Original Article

Bedroom Design Orientation and Sleep Electroencephalography Signals

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Abstract

Background: Orientation is a significant factor in architectural design that may affect well-being. Body direction does not change during sleeping, and sleeping is sensitive and affected by environmental factors. **Aims:** This neuroarchitecture study aimed to assess the effects of bed orientation on sleep quality to enhance bedroom design. **Materials and Methods:** To do so, the effects of earth's electromagnetic field (EMF) on sleep electroencephalography (EEG) signals were evaluated using signal processing techniques. In this cross-sectional study, a total of 21 healthy volunteer participants slept for two consecutive naps, at two rooms with identical interior design and different bed orientations, toward and against earth's EMF in a sleep clinic. **Statistical Analysis:** In this experiment, discrete wavelet transform extracted five subfrequencies of EEG data as delta, theta, alpha, $beta_1$, and $beta_2$. In addition, the energy signals were computed by measurement of wave frequencies. The mean total sleep time was 1.63 h in North–South (N-S) earth's EMF orientation and 1.38 h in the other direction. **Results:** *t*-test results showed significant changes in delta, theta, and alpha frequencies in terms of bed orientation. There was a significant result in the alpha energy ratio over the whole signal energy. Furthermore, there were increases in the average energy of delta, theta, and alpha bands in N-S versus East–West (E-W) bed directions. **Conclusions:** This study indicated that sleep in N-S direction could be more beneficial than E-W and the sleep EEG signals can be sensitive to earth's EMF. The results show the importance of considering orientation in bedroom design and its benefits on inhabitants' well-being.

Keywords: Bedroom design, earth's electromagnetic field, neuroarchitecture, sleeping orientation

Introduction

The built environment has some effects on human's physical and mental well-being.[1] Improvements in housing can enhance well-being and the quality of life. Issues of the design layout in houses have been shown to affect inhabitants, for example, the high rise can cause psychological distress,[2] different interior forms can affect stress and emotion,[3] and bedroom design style affects comfortability and pleasantness.[4] Other lines of evidence suggested that orientation can have some effects on inhabitants' health and well-being.[5]

Orientation is one of the design factors that most were the subject of energy studies. Usually, a compromise between building's function and location and the environmental factors of heat, light, humidity, and wind as well as religious and practical issues in some regions are the issues for building orientation.[6] Furthermore, there are some methods in east architecture to orient the building[7] that may increase inhabitants' well-being,[8,9] especially the bedroom orientation.[10] Overall, the effects of the building orientation on well-being have not been proved yet. Hence, this study tried to assess it in neuroarchitecture field to see the effects of orientation on inhabitants' brain dynamics. Neuroarchitecture is a new field that is focused on the neural effects of the built environments and users.[11,12] Studies showed that the different spaces of daily life can change brain dynamics and behaviors.[13] Recent studies using electroencephalography (EEG) and functional magnetic resonance imaging in architecture,[14] interior design,[4,15] and urban design[16] indicate the usage of neuroscience in architecture. As one-third of our lives are spent sleeping[17]

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and the body direction does not change during sleeping in the bedroom, bedroom orientation is chosen to examine its effects on brain dynamics and sleep quality in this study.

Orientation related to the earth's electromagnetic field (EMF) is the one that can influence a human's life like an animal's migration or bird's nest.[18,19] Studying on cattle and deer showed that they align their body axes in a roughly North–South (N-S) direction for grazing and resting.[18] In addition, the effect of EMF on mood and behavior was studied.[20] Another study showed that those who were instructed to sleep with head in south direction for 12 weeks had the lowest systolic blood pressure, diastolic blood pressure, heart rate, and serum cortisol.[21]

Specifically for the field of sleeping, ample of evidence suggest that EMFs can affect sleep. Besides, spectral analysis revealed qualitative alterations of the EEG signal during rapid eye movement (REM) sleep with an increased spectral power density that the alpha frequency range was mainly affected.[20] Furthermore, another research regarding orientation and sleep indicated that the REM latency is shortened in the East–West (E-W) direction during sleep compared to the N-S position.[22] There were statistically significant differences in the EEG of normal individuals, depending on whether the individuals sit facing the N-S or E-W direction.

Limited evidence exists regarding the effect of bed orientation on sleep parameters and quality of sleep. This study aimed to assess the differences between sleeping toward or against earth's EMF on sleep EEG to shed new light on orientation in architectural design and enhancing the bedroom design quality. Bedrooms are ruled by bed size and its location[23] that orientation is part of it. This study tried to achieve better residential design solutions by scientific evidence, especially for small apartments, which inhabitants do not have the opportunity to change the bed orientation. Furthermore, it can be useful in a hotel and hospital designing that room orientation has a significant effect on the whole design. Thus, we designed a study to compare bed orientation in terms of EEG signals in two similar bedrooms at a standard sleep clinic.

Materials and Methods

A total of 94 volunteer individuals were evaluated to participate in the current study. A written informed consent form was obtained from all eligible study participants. The study was approved by the Ethical Committee of Tehran University of Medical Sciences. The participants with a history of sleep problems, taking alcohol or smoking, and problems with recorded polysomnography were excluded from the study. Participants were completely evaluated regarding sleep problems using validated sleep questionnaires including the Stanford Sleepiness Scale, Epworth Sleepiness Scale, STOP-BANG questionnaire, Pittsburgh Sleep Quality Index, and Insomnia Severity Index. Participants were advised not to use caffeine at least 4 h before the test. Furthermore, they did not use any drugs affecting sleep. The beds were positioned in two different directions: N-S, in the direction of the earth's EMF, and E-W, perpendicular to the earth's EMF [Figure 1]. The rooms were equipped identical ones standardized for light and acoustic characteristics; room dimensions were 3.0 m × 4.0 m × 2.8 m (W × L × H). Participants were divided into two groups: N-S orientation with six male and five female participants and E-W orientation with six male and four female participants. Participants of the two groups were asked to sleep for two consecutive afternoon naps. The duration of each nap was 1 h and 30 min on average, and after 24 h, participants of each group underwent a second nap. The two groups were then compared regarding sleep EEG characteristics.

In the day of the first nap, participants attended in the sleep clinic around 12:30 PM. After having lunch, EEG electrodes were installed and they prepared for sleeping around 1 PM. Participants were told to sleep as much as they wanted.

Polysomnography was recorded by Embla device (N7000 version) at Baharloo Hospital, a sleep clinic. Sleep signals were recorded according to 10–20 standards with ten channels monopolarly with reference to both mastoids. Channels included C3-M2, C4-M1, Cz-M1, F4-M1, F3-M2, Fz-M1, T3-M2, T4-M1, O2-M1, and O1-M2. Two channels for electrooculography and two for chin were used to record signals. Sleep scoring was performed according to the American Academy of Sleep Medicine (AASM guideline 2007) by a trained sleep physician. Frequency sampling and impedance check were adjusted 200 Hz and 10 KOhm, respectively.

To extract delta, theta, alpha, $beta_1$, and $beta_2$ frequency bands, discrete wavelet transform (DWT) was used. First, signals were filtered by 32 Hz low-pass filter, Chebyshev type 2 with order 16. This infinite impulse response filter makes phase distortion – this distortion eliminated by applying zero-phase digital filtering by processing the input data in both forward and reverse directions.[24]

Signals were divided into 30-s windows, and then, DWT with Daubechies mother wavelet with order 10 (db10) was applied on the signals. The signals were divided into seven bands based on their frequencies and then the energies were calculated. The specific bands were delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), $beta_1$ (16–24 Hz), and $beta_2$ (24–32 Hz). Furthermore,

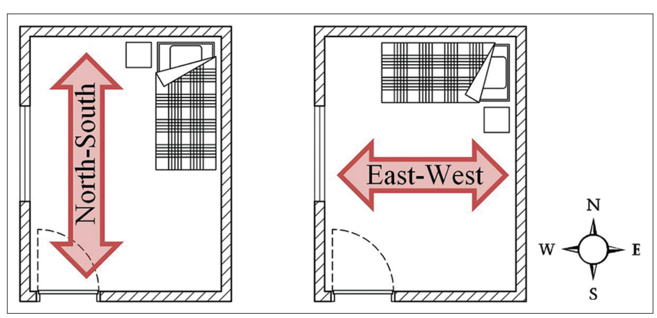

Figure 1: Two similar rooms with different bed orientations. Left: toward the electromagnetic field, Right: against electromagnetic field

the spindle and K-complex frequency ranges were (8–16 Hz) extracted. All these energy bands were calculated and normalized between 0 and 1. Recorded data were analyzed using (The Mathworks, Inc., Natick, MA, USA) MATLAB software version 2014. $P < 0.05$ was considered statistically significant.

Results

A total of 94 participants were entered for primary evaluation in this study and 73 were excluded due to underlying sleep problems and/or technical problems of recorded EEG; among them, 21 participants had eligible data for final analysis. The mean age of participants was 23.5 years.[21-25] Signals were recorded and the average energy of specific bands extracted. *T*-test was used to compare the results of N-S and E-W orientations, which is represented in Table 1. Table 2 represents energy ratio (ER) bands such as delta ER over delta and theta energies, theta ER over delta energies, and alpha ER over delta and theta energies calculated in average, to assess the significance of differences between these two groups. The mean total sleep time was 1 h and 38 min in earth's EMF (N-S) orientation and 1 h and 23 min in the other group.

The percentage of alpha, delta, and theta signal activity ratio to total energy showed that they have significant results in *t*-test according to the EMF [Table 2] ($P = 0.006$, 0.007, and 0.01, respectively). In addition, the only significance frequency band ER over the whole signal energy was alpha ($P < 0.05$).

The REM latency and slow-wave sleep (SWS) latency increased toward the EMF, but it was only significant for the REM latency ($P < 0.04$). The number of arousals and awakenings during sleep increased significantly in the E-W orientation ($P < 0.01$).

For the E-W orientation, the time for the second sleep stage and SWS decreased, but the *P* values were not statistically significant ($P > 0.05$). Furthermore, the whole period of sleeping time decreased for the E-W orientation ($P < 0.001$).

Discussion

The current results provided evidence that sleeping toward N-S direction or toward earth's EMF could improve sleep quality. The results could be used in the design of bedrooms subsequently. Sleeping toward the EMF (N-S) influenced alpha and delta signals of sleep. The average of energy bands increased in the N-S orientation, especially in terms of alpha and delta signals.

The length of the time that a person was in bed to the whole time of sleeping is defined as sleep efficiency.[25] The alpha signal affects sleep quality; thus, the length and depth of each sleep stage can change by alpha alterations.[26] The present findings showed more awakening and arousals in E-W direction which subsequently increases alpha changes and decreases sleep quality. However, Ruhenstroth-Bauer *et al.*

Table 1: Signal's energy of North-South and East-West bed-oriented groups

Signal energies	Frequency range (Hz)	Normalized average energy N-S orientation	Normalized average energy E-W orientation	*P*
Delta	0-4	0.6905	0.9892	0.007**
Theta	4-8	0.6088	0.2792	0.006**
Alpha	8-12	0.6811	0.2893	0.010*
$Beta_1$	16-24	0.5257	0.2742	0.083*
$Beta_2$	24-32	0.5215	0.1394	0.185*
Spindle and K-complex	8-16	0.4922	0.2445	0.016*

*Statistically significant at $P<0.05$; **statistically significant at $P<0.01$. N-S: North-South, E-W: East-West

Table 2: Different ratio of the signal's energy in terms of North-South and East-West directions

Signals energies	Frequency range (Hz)	Normalized average energy N-S orientation	Normalized average energy E-W orientation	*P*
Alpha/(delta+theta)	Alpha ratio to delta and theta	0.8685	0.6425	0.412*
Delta/(theta+alpha)	Delta ratio to theta and alpha	0.6149	0.3144	0.008**
Theta/(delta+alpha)	Theta ratio to delta and alpha	0.4615	0.8545	0.289*
Alpha/total energy	Percentage of alpha activity	0.8673	0.7195	0.022*
Theta/total energy	Percentage of theta activity	0.3669	0.8460	0.251*
Delta/total energy	Percentage of delta activity	0.4713	0.7119	0.272*
Spindle and k-complex/total energy	Percentage of spindle and k-complex activity	0.4713	0.6889	0.272*

*Statistically significant at $P<0.05$, **Statistically significant at $P<0.01$. N-S: North-South, E-W: East-West did not report significant different arousals and awakenings in the two sleep directions (N-S vs. E-W; Ruhenstroth-Bauer, 1987). Different methods of the two studies (daytime nap in present study vs. night sleep in the aforementioned study) may interpret the different results. The other explanation of the different results in terms of arousals and awakenings and/or other sleep parameters between these two studies may be the number of studied EEG channels. In the current study, more EEG channels were studied and the evaluation of sleep studies was performed by a trained sleep physician manually; thus, the number of detected arousals and awakenings could be more compared to the study by Ruhenstroth-Bauer *et al*.

Moreover, in this research, REM latency of participants increased during sleeping in N-S direction. Consistent with this study, Ruhenstroth-Bauer *et al*. indicated shortened REM latency in E-W direction. This evidence confirms Ruhenstroth-Bauer's assumption that the geomagnetic field influences human sleep EEG depending on the sleeping orientation (N-S vs. E-W).

Participants in the E-W group had decreased total sleep time comparing to the ones slept toward the geomagnetic field. Shortened sleep for a long period negatively affects data processing (decoding) during the sleep.[27-30] Thus, designing bedrooms in which beds are oriented toward earth's EMF may be associated with improved sleep and a higher quality of life. More investigation in standard equipped sleep laboratories with manual analysis of sleep EEG by experts is warranted and recommended for future studies. Although improving sleep without medical intervention and just by changing bed orientation with the least complication and investment when compared with medical interventions seems more sophisticated, this study shows the importance of considering orientation as a factor that can influence well-being. Using and implementation of neuroarchitecture is a new evolving research area that needs more elucidation in the field of sleep medicine. As such, interventions in architecture may be used for the treatment of different sleep disorders or as preventive measures in the sleep medicine world. Available data regarding the effects of bed orientation in the treatment of sleep disorders or as preventive measures are lacking and require more elucidation and interdisciplinary collaboration.

The present findings also indicated that the participants who were in the N-S orientation had more K-complexes and spindles, but only the increase of spindles was significant. Furthermore, the energy of specific bands extracted and studied and the results show that the changes can be because of the orientation toward the EMF during the sleep. This finding is not reported by Ruhenstroth-Bauer *et al*. study. Although the methods and time of sleep studies were different, apparently more EEG signals and manual analysis by a sleep physician could represent more accurate findings in terms of sleep stages and number of detected sleep spindles and K-complexes.

Conclusions

The present study findings provide evidence that bed orientation influences sleep EEG signals and sleeping toward the EMF (N-S) can have some positive effects on the sleep EEG. The results can be used to enhance bedroom design. Further investigation in this field and also the influence of geomagnetic field in the prevention and treatment of various sleep disorders are recommended.

This study sheds new light on the importance of orientation and its effect on brain dynamics. It is one of the first studies in neuroarchitecture that used sleep EEG for bedroom design. Unlike many neuroarchitecture studies, the results of the current study are practical. According to the limitations of this study such as region of the experiment, age, and the number of participants, further studies with more sample size are required to recommend some principles and rules for improving bedroom design and having better sleep. Furthermore, the lack of similar studies in EMF and sleep EEG in healthy individuals is another important limitation of the current study.

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Conflicts of interest

There are no conflicts of interest.

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