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Original Research Article

Effects of static electromagnetic fields on sleep patterns: a cross-sectional study

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ABSTRACT

Background: Sleep is an important process of our body and a good sleep will lead to a healthy lifestyle. In medical field, students have sleep patterns changing due to heavy academic workload. This may have ill effects on their health. Though most factors that affect sleep are modifiable and treatment for them exists still there are can be many factors that affect sleep which should be explored. The thermal model of human body is a theoretical model that accounts for thermal effects of electromagnetic waves on a given point in human body. This could be easily affect brain as it has highest electrical activity in body and may lead to sleep related disorders.
Methods: This study is conducted on medical and dental students to analyse the amount of electromagnetic field they get exposed to and any changes in sleep patterns associated with it. The findings of medical and dental students are compared to see if changes in sleep patterns are due to professional course pursued. Any other confounding factors affecting this study are screened by self-rated Pacific Sleep Questionnaire.
Results: There were significant changes seen in the time taken to fall asleep and total sleep period but the time taken to wake up from sleep remained unaffected. The sleeping habits of medical and dental students showed no significant changes.
Conclusions: Static electromagnetic fields have significant impact on sleep onset and sleep duration. This is regardless of academic background.

Keywords: Electromagnetic fields, Pacific sleep questionnaire, Thermal model

INTRODUCTION

Sleep is a vital physiological process. An average human needs at least 7-8 hours of uninterrupted sleep in a day in order to carry out his day to day activities perfectly. The sleeping habits and patterns vary vastly from profession to profession. In medical community heavy workload and stress that accompanies it leads to countless nights without sleep.

Cognition and other higher brain functions are affected by lack of sleep. In a country like India where there are poor health standards in most places and high prevalence of diseases, it is vital for any medical personnel to stay mentally fit. This is necessary to improve the health standards of the country. There can be many factors both physical and mental that can grossly affect the sleep of the patient. There are drug regimens available to take care of all these factors and all of them have proven effective to treat sleep disorders in a wide variety of population. Sleep disorders are common in medical students and a preventive approach can be useful in reducing the incidence of these disorders. Ignorance about sleep disorders and its harmful effect on health is common amongst both undergraduate and postgraduate students leading to an unhealthy lifestyle.[1]

In an era of technological advancement and scientific progress we are surrounded by a large hub of wireless networks that are constantly sending electromagnetic waves all around us. Maximum amount of electrical activity takes place in the brain as compared to any other part of the body. This makes it more susceptible to any deviation from its physiological function. Overall in a day an average person gets exposed to virtually all frequencies of electromagnetic waves. Thus it is almost impossible to determine the total electromagnetic waves that a person gets exposed to in a day. What remains constant is the radiation exposure during night time as the person is stationary in home and is exposed to limited number of devices that transmit electromagnetic waves. Thus effect of these limited electromagnetic fields in the close vicinity of person can be more accurately studied than the random fields exposed to an individual during daytime.

As sleep is one of the major physiological processes of central nervous system in night time it serves as a reliable indicator to study the effects of electromagnetic fields.

Medical students perfectly fit in the strata of population as they are having both good interactions with advanced technological devices and need to have a good night sleep in order to function properly. Most of them belong to an age group where health problems and comorbidities are minimal. This lowers the chances of any confounding factors that can affect the sleep of an individual. Any retrospective or prospective studies conducted can take a lot of time and be quite cost effective. A simpler way is to conduct a cross sectional study assessing the current status of the population.

A cell phone can be doing a variety of function ranging from downloading data to GPS coordinating. This results in a random amount of electromagnetic waves, but when a device is kept in close proximity to the individual, the major wave incident on the body are due to a static field generated by the device. This is unique for every device and remains constant for a short distance (approximately 1 meter) beyond which it decreases gradually. This decrease depends on the transmissions sent and received by processes going on in the device.[2] The constant electromagnetic field is calculated by the phone manufacturer and stated along with all the device specifications as SAR (specific absorption rate). SAR is the amount of radiation absorbed by a unit mass of tissue for a certain period of time. This is calculated separately for the head and the body as the head is having more electrical activity and stays in close proximity to the device during usage than any other part of body.

The most widely accepted hypothesis is the thermal model of human body which tells the change in temperature in unit time per unit volume of tissue in the body as a result of incident electromagnetic wave. This is given by the following equation.

$$\nabla \cdot (K(r)\nabla T) + A(r,T) + Q_v(r) - RL(r) - B(r,T)(T - T_B) = C(r)\rho(r)\frac{\partial T}{\partial t}\left[\frac{W}{m^3}\right]$$

In the given equation:

- r = a point in the body
- T= temperature at point r {°C}
- K= conduction of heat by body tissues {J/(s·m·°C)}
- A= heat produced by cellular metabolism {J/(s·m^3)}
- Q_v = electromagnetic power deposited on tissue {J/(s·m^3)}
- RL= heat lost to respiration {J/(s·m^3)}
- B= heat lost by blood flow {J/(s·°C·m^3)}
- T_B = temperature of blood {°C}

The value of SAR is calculated considering all these parameters and that of a certain point in the body is stated as:

$$SAR(i,j,k) = \frac{\sigma(i,j,k)\left[\hat{E}_x^2(i,j,k) + \hat{E}_y^2(i,j,k) + \hat{E}_z^2(i,j,k)\right]}{2\rho(i,j,k)}$$

Where σ and ρ are overall conductivity and density of tissue respectively.[3]

Now during sleep, the major electrical activity takes place in thalamus, pineal gland and pituitary gland which happen to have very rich network of capillaries including pituitary-hypophyseal portal system. This correlates to the two of four major variables in thermal model of human body. So sleep can be susceptible to changes under influence of an electromagnetic field.

On exposure to 0.25-0.8 pulsed radiofrequency, there were changes seen in the EEG slow wave pattern and direct effect was noted on sleep duration and waking up from sleep on 16 participants.[4] Tough EEG can tell about the electrical activity in brain it has poor spatial resolution and cannot perfectly detect changes in thalamic nuclei. It is a useful tool to study sleep architecture on acute and constant exposure but on chronic exposure there can be gross changes in sleep patterns which will be evident on study of a large population with varied exposure in each.

The thermal model of human body as described above readily explains the changes that occur in the body. To see its action on sleep, a lot of studies were conducted. A cross sectional study done by Liu H, et al, on a population that was exposed to high amount of fields for long time showed very poor sleep quality but it considered only 4 to 5 confounding factors.[5] A typical phone signal has about 900 MHz frequency but in a study conducted by Altpeter E, et al, on exposure to only 6-22MHz of frequency there was 15% drop in the salivary melatonin levels.[6] Change in melatonin levels shows that there is a significant effect of electromagnetic field on pineal gland function. When a study was conducted on a 902 MHz carrier frequency with 217 Hz wave modulation by Curcio G, et al, there was increase in the spectral power of EEG.[7] Lustenberger C, et al, on doing a clinical trial with 900MHz frequency showed changes in spindle pattern, δ waves and θ waves coming from thalamus signifying changes in stage 1 to stage 3 of sleep in a laboratory environment but they were unable to reproduce these results.[8] Awake patients showed mild spikes in alpha rhythm indicating a poor attention in study by Croft R, et al.[9] This confirms that other aspects of thalamus involved in higher functions are also affected.

It is still unclear what changes take place on a cellular level studies show that they do have an impact on brain function. When electromagnetic field incident by a cell phone during talk mode is exposed to human brain, there is delay in sleep onset as compared to any other mode according to EEG changes recorded by Hung C, et al.[10] When electromagnetic waves were incident intermittently every 15 minutes by Borbély A, et al, the sleep period overall increased and total time taken to wake up from sleep also increased.[11]

When a specific pattern of electromagnetic waves was incident on subjects for the whole sleep duration, on waking up they were able to perform better at cognitive tasks and showed a good sleep quality according to Lustenberger C, et al, and EEG changes were seen in slow wave activity.[4] On exposure to 50Hz/1µ tesla field by Åkerstedt T, et al, there was less sleep duration, efficiency, stage 3 and stage 4 slow wave sleep and activity.[12] There was increase in sleep onset, but none in sleep period or on waking up from sleep but the spindle frequency varied with the dose of radiation to which participants were exposed by Regel S, et al.[13] When the standard 900MHz frequency was incident during sleep, rapid changes in EEG were observed and effect on waking from sleep was significant in study done by Huber R, et al.[14]

Studies no change in overall sleep pattern of the patients but changes were noted in the waveforms of EEG. Schmid M, et al, showed that rather than 217Hz pulse modulation, a 14Hz modulation increases the frequency of spindle waveforms in stage 2 of sleep.[15] The slow spindle range also changed on 1930-1990MHz frequency exposure as concluded by Lowden A, et al.[16] This is confirmed by Loughran S, et al, who found that EEG changes are separate for every individual and cannot be unified for the whole population.[17] Regardless of any specific frequency both pulsed and pulse-modulated electromagnetic waves will have a grossly different and variable action on spindle waves, θ waves, δ waves and α waves as seen on EEG by Schmid M, et al.[18]

The changes in spindle wave patterns occur uniformly in both left and right hemispheres of brain regardless of the direction of incident wave and may outlast the exposure time as seen by Huber R, et al.[19] No changes were noted due to pulse modulated electromagnetic fields on any of the sleep architecture by Huber R, et al, but on doing positron emission tomography during sleep, it was evident that there is increase in the cerebral blood flow of dorsolateral prefrontal cortex of left hemisphere.[20]

A slight variation of above studies was done where purely magnetic fields were incident on the subjects and there were no changes at al, in sleep according to Tworoger S, et al.[21] A prospective cohort study was conducted by Mohler E, et al, was unable to find any evidence of effect of electromagnetic fields on sleep of healthy individuals.[22]

In all the studies conducted, there were variations in frequency of electromagnetic waves and various pulse modulations were done as a part of clinical trial or a prospective study. But the total SAR incident remained more or less the same in order to mimic a mobile phone radiation. In this study all participants get radiation incident on them from their own device so we can find a correlation between variable radiation exposed and variable sleep schedules. The studies were conducted in a laboratory environment but compared to that a household environment is more convenient for patient.

Due to complicated study designs, the sample size of these studies was very limited and not be sufficient to generalise for whole population. A novel idea adopted by the investigators in almost all the studies included a habituation or accommodation phase where the participants get familiar to study design and sleep in laboratory condition. During this they were monitored for any confounding factors that may affect any of the aspects of sleep. This has a high probability of missing out on any confounding factors as most accommodative phases lasted for 1 day. This is compensated by the Pacific Sleep Questionnaire.[23]

Where authors can screen for any incidence of confounding factors and exclude the subjects that have either severe intensity or high occurrence. All the studies done above have the participants exposed to the electromagnetic waves prior to sleep and a resting period was given between the exposure and onset of sleep or they were exposed intermittently. But in a practical scenario, people are exposed to electromagnetic fields from the time before they fall asleep to long after they wake up from their sleep. Thus there is a huge change in the total electromagnetic waves incident on brain of subjects in laboratory conditions and real-world scenario.

METHODS

Cross sectional study was performed at tertiary health care hospital during 1st June 2019 to 30th July 2019. The sample size of study was 100 (50 MBBS and 50 BDS students) undergraduate medical and dental students.

Inclusion criteria

- Subjects willing to take part in study.
- Subjects who keep their cell phone less than 1 meter from their head while sleeping as the electromagnetic radiation from cell phone is constant in that distance.

- Subjects who scored less than or equal to 3 in all parameter of Pacific Sleep Questionnaire.[23]

Exclusion criteria

- Subjects with any sleep disorders.
- Subjects with multiple cell phones kept less than 1 meter from head as it may have a variable effect on total amount of radiation incident on head.

After getting approval from institutional ethics committee, and informed consent taken from all the participants, they were given smartphone usage questionnaire (Form A) to see radiation exposure and pacific sleep questionnaire for sleep patterns and confounding factors that may affect sleep.[23]

Statistical analysis

Total radiation absorbed by the brain tissue was calculated as:

$$total\ radiation = SAR \times time(in\ seconds)$$

Radiation exposure was separate for sleep onset, sleep period and waking up from sleep. This was correlated with duration of each phase using t-test with level of significance 0.05 and Karl-Pearson correlation coefficient was calculated. Comparison between MBBS and BDS students' sleep patterns was done by calculating mean of values and doing t test in EPI Info Software version 7.

RESULTS

Respondents' profile

In MBBS students 30%(n=15) were male and 70%(n=35) were female while among BDS students 14%(n=7) were male and 86%(n=43) were female so overall the study had 22%(n=22) male and 78%(n=78) female participants. Overall the study had 64%(n=64) day scholars and 36%(n=36) hostelites out of which in MBBS students there were 74%(n=37) day scholars and 26%(n=13) hostelites. There were 54%(n=27) day scholars and 46%(n=23) hostelites out of all BDS students. The average age of whole population is 20.66±0.76 years while that of MBBS students and BDS students was 20.66±0.65 years and 20.66±0.76 years respectively. The average weight of study participants is 59.84±13.88 kgs out of which MBBS and BDS students have average weights of 61.78±12.58 kgs and 57.9±13.88 kgs respectively. MBBS students have average height of 1.64±0.07 and BDS students have average height of 1.61±0.09m, thus the average height of study participants is 1.63±0.09m. From the above data we can decide that the average BMI (body mass index) of whole population is 22.47±5 kg/m^2 out of which MBBS students had average BMI of 22.72±4.06 kg/m^2 and BDS students had 22.21±5 kg/m^2.

Effect of electromagnetic field on sleep

The time taken to fall asleep was significantly affected by total electromagnetic field exposed at that time as p=0.000932895 ($p<0.05$) and KP was 0.708470673. There were significant changes seen in the overall sleep period as p=0.001169923 ($p<0.05$) and KP was 0.332688938. The changes in the time of waking up from sleep had no significant effect as p=0.551790679 ($p>0.05$) and KP was 0.89934543. Thus we can say that electromagnetic waves affected the sleep onset and duration of sleep of this study population.

Sleep patterns of dental and medical students

In this study we found that the average time to go to sleep for this study population was 23:10±0.466866773 hrs out of which MBBS students slept around 00:13±0.464376 hrs and BDS students slept at 10:08±0.465326 hrs but overall no significant difference was found between them as p value was 0.358363046 ($p>0.05$). MBBS students woke up at 7:03±0.055941 hrs while BDS students woke up at 06:55±0.039531 hrs which is quite similar to MBBS as P value was 0.610527028 ($p>0.05$) and overall time of getting up was 06:59±0.048500072 hrs. MBBS students got a total sleep of 7.33±1.440868 hrs and BDS students got about 7.27±1.001049 hrs of sleep. The overall sleep period of this study population was 7.30±1.240967365 hrs. No significant change was observed between MBBS and BDS students for that as p value was 0.809440224 ($p>0.05$). The study population on an average took 0.4688±0.432558158 hrs to fall sleep out of which MBBS students took 0.4526±0.43856 hrs and BDS students took 0.485±0.425856 hrs. On comparing them, the difference in onset of sleep is almost same as p value is 0.708653954 ($p>0.05$). During their regular sleep, on an average the study participants woke up for 0.93±1.032036821 times. MBBS students woke up for 0.78±0.851625 times while BDS students woke up for 1.08±1.180508 times which is almost same as p value is 0.145032987 ($p>0.05$). To wake up from sleep, the study participants took approximately 0.3407±0.5584344513 hrs MBBS students took about 0.4172±0.771909 hrs and BDS students took 0.2642±0.274533 hrs which is not different as p value is 0.189748158 ($p>0.05$).

From the above data we can conclude that sleep patterns are not changed by the professional course pursued by students, the changes in sleep pattern is the electromagnetic field coming from cell phones of the participants.

DISCUSSION

Sleep is a complex physiological process but in this study for the sake of simplicity we divided this into 3 phases. These were period of sleep onset, total sleep duration, and transitive phase from sleep to awake state (i.e. waking up from sleep). Due to variable duration of each phase, the brain tissue absorbed different amount of radiation in each phase thus causing a different effect to each phase.

In this study we found that there were significant changes in sleep onset indicating a strong correlation between sleep onset period and radiation exposed during that phase. Hung C, et al, also found a significant delay in sleep onset as detected on EEG when mobile phones were kept in talk mode for 30minutes before going to sleep.[10] This was also confirmed by Regel S, et al, who concluded that sleep onset increased with dose of radiation given to the subjects.[13] Huber R, et al, conducted a study seeing changes in cerebral blood flow and EEG by pulse modulated waves and found no significant changes in sleep onset.[20] In a prospective cohort study done in a span of one year by Mohler E, et al, where they studied self-rated changes in sleep patterns of patients, there was no change in onset of sleep seen.[22]

The total duration of sleep was significantly affected by the electromagnetic waves. The duration and efficiency of sleep was also reduced in a study conducted by Akerstedt T, et al, who exposed the study population to a wave of 50 Hz.[12] Similar results were obtained during the Schwarzenburg shut-down study conducted by Altpeter E, et al, where there was reduction of sleep quality by 3.9 units per mA/m increase in field.[6] Schmid M, et al, conducted a comparative study to see if pulsed magnetic fields have more impact or pulse modulated electromagnetic fields on sleep. They found changes in EEG waveforms but grossly there was no change in the sleep pattern overall which is opposite to the findings of this study.[18] Another study conducted by Danker-Hopfe H, et al, showed that fields from mobile phone have no significant impact on macrostructure of sleep.[24]

This study showed that exposure to electromagnetic fields had no significant changes in waking up from sleep. Consistent with this findings when purely magnetic field of 0.41-1.21 µT was incident on the study population in 15 minute intervals by Tworoger S, et al, there was no significant change in waking up from sleep.[21] This was also confirmed in a study by Lowden A, et al, where they exposed the subjects for 3 hours before going to bed.[16] When Borbély A, et al, exposed their subjects to 900MHz radiation overnight in a specific pattern, the waking up after sleep was significantly reduced.[11] Similar findings were found in a study conducted by Huber R, et al, where subjects were exposed to same amount of radiation intermittently during sleep leading to a reduced waking from sleep.[14]

Due to very different study design, experiment setup, type and duration of exposure and the study population, variations are seen between the results of all these studies.

Based on the results this study, we can conclude that on exposure to electromagnetic waves significantly affects the onset of sleep and whole sleep period in young age group. This is consistent with the thermal model of human body. No impact is seen on the period of waking up from sleep. The sleep patterns of both medical and dental students are same.

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ANNEXURE

Form A: Smartphone questionnaire.

Smartphone usage questionnaire

Age: MBBS/BDS (tick appropriate response)

Sex: Day-Scholar/ Hostelite (tick appropriate response)

Weight:

Height:

SAR value as provided by Cell phone Company:

Distance from bed:

Number of cell phones kept close to head during sleep: