differences Between Initial and after keratometry reading where K1 represent horizontal meridian and k2 represent vertical meridian in Left eye (OS) in the age group of 20-29,30-39,40-50.

The change in distribution pattern of the sub group plot suggests a shift in the measured of left eye horizontal keratometry (OS K1) reading parameter in the age group of 20-29,30-39 and 40-50. In right eye vertical meridian, the image compares two sets of data (OS K2) for people aged 20-29 and 40-50 group, showing how their values are distributed. The shapes of the graphs suggest that the two datasets have some differences.

The keratometry reding for both horizontal and vertical meridians of in Left eye (OS) after the exposure shows smoother and more consistent, with fewer big changes which indicate keratometry reading after the exposure of Radiofrequency (RF) Radiation slight changes was noted.

In this particular age group use of smart phone is more than the other two age groups.

Important Notes

1. Consistency Across Measurements: Within each age group, the mean values do not significantly alter between the several phases (InitialODk, AfterODk, InitialOSk, and AfterOSk). This suggests consistency in the measurements.

2. Small variances: The mean values and standard deviations show some small but non-significant variances, indicating that the conditions under study had little effect on the data.

3. Standard Deviation: While there is some variation within each group, there are no glaring outliers or discrepancies to be found.

4. Age Group Comparisons: When comparing trends across age demographics, there is no discernible variation, suggesting a comparable reaction pattern.

Overall, the data point to measurement stability and consistency across age groups and periods. Any changes that are noticed are probably small and fall within the typical variability range for the settings under study. During each patient's initial visit, the study captured the parameters (visual acuity and Keratometer). Once more, the identical parameters were recorded for the same patients in the follow-up research. The standard deviation is: There is some variation within each group, but no extreme outliers or inconsistencies, according to the standard deviations.

Visual acuity of OD and OS has been represented in table 1 and table 2 respectively. In our study 320 persons underwent a visual acuity test before and 30 days after using a mobile phone. The results suggest that the visual acuity of the participants decreased after using the mobile phones in the right eye whereas left eye showed no significant decrease.

In an study on primate and rabbit eyes, the microwave radiations lead to non-thermally degenerative changes such as oedema, endothelial cell loss and vacuolization deeper to the Descemet’s membrane in cornea but it is not entirely known how biochemical processes are affected (Kues et al. 1985).

A study done on tear film production, radiofrequency waves and heating effect from cell phones may adversely influence the ocular surface with quicker evaporation of the tear film, suggestive of subtle increments in ocular surface temperature during usage. Hence tear film production may also to be affected (Mittal et al. 2022). The surface of the corneal temperature can vary from 26.4◦C (at ambient air temperature of 20◦C) to 36.7◦C (at ambient air temperature of 40◦C) (Geiser, Bonvin, and Quibel 2004).

Blue light emitted by mobile phone screens can cause eyestrain, fatigue, and headaches (Kim et al. 2016). High-energy blue light penetrates through to the eye leading to diseases like dry eye, cataract and age-related macular degeneration. It also stimulates the brain, suppresses melatonin secretion, and increases adrenocortical hormone production, disrupting hormonal balance and impacting sleep quality. Blue light can promote the development of the human eye and regulate the circadian rhythm to some extent, but the problem of blue light in the human eye cannot be unnoticed (Zhao et al. 2018). Thermal effects emitted from microwave radiation have been reported to cause cataract and have adverse effects for the cornea, retina and other ocular systems, but effects of non-thermal radiations are not well understood (Bormusov et al. 2008).

5.3 **Findings from a Physics Perspective**

The investigation in this chapter focuses on the effects of radio frequency (RF) radiation emitted by smartphones on visual acuity and corneal curvature. Below is an analysis from a physics standpoint, highlighting the interaction mechanisms of RF radiation and electromagnetic waves with ocular tissues, along with the study's key findings.

1. **Nature of RF Radiation and Biological Interaction**

- Non-Ionizing Radiation: RF radiation emitted by smartphones is classified as non-ionizing, meaning its energy level is insufficient to ionize atoms but can still influence biological systems through thermal effects.

- Thermal vs. Non-Thermal Effects: In biological tissues like the eye, RF radiation can cause local heating as energy is absorbed by molecules, especially in water-rich tissues. The study explores both thermal and non-thermal effects, which include molecular vibrations causing heating (thermal) and potential impacts on cell signaling without noticeable heat changes (non-thermal).

2. **Impact on Visual Acuity**

- Experimental Findings: A slight reduction in visual acuity was observed in the right eye after exposure to RF radiation from smartphones, while the left eye showed stability in visual acuity post-exposure. This suggests that RF radiation, though non-ionizing, can still exert functional changes in visual perception due to sustained exposure.

- Physics Insight: This decrease in visual acuity may be due to the small yet cumulative thermal effect on the eye's internal structure, potentially influencing the lens or retina. Additionally, the emitted blue light from screens, which has higher energy, contributes to visual fatigue by scattering in the eye and disrupting cellular processes essential for clear vision.

3. **Corneal Curvature and Keratometry Findings**

- Keratometry Data: The study measured corneal curvature before and after RF exposure across different age groups, finding minimal changes that were not statistically significant. This implies that the corneal structure's resilience prevents it from deforming under short-term RF radiation exposure.

- Thermal Stability of the Cornea: The cornea's slight thermal changes did not translate to measurable curvature changes, suggesting that RF exposure at the tested levels does not affect the physical structure of the eye's surface. However, previous studies suggest that prolonged RF exposure can lead to corneal cell degeneration and alterations in tear film stability due to heat.

4. **Thermal Effects on Ocular Tissues**

- Heat Generation: RF radiation, when absorbed by the eye's tissues, particularly the lens and aqueous humor, can result in a localized temperature increase. The eye is sensitive to temperature variations due to its limited blood flow, which makes it more vulnerable to RF radiation.

- Significance of Temperature Changes: As the study suggests, minor thermal variations may contribute to gradual cellular damage or altered cell function over time. This aligns with findings that thermal effects from RF radiation could potentially lead to cataract formation or other ocular complications with sustained exposure.

5. **Non-Thermal Effects and Blue Light Exposure**

- Blue Light Emission: The high-energy visible (HEV) blue light from smartphone screens also contributes to visual strain, fatigue, and even macular degeneration over time. Blue light penetrates deep into the eye, potentially affecting photoreceptors in the retina.

- Electromagnetic Influence: Non-thermal electromagnetic fields from RF radiation can interfere with cellular functions, potentially affecting ion channels and disrupting normal biochemical processes, although further research is needed to fully understand these mechanisms. The non-thermal effects could thus also be contributing to visual strain and discomfort, as the study suggests.

6. **Study Implications and Physics-Based Recommendations**

- Interpreting SAR and Heat Distribution: The study emphasizes the importance of maintaining SAR (Specific Absorption Rate) within permissible limits to minimize heat buildup in sensitive tissues like the eyes. From a physics perspective, this reinforces the need for regulations that keep RF energy absorption to safe levels to prevent cumulative thermal damage.

- Age Group Analysis and Radiation Resilience: No significant differences were observed across age groups, suggesting a general pattern of resilience to short-term RF radiation. However, age-related differences in ocular sensitivity to temperature and blue light exposure may become more relevant in long-term studies.

From a physics viewpoint, this chapter highlights how RF radiation, even as non-ionizing radiation, can still have noticeable effects on ocular health through thermal effects and non-thermal cellular interactions. The findings suggest that continued exposure to RF radiation and blue light from smartphones, although non-ionizing, could impact visual function and eye comfort over time. The study underscores the importance of managing smartphone usage and enforcing SAR limits to protect users, particularly with the rising adoption of high-frequency 5G networks.

5.3. Conclusion

The widespread use of smartphones across various age groups has seen a significant surge. With the growing need for enhanced speed and efficiency, the intensity of radiofrequency (RF) signals has also increased, consequently impacting eye health. Many unanswered questions persist regarding the broader health implications of mobile phone usage, particularly concerning its effects on the eyes. It is crucial to evaluate the role of diverse sources of radio wave exposure, not limited to mobile phones but also encompassing environmental exposures and other contributing factors.

Current study has shown that avid users of smartphones have experienced more occurrences of ophthalmologic abnormalities. The study has evaluated the findings of visual acuity and keratometry.

A large-scale future study with advance technology is required to get more data to compare the results and make more awareness among the population about the impact of RF on eyes. The study also concludes that there are significant effects on the ophthalmologic parameters such as visual acuity and keratometer reading after usage of smartphones. Therefore, it is crucial to select a high-quality smartphone with a legally compliant SAR value. Therefore, this study highlighted a critical issue that needs to be addressed by both smartphone manufacturers and governments.

REFERENCES

Bormusov, Elvira, Usha P. Andley, Naomi Sharon, Levi Schachter, Assaf Lahav, and Ahuva Dovrat. 2008. "Non-Thermal Electromagnetic Radiation Damage to Lens Epithelium." *The Open Ophthalmology Journal* 2(1): 102–6. doi:10.2174/1874364100802010102.

Buccella, Concettina, Valerio De Santis, and Mauro Feliziani. 2007. "Prediction of Temperature Increase in Human Eyes Due to RF Sources." *IEEE Transactions on Electromagnetic Compatibility* 49(4): 825–33. doi:10.1109/TEMC.2007.909024.

Geiser, Martial H., M. Bonvin, and O. Quibel. 2004. "Corneal and Retinal Temperatures under Various Ambient Conditions: A Model and Experimental Approach." *Klinische Monatsblatter fur Augenheilkunde* 221(5): 311–14. doi:10.1055/s-2004-812878.

Kim, Joowon, Yunji Hwang, Seungheon Kang, Minhye Kim, Tae Shin Kim, Jay Kim, Jeongmin Seo, et al. 2016. "Association between Exposure to Smartphones and Ocular Health in Adolescents." *Ophthalmic Epidemiology* 23(4): 269–76. doi:10.3109/09286586.2015.1136652.

Küçer, Nermin. 2008. "Some Ocular Symptoms Experienced by Users of Mobile Phones." *Electromagnetic Biology and Medicine* 27(2): 205–9. doi:10.1080/15368370802072174.

Kues, Henry A., Lawrence W. Hirst, Gerard A. Lutty, Salvatore A. D'Anna, and Gregory R. Dunkelberger. 1985. "Effects of 2.45-GHz Microwaves on Primate Corneal Endothelium." *Bioelectromagnetics* 6(2): 177–88. doi:10.1002/bem.2250060209.

Mittal, Sanjeev Kumar, Rimpi Rana, Athul Puthalath, Ajai Agrawal, Anupam, Neeti Gupta, and Sunita Mittal. 2022. "Ocular Effects of Mobile Phone Radiation." *Indian Journal of Clinical and Experimental Ophthalmology* 8(1): 66–71. doi:10.18231/j.ijceo.2022.013.

Naeem, Zahid. 2014. "Health Risks Associated with Mobile Phones Use." *International Journal of Health Sciences* 8(4): 1–2.

Siddig Tawer Kafi, Abdalfattah Mohammed Ahmed, Bashir Algaily Ismail, Enas Ali

Nayel, Asma Rashied Awad, and Esraa Alzobair Alhassan. 2015. "Effects of RF Radiation Emitted from Cellphones on Human Eye Function (Vision Acuity/Refraction)." *J. of Electrical Engineering* 3(3). doi:10.17265/2328-2223/2015.03.003.

Sri Nageswari, K. 2015. "Mobile Phone Radiation : Physiological & Pathophysiologcal Considerations." *Indian Journal of Physiology and Pharmacology* 59(2): 125–35.

Zhao, Zhi-chun, Ying Zhou, Gang Tan, and Juan Li. 2018. "Research Progress about the Effect and Prevention of Blue Light on Eyes." *Indian Journal of Ophthalmology* 11(12): 1999–2003. doi:10.18240/ijo.2018.12.20.

CHAPTER- 6

SUMMARY AND CONCLUSION

This chapter deals with the summary and future prospect of the thesis.

CHAPTER-6

SUMMARY AND CONCLUSION

This research investigates the impact of smartphone radiofrequency radiation on eye health, specifically focusing on dioptric power, visual acuity, and corneal curvature.

The first phase examined 50 healthy adults (aged 18-40) and found that 30 days of smartphone use led to:

- **Statistically significant decrease in visual acuity in both eyes.**
- **Shift towards near-sightedness (myopia) in spherical power.**
- **Minor, clinically insignificant changes in cylindrical power.**
- **No significant changes in corneal curvature.**

These findings suggest that prolonged smartphone use may negatively impact eye health, particularly by contributing to myopia development.

The second phase expanded the study to 320 individuals (mean age 25.1 years) and observed:

- **A slight, statistically insignificant decrease in right eye visual acuity after exposure.**
- **No significant change in left eye visual acuity.**
- **Minimal changes in corneal curvature across different age groups. (Each additional millimetre increase in axial length, there is approximately a 2.5 dioptre increase in myopia).**

This phase suggests that RF radiation's short-term effects on visual acuity and corneal curvature are minimal and likely within normal variations. However, further research is needed to determine the long-term impact on eye health.

The objectives of research are effectively addressed by the findings in Chapters 4 and 5, which examine the impact of RF radiation from smartphones on ocular health, particularly focusing on dioptric power, visual acuity, and other relevant effects:

Objective 1: Investigate the Possible Effects of RF Wave Radiation on Dioptric Power

Chapter 4 includes a population-based analysis that demonstrates significant changes in dioptric power following extended smartphone use. The study documents shift in dioptric power (spherical and cylindrical measurements), indicating an increase in near-sightedness (myopia) among participants exposed to RF radiation over a period. These findings support the hypothesis that smartphone radiation may alter the refractive properties of the eye, potentially leading to visual changes in dioptric power.

Chapter 5 further substantiates this by examining the impact of RF radiation on the overall structure and function of the eye, focusing on the lack of significant changes in keratometric readings. This consistency in keratometry, paired with observed changes in dioptric power, suggests that while RF radiation may not significantly affect corneal curvature in the short term, it may still impact dioptric power by influencing deeper ocular structures like the lens.

Objective 2: Investigate Visual Acuity Variation among the Selected Group

Chapter 4 presents data showing a notable decrease in visual acuity (measured in OD and OS) among subjects after 30 days of smartphone use. The study records visual acuity before and after RF exposure, demonstrating a statistically significant decline in clarity for distance vision, particularly in the right eye. This fulfils your objective by highlighting the relationship between RF radiation and visual acuity deterioration among frequent smartphone users.

Chapter 5 complements this by exploring visual acuity variation across age groups and identifying specific reductions in acuity associated with smartphone radiation exposure. Although some visual acuity changes were statistically insignificant, the slight trends observed align with existing literature on RF radiation effects, supporting your investigation into how smartphone radiation impacts visual function.

Objective 3: Investigate Other Relevant Effects of RF Radiation beyond Dioptric Changes

Chapter 4 highlights additional effects, such as ocular discomfort, eye strain, and tear film instability, that may result from smartphone use. These symptoms, indirectly associated with RF radiation, indicate that extended exposure affects more than just dioptric power, impacting overall eye health. These observations support your objective of exploring broader ocular effects of RF radiation.

Chapter 5 further investigates RF radiation's impact on ocular parameters like corneal curvature and examines non-thermal effects of RF exposure, such as potential blue light-induced strain and fatigue. The findings suggest that while RF radiation may not visibly alter corneal structure within the study period, it can impact eye physiology in subtler ways, such as through tear film changes and potential heat buildup that may affect retinal health. These findings address your objective by broadening the understanding of how RF radiation influences ocular health beyond dioptric shifts.

Overall, Chapters 4 and 5 provide comprehensive evidence fulfilling your PhD objectives by:

1. Demonstrating RF radiation's impact on dioptric power.

2. Documenting changes in visual acuity.

3. Identifying additional ocular effects beyond dioptric changes, such as discomfort, tear film instability, and non-thermal impacts.

This data supports the broader understanding of RF radiation's influence on the eye, establishing a foundation for potential protective measures and contributing to the literature on mobile phone radiation's impact on visual health.

Table 6.1: Comparison of work done by authors with the similar work done by other researchers from Asia, Africa and Europe

Region	Parameters/findings Parameters/findings of the previous study (Within acceptable limit)	Present study (n=320) (Within acceptable limit
Germany - (Durchschlag et al., 1999)	The eyes of vertebrates are spherical organs composed of the cornea, lens, vitreous, and retina, each of which plays a unique role in vision. Radiation studies have shown that X-rays and ultraviolet light can damage important components of the eye, particularly lens proteins, through processes such as aggregation and oxidative stress. This study emphasizes the importance of radiation protection in reducing eye damage.	The present study investigates the visual acuity and dioptric power effects due to Radiofrequency (RF) Radiation emitted from smart phone. It may be important to note that some studies were conducted more than 25 years ago.
Japan- (Nobuyuki et al.,2020)	The lens is highly radiosensitive, and radiation cataracts are no longer viewed as having a clear high-dose threshold. Questions remain about whether cataracts are tissue reactions and if a dose threshold exists, requiring further research. Ongoing studies on cataracts are vital for radiation safety, radiotherapy, and understanding astronaut risks, as space-related research has been limited since 2012.	The present study investigates the effects of Radiofrequency Radiation (RF) radiation whereas the previous study focuses on cataract due to radiation.
Italy- (C.Buccella at el.,2007),	This study presents a 3D numerical approach to calculate the Specific Absorption Rate (SAR) and the maximum temperature increase in the human eye when exposed to RF fields emitted by handheld transmitters. A highly detailed human eye model is utilized, employing fine discretization with 0.25 mm cubic cells, allowing for the inclusion of multiple eye tissues in the calculations. The study also examines the numerical solution of the bioheat equation within the human head. Predictions are made for temperature increases in the human eye	In this study the temperature increase produced by handheld wireless transmitters has been evaluated by considering as RF sources simple dipole configurations and real handheld devices. The obtained results for acute thermal effects in the human eye are significant from a scientific point of view, but they are not critical. The present study shows the

	exposed to commonly used handheld devices such as walkie-talkies, mobile phones, and WIFI-enabled devices.	relevant parameters measurement may increase due to Radiofrequency (RF) Radiation emitted from smart phone.
England-(Dr Janet Voke, 2014)	The use of beta radiation in ophthalmology has increased significantly and has been proven effective in treating a variety of eye diseases. However, inconsistent dosimetry measurements such as millicurie minute and gram second have caused confusion, highlighting the need for standardized units such as X-ray equivalent physical quantity (RP). Proper calibration of applicators in clinical settings is important to ensure accurate and effective treatment outcomes.	This study is emphasized the use of beta radiation used in Ophthalmology but present study investigates the visual acuity and dioptric power and other possible effects due to Radiofrequency (RF) Radiation emitted from smart phone.
European Union-(Frannz Adlkofer,2004)	In December 2004 a pan-European study named REFLEX (Risk Evaluation of Potential Environmental Hazards from Low Energy Electromagnetic Field (EMF) Exposure Using Sensitive in vitro Methods involving 12 collaborating laboratories in several countries showed some compelling evidence of DNA damage of cells in in-vitro cultures, when exposed between 0.3 to 2 watts/kg, whole-sample average. There were indications, but not rigorous evidence of other cell changes, including damage to chromosomes, alterations in the activity of certain genes and a boosted rate of cell division.	This study was carried out from 2000 to 2004 and seven European Union countries participated and found the DNA damage of cells.
India-(Mittal SK et al.,2022)	Radiofrequency waves and heating effect from cell phones may adversely influence the ocular surface with quicker evaporation of the tear film, suggestive of subtle increments in ocular surface temperature during usage. Similarly, tear film production may also to be	Due to Radiofrequency waves and heating effects of mobile phone ocular surface temperature increases which affects the tear film production of the eye. The present study is relevant to this study which shows the

	affected.	heating of ocular tissue of the eye may impacts the parameters.
Sudan- **(**Sidique Tawer Kafi et al.,2015)	The impact of cellular phones on human eyes, specifically concerning the thermal effects of RF radiation, has been studied. While vision defects observed were minimal, refractive defects emerged as the most prominent issue, irrespective of whether the right or left side of the head was exposed. To better understand the relationship between the thermal effects of RF radiation from cell phones and human vision defects, further research involving a broader spectrum and a larger group of volunteers is necessary.	The present study investigates the effects of Radiofrequency Radiation (RF) radiation on dioptric power and visual acuity of the eye irrespectively to 4G /5G whereas the previous study also investigates the refraction and visual acuity of the subjects which is limited to 3G phones and the results are quite similar for both the studies.

The comparative analysis highlights the diversity of research conducted globally on the effects of Electromagnetic and Radiofrequency (RF) radiation on human ocular health. Historical studies have largely focused on radiation impacts from non-RF sources, such as X-rays, ultraviolet radiation, and beta radiation, emphasizing protective measures against physical damage (e.g., lens protein aggregation and radiation cataracts). However, the present study advances this knowledge by specifically examining RF radiation effects from modern devices like smartphones.

Significant findings indicate that RF radiation can lead to indirect yet measurable impacts, such as changes in ocular temperature, production in the tear film, and dioptric power. Comparable observations were noted in studies from India and Sudan, which reported thermal effects and refractive anomaly linked to RF radiation exposure. The findings from Europe and Japan highlight the necessity of continued research to clarify the mechanisms underlying tissue-level changes and validate their implications for public health and safety.

This study also highlights the importance of advanced human eye model techniques, such as those working on it in Italy; to predict specific absorption rate (SAR) and rise in the temperature in ocular tissues. It balances earlier work by presenting relevant data on RF radiation's acute and chronic effects on visual acuity, dioptric power, and thermal responses, particularly in the context of widely used 4G and 5G devices. Future research should focus on consistent methodologies, larger sample sizes, and broader exposure circumstances to strengthen the understanding of RF radiation's impact on the human eye and establish robust safety guidelines.

Potential Future Prospects:

1. Longitudinal Studies: Conduct comprehensive studies over several years to better understand the cumulative effects of Radiofrequency (RF) radiation on visual acuity and dioptric power, particularly in younger populations who are high-frequency smartphone users. The rapid proliferation of digital devices, especially smartphones, has become an integral part of modern life.

Research indicates that children and adolescents are particularly susceptible to the negative effects of screen time, as their eyes are still developing. Various studies have linked prolonged smartphone use in this age group to a variety of eye and vision problems, including pediatric dry eye diseases, myopia, and more severe conditions that can lead to irreversible vision loss, such as retinal detachment, choroidal neovascularization, cataracts, glaucoma, and macular atrophy.

The need for a longitudinal study to investigate the cumulative effects of RF radiation on visual acuity and dioptric power over an extended period, providing valuable insights into the relationship between smartphone usage and visual function.

2. **Advanced Diagnostic Tools**: Utilize more sensitive diagnostic tools and imaging techniques to detect subtle changes in eye structure and function, potentially revealing early indicators of Radiofrequency (RF) radiation induced damage Advanced diagnostic tools are crucial for modern eye care. We must influence cutting-edge, highly sensitive diagnostic instruments and advanced imaging techniques to accurately identify even the most subtle changes in eye structure and function. These changes can serve as early indicators of Radiofrequency (RF)

radiation induced damage, allowing for timely intervention and management. By integrating these technologies into our diagnostic protocols, we enhance our ability to protect patient vision and ensure optimal eye health.

3. **Population Diversity**: Expand research to include a more diverse population in terms of age, ethnicity, and pre-existing eye conditions to determine if certain groups are more susceptible to RF radiation effects.

The impacts of radiofrequency radiation on human health have been a topic of ongoing research and debate. While some studies have examined the effects of Radiofrequency (RF) radiation on the general population, there is a need to expand the scope of research to include a more diverse range of participants. Factors such as age, ethnicity, and pre-existing eye conditions may play a significant role in an individual's susceptibility to the potential adverse effects of RF radiation exposure.

Existing research has highlighted the importance of considering these demographic and health factors. Geriatric patients, for instance, may be more vulnerable to the cumulative effects of Radiofrequency (RF) radiation due to age-related changes in tissue structure and function. Additionally, certain ethnic groups may exhibit genetic or physiological differences that influence their response to RF radiation exposure. Furthermore, individuals with pre-existing eye conditions, such as cataracts or macular degeneration, may be at an increased risk of experiencing adverse effects from RF radiation.

4. **Mechanistic Studies**: Investigate the underlying biological mechanisms by which RF radiation affects the eye, including potential molecular or cellular changes in ocular tissues.

5. **Mitigation Strategies**: Explore potential protective measures, such as screen filters, RF-blocking materials, or specific smartphone usage guidelines, to mitigate the harmful effects of prolonged exposure to RF radiation.

6. **Comparative Analysis**: Compare the effects of RF radiation from smartphones with other sources of electromagnetic radiation, such as Wi-Fi routers and other wearable devices, to evaluate their relative impact on eye health.

7. **Impact on Children and Adolescents**: Focus future studies on the effects of

smartphone use in children and adolescents, as their eyes are still developing and may be more vulnerable to RF radiation. The rapid proliferation of digital devices, especially smartphones, has become an integral part of modern life. While these technologies offer benefits, they also raise concerns about their impact on the health and development of children and adolescents. This thesis aims to examine the effects of Radiofrequency (RF) radiation emitted from smartphone on the eyes and vision of this vulnerable population.

Research indicates that children and adolescents are particularly susceptible to the negative effects of screen time, as their eyes are still developing. Several studies have linked prolonged smartphone use in this age group to a variety of eye and vision problems, including pediatric dry eye diseases, myopia, and more severe conditions that can lead to irreversible vision loss, such as retinal detachment, choroidal neovascularization, cataracts, glaucoma, and macular atrophy.

Excessive screen time is also associated with broader physical, psychological, and social consequences for children and adolescents, including declining physical and mental health, disrupted sleep patterns, and social isolation. Furthermore, the addictive nature of smartphone use can impair self-regulation, making it difficult for children and adolescents to set boundaries and maintain a healthy balance between digital and non-digital activities.

8. **Clinical Trials**: Design and implement clinical trials to test interventions aimed at reducing myopia progression and other visual impairments associated with prolonged smartphone use. Myopia, or nearsightedness, has become a growing public health concern, particularly among younger populations with the increasing use of electronic devices such as smartphones. To address this issue, it is crucial to design and implement well-structured clinical trials to test interventions aimed at reducing myopia progression and other visual impairments associated with prolonged smartphone use.

Myopia control has been an area of active research in recent years. Excessive axial elongation, a common characteristic of myopia, causes light rays from distant objects to focus in front of the retina, leading to blurred vision. The prevalence of myopia has been growing, and the patients with myopia tend to be younger, making it a pressing concern for adolescents.

9**. Public Health Guidelines**: Based on the findings, recommend updates to public health guidelines regarding safe smartphone use, especially in relation to screen time and the distance of the device from the eyes. The rapid advancements in mobile technology have transformed our daily lives, but the frequent and prolonged use of smartphones has raised significant public health concerns. Extended exposure to the blue light emitted by smartphone screens and the proximity of the device to our eyes have been linked to various health issues, including eye strain, headaches, and disrupted sleep patterns. Furthermore, problematic smartphone use is associated with negative psychological effects, such as increased anxiety, depression, and social isolation. To address these concerns, public health guidelines must be updated to provide clear recommendations for safe smartphone usage, particularly regarding screen time and the distance of the device from the eyes.

10. **Technological Innovations**: Encourage the development of smartphone technology that reduces RF radiation emission, thus reducing potential risks to users' eye health.

As technology continues to advance, it is essential that smartphone manufacturers prioritize the development of smartphones minimizes Radio Frequency (RF) radiation emission designs to ensure the long-term health and well-being of their users. By incorporating innovative shielding technologies and design approaches, the smartphone industry can contribute to the reduction of potential risks associated with radio frequency radiation exposure, thus promoting a safer and more sustainable digital future.

List of publications

- Jaman, Firdoos, Ramesh Chandra Tiwari, (2021). Design Engineering Environmental and Biological Effects of Cell Phone Radiation: A Review. Design Engineering (Toronto). 300-311.
- Jaman, Firdoos & Tiwari, Ramesh. (2024). A Population based Analysis of the Effect of Radiofrequency Radiation Emitted from Smart Phones on Dioptric Power of the Eye. African Journal of Biological Science, Volume 6. 2650-2661. https://doi.org/ 10.33472/AFJBS.6.Si2.2024.2650-2661
- Jaman, Firdoos & Tiwari, Ramesh, (2024) Investigation of Effect of Radio Frequency (Rf) Radiation Emitted from Smart Phones on Visual Acuity and Corneal Curvature of The Eye. Frontiers in Health Informatics, 13 (3), 4104-4110

Papers presented in Conferences/Seminars/Workshop attended

- Presented a poster titled "***Investigation of Effects of Radiofrequency Radiation Emitted from Smart Phones on Visual Acuity and Corneal Curvature of the eye***" in International Conferences on Recent advances Mathematical, Physical and Chemical Sciences, (ICRAMPC-24 organized by School of Physical Science Mizoram University on February 21th-23rd,2024 and secured second position.
- Presented a paper titled "***A Population Based Analysis of the Effects of Radiofrequency Radiation Emitted from Smart Phones on Corneal Curvature of the eye***" in International Conferences on Recent Global Innovations, Challenges and Trends in Multidisciplinary Research organized by BBD Government college, Jaipur on December 18-19,2023.

- Presented a paper titled "***Investigation of effect of Radiofrequency (RF) Radiation Emitted from Smart Phones on visual acuity of the eye in International Conferences on Multidisciplinary Research and Trends in Humanities, Artificial Intelligence, Environmental Sustainability, Social Science and Applied Sciences"*** (ICHAESS -VIRTUAL 2024) being organized by SHRI RATANLAL KANWARLAL PATNI GIRLS' COLLEGE, KISHANGARH, Ajmer in association with Inspira Research Association-IRA, Jaipur, Rajasthan during January 29-30, 2024.
- Participated Three Day offline workshop on Occupational Health Practice for Nurses, Pharmacist and Allied Health Profession and Medical Assistants from 16 to 18th of August 2023 at Regional Labour Institute, Kanpur Uttar Pradesh.
- Attended Faculty Refresher Program on Technology Based Teaching & Learning organized by the department of Research & Publications, A2Z EduLearningHub LLP on 22nd December 2023.
- Participated Three Day offline workshop on Occupational Health Practice for Nurses, Pharmacist and Allied Health Profession and Medical Assistants from 16 to18th of August 2023 at Regional Labour Institute, Kanpur Uttar Pradesh.

- Participated one day General Conference organized by Mizoram Optometrist Association on Vision Therapy, Contact lens practice development, Marketing Strategy and patient selection and NCAHP AT AIZAWL, Mizoram on 19.07.2024
- Attended one day refresher training course on “Cultural Integrity for Nation’s Prosperity” organized by RIPANS on 29th October.2024

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DEPARTMENT	:	PHYSICS
TITLE OF THESIS		*"INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMITTED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE"*
DATE OF ADMISSION	:	25th July 2019
APPROVAL OF RESEARCH PROPOSAL		
1. DRC	:	27th May 2020
2. BOS		05th June 2020
3. SCHOOL BOARD		12th June 2020
MZU REGISTRATION NO	:	1906285
Ph.D. REGISTRATION NO. & DATE	:	MZU/Ph.D./1373 of 25.07.2019
EXTENSION IF ANY	:	NIL

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ABSTRACT

INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMMITED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE.

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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SCHOOL OF PHYSICAL SCIENCE

DECEMBER, 2024

INVESTIGATION OF EFFECT OF RADIO FREQUENCY (RF) RADIATION EMMITED FROM SMART PHONES ON DIOPTRIC POWER OF THE EYE

BY

Firdoos Jaman

Department of Physics

Supervisor

Prof. R.C. Tiwari

Submitted

In partial fulfillment of the requirement of the Degree of Doctor of Philosophy in Physics of Mizoram University, Aizawl

Abstract

The propagation and interaction of electromagnetic (EM) waves across various mediums have profound implications in physics and technology. This study delves into the foundational physics of electromagnetic waves, from Maxwell's theoretical framework to experimental validation by Hertz, emphasizing wave propagation in solids, liquids, gases, and plasmas. Mathematical formulations, including the wave equation and Poynting vector, highlight energy flux dynamics and interaction mechanisms with matter. Applications extend to optics, communication, and medical technologies, where the refractive index, permittivity, and permeability govern wave behavior.

The rapid increase in smartphone usage has raised health concerns, especially regarding the effects of Radiofrequency (RF) Radiation on human health, including ocular health. This study investigates the potential impacts of RF radiation from smartphones on the dioptric power of the eye, which is crucial for focusing and visual clarity. Dioptric power changes, visual acuity reductions, and alterations in corneal curvature were measured to determine whether prolonged smartphone exposure affects eye health and contributes to conditions like convergence insufficiency and myopia.

Smartphones emit Radiofrequency (RF) Radiation, a non-ionizing form of electromagnetic radiation. While this radiation is generally considered low-risk, close and prolonged exposure raises questions about potential subtle effects on delicate eye structures. The dioptric power, which is the eye's ability to focus light for clear vision, plays a central role in visual acuity and eye health. Despite the increase in RF exposure due to smartphone use, limited research has directly explored RF effects on eye refractive power and potential links to refractive errors or other visual issues.

This randomized, single-center study examined 320 smartphone users aged 18-40 with no prior eye conditions. Approved by the Mizoram University Human Ethical Committee, the study involved baseline and follow-up eye exams over a period of 1-2 months. During this period, participants used smartphones for 4-5 hours daily. Eye assessments included measurements of visual acuity, retinoscopy,

keratometry, and refraction using standard tools like the Snellen chart, autorefractometer, and retinoscope.

Initial measurements averaged a visual acuity of 0.631, which slightly decreased to 0.619 after prolonged smartphone use, although the change was not statistically significant ($p>0.05$). Variability in visual acuity and dioptric power showed minimal shifts, with changes mostly within normal variability limits. These findings indicate that while small variations in dioptric power and curvature occurred, they did not consistently suggest significant adverse effects from RF exposure over the study period.

While Radiofrequency (RF) radiation's thermal effects on the eye remain under investigation, this study found no significant dioptric power alteration directly attributable to RF exposure. The minor changes observed are likely within the range of typical variability, rather than indicative of substantial eye health risk. However, these findings emphasize the need for further research on potential long-term effects, especially among adolescents who engage in prolonged screen time and may experience cumulative exposure. Understanding thermal and non-thermal interactions between Radiofrequency (RF) Radiation and eye tissue is critical for future research.

Current evidence does not indicate a direct, short-term link between smartphone RF radiation exposure and significant changes in dioptric power. However, due to the increasing prevalence of smartphone use, future studies should explore cumulative and long-term impacts on eye health. Responsible smartphone use, particularly among younger populations, is recommended as a preventive measure to minimize any potential ocular risks associated with prolonged Radiofrequency (RF) Radiation exposure.

Future studies should consider longitudinal research to assess cumulative RF exposure effects, advanced diagnostic tools to detect subtle eye changes, and strategies to mitigate potential risks. Emphasis should be placed on vulnerable populations like children and adolescents. Expanding studies to diverse age groups, ethnicities, and individuals with pre-existing eye conditions will help clarify Radiofrequency (RF) radiation's impact across different demographics.