JEB®
Journal of Environmental Biology
p-ISSN: 0254-8704 • e-ISSN: 2394-0379 • CODEN: JEBIDP
Journal website : www.jeb.co.in ★ **E-mail :** editor@jeb.co.in
Triveni Enterprises
(Educational Services Set-up)

Original Research

DOI : http://doi.org/10.22438/jeb/43/3/MRN-1807

Determination of short-interval time estimates in humans exposed to radiofrequency electromagnetic radiation

P. Chandel[1], M.M. Singh[1], A.K. Pati[1,2,3], V. Choudhary[4] and A. Parganiha[1,2]*

[1]School of Studies in Life Science, Pandit Ravishankar Shukla University, Raipur–492 010, India
[2]Center for Translational Chronobiology, Pandit Ravishankar Shukla University, Raipur–492 010, India
[3]Professor Emeritus at Kalinga Institute of Social Sciences – Deemed to be University, Bhubaneswar–751 024, India
[4]Regional Cancer Center, Pt. Jawaharlal Nehru Medical College, Dr. B.R. Ambedkar Memorial Hospital, Raipur-492 001, India

***Corresponding Author Email :** arti.parganiha@gmail.com

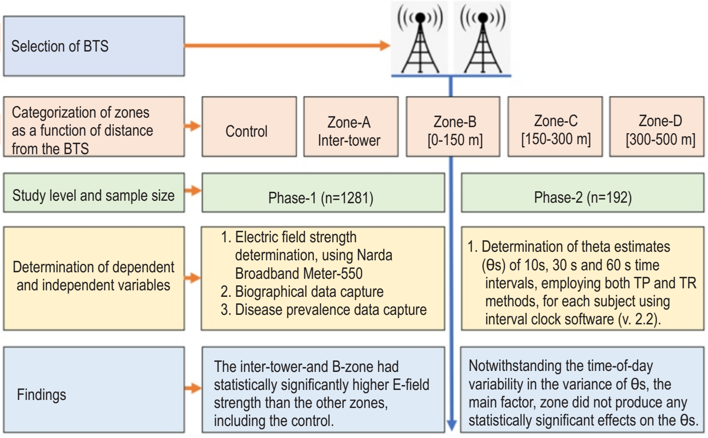
Received: 22.02.2021 *Revised*: 26.08.2021 *Accepted*: 13.11.2021

Abstract

Aim: The present study aimed at evaluating the effects of radiofrequency electromagnetic radiation exposure on short-interval time estimates in humans living in the vicinity of base transceiver stations.

Methodology: The study was conducted in Phase-1 and Phase-2 with 1281 and 192 subjects, respectively. Four groups with one control were identified in each phase depending on the distance from the ground-based transceiver stations. The cognitive ability of the subjects of each group was determined by measuring short-interval time estimates, namely 10 s, 30 s, and 60 s, with time production and time reproduction methods using the Interval Clock software (Version 2.2). The electric field strength at each participant's house was determined using the Narda Broadband Meter-550 with a probe EF0-391.

Results: ANOVA results demonstrated a statistically significant difference in electric field strength among different zones around the installations of base transceiver stations ($F_{4,1274}$ = 50.071; p<0.001). It was significantly higher in the inter-tower zone than in all other zones. The prevalence of various clinical problems was higher among the individuals living in the inter-tower zone. ANCOVA results revealed that the main factors zone, gender, and year of residence, did not significantly affect any short-interval time estimates. However, a statistically significant 'time of the day' variation in most of the target short-interval time estimates with both the methods for all the studied groups, except the inter-tower zone, was observed.



1. Electric field strength determination, using Narda Broadband Meter-550
2. Biographical data capture
3. Disease prevalence data capture

1. Determination of theta estimates (θs) of 10s, 30 s and 60 s time intervals, employing both TP and TR methods, for each subject using interval clock software (v. 2.2).

The inter-tower-and B-zone had statistically significantly higher E-field strength than the other zones, including the control.

Notwithstanding the time-of-day variability in the variance of θs, the main factor, zone did not produce any statistically significant effects on the θs.

Interpretation: The radiofrequency electromagnetic radiation emitted from base transceiver stations did not significantly impact the ability to estimate short-time intervals in humans.

Key words: Base transceiver station, Electric-field strength, Narda Broadband Meter-550, Radiofrequency electromagnetic radiation, Short-interval time estimation.

How to cite : Chandel, P., M.M. Singh, A.K. Pati, V. Choudhary and A. Parganiha: Determination of short-interval time estimates in humans exposed to radiofrequency electromagnetic radiation. *J. Environ. Biol.*, **43**, 369-376 (2022).

Introduction

Base Transceiver Station setup of the telecom industry operates in the radiofrequency electromagnetic radiation range. The non-ionizing radiofrequency electromagnetic radiation ranges from 3 kilohertz (kHz) to 300 gigahertz (Ghz), as reported by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA Regulations, 2018). To provide the best possible network services to the customers, the mobile phone companies have laid base transceiver stations mounting amid densely populated residential areas (Buckus *et al.,* 2017). The radiation from base transceiver stations depends on several factors, such as direction of signal transmission, radiated power density, diffusion due to buildings and trees, attenuation due to obstructions, and distance of base stations from each other (Wiedemann *et al.,* 2017). Exposure to radiofrequency electromagnetic radiation causes thermal (>2500 MHz) and non-thermal (<2500 MHz) effects on the biological system as per the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998). People with continuous exposure to radiofrequency electromagnetic radiation show physiological health symptoms (Santini *et al.,* 2003), sleep disturbances (Abelin *et al*., 2005), neuropsychological symptoms (Pachuau *et al.,* 2014), and cognitive impairment (Meo *et al.,* 2018).

On the contrary, several researchers have established that radiofrequency electromagnetic radiation exposure does not produce significant adverse effects on humans' health (Berg-Beckhoff *et al.,* 2009), sleep quality (Hutter *et al.,* 2006), cognitive performance (Riddervold *et al.,* 2008; Malek *et al.,* 2015). Berg-Beckhoff *et al.* (2009) conducted a large cross-sectional study involving 3526 subjects and evaluated five variables, namely sleep disturbances, headaches, health complaints, and mental and physical health using standardized health questionnaires in both exposed and control groups. The authors did not find any statistically significant differences between the exposed and the control participants with respect to the above five examined variables. In another study Hutter *et al.* (2006) conducted on both rural and urban inhabitants, it was revealed that the radiation exposure did not alter sleep quality in 365 subjects living near 10 selected base stations. However, at higher exposure levels, the subjects reported headaches more frequently.

The radiation exposure did not significantly alter cognitive performances, such as immediate memory, perceptual speed, and reaction time in those subjects (Hutter *et al.,* 2006). Riddervold *et al.* (2008) and Malek *et al.* (2015) did not find any statistically significant effects of radiofrequency (RF) electromagnetic fields (EMF) on human cognitive function. The former group of authors studied the effects of radiofrequency electromagnetic fields on cognitive tasks with the Trail Making B (TMB) test, while Malek *et al.* (2015) did not register any statistically significant effect of radiations emanating from the typical Global System for Mobile Communication and Universal Mobile Telecommunications System (UMTS) on cognitive function gauged from Reaction Time (RTI), Rapid Visual Processing (RVP), Paired Associates Learning (PAL) and Spatial Span (SSP). They also did not find any effects on physiological variables, namely body temperature, blood pressure, and heart rate of subjects exposed to UMTS radiation. Based on the available literature, Singh and Pati (2016) in their review concluded that the effects of radiofrequency electromagnetic radiation on human health remain contradictory. Even today the issue is debatable. The human brain absorbs radiofrequency electromagnetic radiation, which may influence normal brain function (Kim *et al.,* 2019). Short-interval time estimation is a cognitive ability that coordinates successful and sequential performance (Buonomano and Laje, 2010).

In humans, several brain regions are involved in gauging short-interval time, such as the prefrontal cortex and the cerebellum, and the neurotransmitter dopamine (Matell and Meck, 2000). Time intervals in the range of 1-120 sec fall in the category of short-interval time perception (Aschoff, 1998). Earlier findings from our laboratory (Pati and Pande, 2013; Pande *et al.,* 2013, 2014) revealed that perception of short-interval time varies as a function of sleep duration, length of sunlight exposure, season, and methods of estimation. Further, to the best of our knowledge, the information on the effects of radiofrequency electromagnetic radiation emanating from base transceiver stations on cognitive performance with particular reference to estimation of short-interval time in humans is completely absent. Therefore, the present study was undertaken to examine the non-thermal effects of radiofrequency electromagnetic radiation emitted from the base transceiver station on short-interval time estimates in subjects (populations) living in and around the base transceiver stations in Raipur.

Materials and Methods

Identification of locations of base transceiver station: The transceiver stations installed 10 years ago in Raipur city of Chhattisgarh were selected for the present study. The base transceiver stations are ground-based towers operating at the non-thermal frequency range of 2144 MHZ.

Categorization of zones: The areas around base transceiver stations of 2 locations (Shanti Vihar and Kabir Nagar) were divided into four zones, *i.e.,* zone A, zone B, zone C, and zone D. The zones were categorized using Garmin GPS eTrex 10.

Study design, participants and inclusion-exclusion criteria: The Phase I study included the voluntary participation of 1281 randomly selected individuals comprising control subjects (N=152), exposed residents at base transceiver station 1 (N=621), and base transceiver station 2 (N=508). Out of 1281, 162 subjects were from zone A (median age: 35 y), 389 from zone B (35 y), 363 from zone C (33 y), and 215 from zone D (32 y). Control subjects (33 y) were selected from the area without the installations of base transceiver stations. The study included 565 males (34 y; 18-70 y) and 716 females (34 y; 18-68 y). The data of the respective zones from both the base transceiver stations were merged. The frequency of all clinical diseases was recorded using inventories and interviews. All clinical diseases included cardiovascular diseases, metabolic diseases, and other clinical diseases. Hypertension, hypotension, and heart diseases were included under the category of cardiovascular diseases; diabetes, thyroid, obesity, lipid, and carbohydrate metabolism diseases were included under the category of metabolic diseases; and sickle cell disease, neuropsychological disease, migraine, kidney stone, polycystic kidney, asthma, arthritis, hormonal imbalance, ovarian cyst, etc. were included under other clinical diseases. Of the subjects of Phase I study, 204 participants voluntarily participated in the Phase II study.

The participants for the Phase II study were chosen following inclusion and exclusion criteria (Hutter *et al.,* 2006). Inclusion criteria were: (1) self-declared healthy, (2) ≥ 18 years old, (3) diurnal work type, (4) having a regular sleep-wake cycle, and (5) >1 year of residence; and exclusion criteria were: (1) pregnancy, (2) psychological and chronic illness, (3) regular smoker, and (4) regular alcohol consumption. Twelve participants were excluded due to exclusion criteria. Finally, 192 healthy individuals, including 91 males and 101 females, took part in the study. The zone-wise distribution of the subjects was: 28 subjects were from zone A (median age: 28 y), 48 from zone B (30 y), 54 from zone C (29 y), and 22 from zone D (30 y). Forty (31y) control subjects were from an area without the installations of base transceiver stations.

Ethical approval: The Institutional Ethics Committee (IEC) for Human Research of the Pt. Ravishankar Shukla University, Raipur, India (IEC Ref. No.: 142/IEC/PRSU/2016; Date: 03/02/2016) approved the design and protocol of the study. All the participants were informed about the objectives of the study. Both verbal and written informed consents were procured from all the participants. The participants were informed categorically that they could quit the study whenever they wanted.

Assessment of socio-demographic and electric-field strength: In the present study, various biographical variables, such as age, height, weight, profession, education, family type, food habits, and year of residence were recorded through the administration of a self-designed socio-demographic biographical datasheet. All subjects were advised to provide their clinical background and habits of smoking, alcohol, and sleeping pills usages. The body mass index (BMI, kg m^{-2}) for each participant was computed. A one-to-one interview method was adopted during data capturing. The Narda Broadband Meter (NBM-550) along with EF0-391 probe was used to measure the electric field (E-Field) strength at the living room of each participant's house within the frequency range of 100 kHz-3 GHz.

Estimation of short-interval time: Before starting the experimental session, a brief demo was presented to all participants regarding the purpose of the study and the procedures to be followed during the assessment of short-interval time estimates. Two methods, namely Time Production (TP) and Time Reproduction (TR), were employed to estimate the target intervals, such as 10 s, 30 s, and 60 s using the Interval Clock (version 2.2) software (Pande *et al.,* 2013). The whole experiment was conducted under normal free-living conditions. The subjects were instructed not to resort to the counting strategy and not to keep with them any timekeeping devices like watches. Each participant separately performed the task, and the findings were not disclosed to the participants till the completion of the study.

Time production method: The target intervals appeared on the laptop screen in standard units (number in seconds for production) using gray Arabic digits on a black background. The participants saw the target intervals on display. They reproduced the target interval by instantly pressing the space bar on the laptop's keyboard until they thought the perceived time had elapsed.

Time reproduction method: The stimulus durations were presented at the center of the laptop screen through the appearance of a gray squared box on black background for the duration of the target time intervals. The box disappeared from the screen as soon as the target interval had elapsed. The participants pressed (hold) the space bar until they judged that the time duration of pressing the space bar was equal to the period of display of the gray stimulus box on the laptop screen. In both methods, the target intervals (digits and box) appeared randomly and were presented to the participants three times. The data on the subjective judgments of the target intervals were stored in the MS-Excel worksheet.

Computation of accuracy score, 'Theta (θ)': The average of two nearest time estimates was considered. Each time estimate was converted into duration judgment ratio "theta (θ)" (Pande and Pati, 2010).

Statistical analyses: Data on E-Field strength, age, and body mass index were analyzed by one-way ANOVA followed by Duncan's Multiple Range Test. The Chi-square statistic was employed to test the independence of attributes, *i.e.,* between the 'zone' and the 'frequency of clinical problems.' In the phase II study, ANCOVA was applied to evaluate the effects of exposure to the radiofrequency electromagnetic radiations on inter-group variability in short-interval time estimates. The normality and homogeneity of data were checked using Shapiro-Wilk's statistics and Levene's statistics, respectively. The *F*-test was used for comparing the variances in the observed estimates of target intervals between the forenoon and the afternoon.

Results and Discussion

The results of one-way ANOVA revealed a statistically significant difference in E-field among different zones ($F_{4,1274}$ = 50.071; p<0.001). E-field was significantly higher in zone A than other zones, *i.e.,* zone B, C, and D, and control. E-field in zone B was more elevated than zones C and D, and the control zone. Further, the Chi-square statistic results revealed an association

Table 1: Mean ± 1 standard error of theta estimates of 10 s, 30 s and 60 s obtained using time production (TP) and time reproduction (TR) methods as a function of the zone, gender, and year of residence (YoR)

Source	**Main Factor**	**Dependent Variable**					
		TP 10 s	**TP 30 s**	**TP 60 s**	**TR 10 s**	**TR 30 s**	**TR 60 s**
	N	170	192	187	158	169	187
Zone	Control	1.03±0.08^a	0.90±0.06^a	0.80±0.05^a	1.36±0.06^a	1.07±0.05^a	0.95±0.05^a
	Zone A	1.21±0.09^a	1.00±0.07^a	0.81±0.06^a	1.25±0.08^a	1.06±0.05^a	0.83±0.06^a
	Zone B	1.11±0.07^a	0.86±0.05^a	0.78±0.04^a	1.34±0.05^a	1.08±0.04^a	0.95±0.04^a
	Zone C	1.13±0.06^a	0.88±0.05^a	0.77±0.04^a	1.34±0.06^a	1.04±0.04^a	0.91±0.04^a
	Zone D	1.13±0.10^a	0.97±0.09^a	0.82±0.07^a	1.33±0.09^a	0.99±0.06^a	0.91±0.07^a
Gender	Male	1.14±0.06^a	0.93±0.05^a	0.81±0.04^a	1.28±0.05^a	1.03±0.03^a	0.90±0.04^a
	Female	1.10±0.05^a	0.91±0.04^a	0.78±0.03^a	1.36±0.04^a	1.06±0.03^a	0.91±0.03^a
YoR	1-5 years	1.16±0.05^a	0.94±0.04^a	0.80±0.03^a	1.35±0.04^a	1.06±0.03^a	0.90±0.03^a
	>5 years	1.08±0.05^a	0.91±0.04^a	0.79±0.03^a	1.30±0.05^a	1.03±0.03^a	0.91±0.03^a

Abbreviation: Zone A = inter-tower zone; Zone B = 0-150m; Zone C = 150-300m; Zone D = 300-500m; Means having similar alphabets are not statistically significant at p < 0.05 (based on LSD test).

between 'zone' and 'distribution of various clinical problems.' A significantly high frequency for all clinical diseases was found in the subjects from zone A ($x^2_4 = 33.061$; $p<0.001$). The maximum frequencies of both cardiovascular ($x^2_4 = 29.207$; $p<0.001$) and metabolic diseases ($x^2_4 = 13.148$; $p<0.05$) were found in the residents from zone B. Of the 192 subjects who participated in the Phase II study, 47.4% were males and 52.6% were females. The subjects were either students (32.8%) or housewives (26.6%), employed (39.1%), or unemployed (1.6%). A majority of the participants belonged to nuclear family (70.8%) and about 73.4% were graduates. Of the total number of participants, 53.1% were vegetarian and 46.9% were non-vegetarian. About 53.1% of participants lived in the locality for a period ranging between 1 and 5 years, while 53.6% of subjects lived here for longer than five years at the time of this study. The average of E-field strength, age, and BMI obtained from the Phase II study were also compared using one-way ANOVA. The results revealed that there was a statistically significant difference in the E-field strength ($F_{4,187} = 3.386$; $p<0.05$) among the studied groups; it was significantly higher in zone A as compared to zone C.

The data on short-interval time estimates exhibited normal distribution. Also, there was equality of variance across the studied groups (Shapiro-Wilk statistic, p>0.05; Levene's test, p>0.05). The ANCOVA was applied to assess the effects of main factors zone, gender, and year of residence on the mean theta estimates of the target short-intervals, *i.e.,* 10 s, 30 s, and 60 s with the time production and time reproduction methods. The effects of main factors were not statistically significant. The effects of covariates on any of the mean theta estimates were not statistically significant, except the impact of age on 60 s with time production ($p<0.05$, $\eta^2=0.035$) and BMI on 30 s with time production ($p<0.05$, $\eta^2=0.027$). The Eta-squared (η^2) was used as a measure of effect size; effect sizes between 0.01 and 0.05 were considered low, between 0.06 and 0.13 moderate, and that >0.14 high (Randler, 2008). In this study, the effect sizes for age and BMI were small. The results indicated that the target time intervals with time production and time reproduction methods did not differ statistically significantly on account of zone, gender, and year of residence. However, all the studied subjects, irrespective of zones, overestimated 60 s with time production and underestimated 10 s with time reproduction methods (Table 1). They estimated 30 s accurately with both time production and time reproduction methods. Subjects from zone A underestimated 10 s with time production and overestimated 60 s with time reproduction methods.

The results of Chi-square test revealed that the frequency of overestimation, accurate estimation, or underestimation of short-time intervals in both time production and time reproduction methods did not vary as a function of zone (Table 2). Variability in the variance of mean theta estimates of short-interval time as a function of 'time of the day,' *i.e.,* forenoon *versus* afternoon is depicted in Fig. 1(a-j). The results indicate that variability in estimating 10 s with the time production method was higher during afternoon than forenoon in controls (Fig. 1a) and subjects from zone B (Fig. 1e). Similarly, the variance was more for 10 s estimation with the time reproduction method during afternoon than forenoon in the subjects from zones B, C, and D (Fig. 1f, h, j). Also, the time of day variability in variance of 30 s with the time production in zone D (Fig. 1i) and 30 s with the time reproduction in subjects from zones C and D (Fig. 1h and j) were observed. However, the 'time of the day' effects on the variance of time estimates among zone A people for any target intervals (Fig. 1c, d) were not observed.

In the current research work, the effects of exposure to radiofrequency electromagnetic radiation on humans' cognitive performance were measured. Most importantly, this is the first study investigating the impact of base transceiver station-

Table 2: Frequency of mean theta estimates (θs) of 10 s, 30 s, and 60 s short time intervals, under three categories of estimation accuracy range, $\theta<0.95$ (OE), $\theta=0.95\text{-}1.05$ (AE), and $\theta>1.05$ (UE). The subjects across different classified zones judged the intervals using both time production (TP) and time reproduction (TR) methods

Short time interval estimates			Control	Zone A	Zone B	Zone C	Zone D	Total	Summary statistic		
									χ^2	df	p-Value
TP	10 s	OE	13	8	17	13	7	58	-!		
		AE	5	2	4	4	0	15			
		UE	22	18	27	37	15	119			
	30 s	OE	24	15	23	31	11	104	3.146*	8	0.925
		AE	3	3	10	6	3	25			
		UE	13	10	15	17	8	63			
	60 s	OE	27	15	33	39	16	130	3.466*	8	0.902
		AE	5	4	7	3	2	21			
		UE	8	9	8	12	4	41			
TR	10 s	OE	6	3	5	7	0	21	-!		
		AE	1	2	3	4	2	12			
		UE	33	23	40	43	20	159			
	30 s	OE	10	12	15	20	6	63	3.653*	8	0.887
		AE	7	4	13	11	6	41			
		UE	23	12	20	23	10	88			
	60 s	OE	18	16	22	27	14	97	2.509*	8	0.961
		AE	9	5	12	15	3	44			
		UE	13	7	14	12	5	51			

Abbreviation: Zone A = inter-tower zone; Zone B = 0-150m; Zone C = 150-300m; Zone D = 300-500m; TP = time production; TR = time reproduction; OE = over estimation; AE = accurate estimation; UE = under estimation; χ^2 = chi-square; df = degrees of freedom; *p* = significance level; *Yates corrected; -! = did not perform chi-square statistic as cells have zero frequency.

generated radiofrequency electromagnetic radiation on cognitive performance with particular reference to short-interval time estimates in humans. However, we came across many studies dealing with the effects of electromagnetic radiation on spatial cognition (Isgor *et al.,* 2004; Narayanan *et al.,* 2015) and recognition memory (Gökçek-Saraç, 2020), emotional memory (Bouji *et al.,* 2012), and spatial memory (Fragopoulou *et al.,* 2010; Hao *et al.,* 2013). The experimental models in these studies were rodents. There is not even a single scientific study on the radiofrequency electromagnetic radiation exposure on short-interval time estimates in humans living in proximity to base transceiver stations. In this study, electric field strength was used as an exposure matrix to measure an individual's exposure to radiofrequency electromagnetic radiation from base transceiver stations. The electric field strength measurements complied with the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998) guidelines applicable to public exposure (1.375f1/2=1.375*21441/2=64 V/m). The recorded exposure level was under the range for all the investigated zones. However, the mean E-Field strength across the zones was higher than the level of 1-250 microvolts at which the biological processes occur (Söğüt and Karadeniz, 2017).

In this study, the electric field strength was significantly higher in zone A as compared to other zones. The results compared favorably with earlier studies (Buckus *et al.,* 2017). It has been documented that the electric field strength declined with increasing distance from the mobile phone base station's antenna (Singh *et al.,* 2021). Further, the observed clinical problems that include cardiovascular, metabolic, and other clinical diseases are more prevalent among the individuals at zone A (inter-tower zone). It means that a significant increase in the frequency of health problems concerning the reference group (nearest to the base transceiver stations) existed. This finding is in agreement with the study conducted by Shahbazi-Gahrouei *et al.* (2014).

The results published by these authors showed that most of the health symptoms were significantly higher in the inhabitants living near the base transceiver stations antenna (<300 m distances) compared to those living far away from the base transceiver station antenna (>300 m). A higher frequency of cardiovascular and metabolic diseases was noticed among people living in zone B. This study validates the earlier findings by Meo *et al.* (2015) and Singh *et al.* (2016). They reported that most of the subjects living close to the base stations complained about the cardiovascular, nervous system associated with clinical symptoms and type 2 diabetes mellitus. The present study did not show any statistically significant effects of main factors, zone, gender, and year of residence, and the covariates on any one of the mean theta estimates, except the impact of age on 60 s and body mass index on 30 s with the time production method.

This outcome is consistent with similar findings performed on other cognitive attributes, namely reaction time,

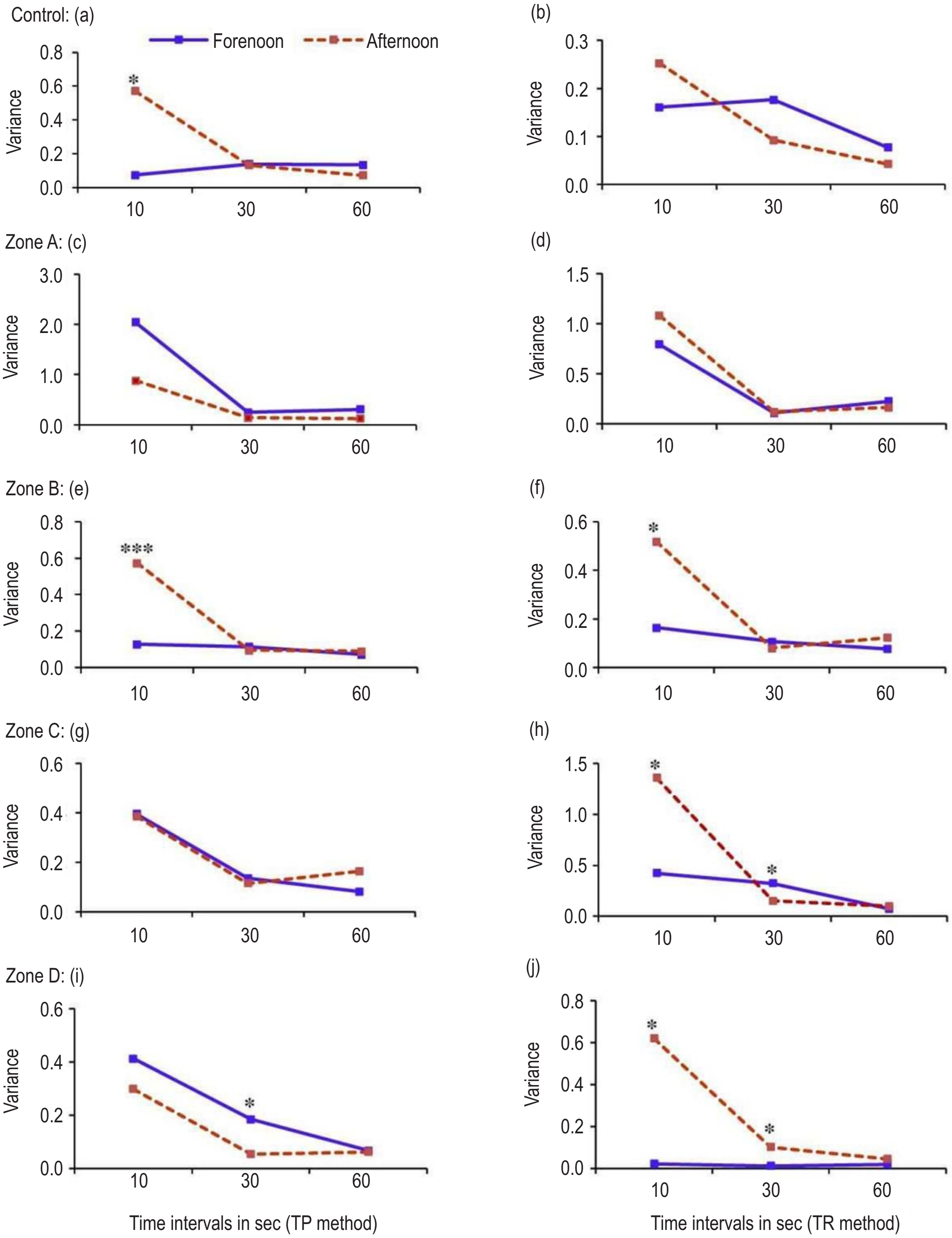


Fig. 1: (a-j) Comparison of sample variances for theta estimates (θs) judged in the forenoon (FN) and afternoon (AN). The subjects across different classified zones measured the short-time intervals (i.e., 10 s, 30 s, and 60 s) using time production (TP) and time reproduction (TR) methods. Controls (a, b), subjects from Zone A (c, d), Zone B (e, f), Zone C (g, h), and Zone D (i, j). Zone A = inter-tower zone; Zone B = 0-150m; Zone C = 150-300m; Zone D = 300-500m.
$^*p \leq 0.05$, or $^{***}p \leq 0.001$ indicates a statistically significant difference between forenoon (FN) and afternoon (AN) variances for the respective mean theta estimates (θs).

rapid visual processing, paired associates learning, spatial span, and trail making B (Riddervold *et al.,* 2008; Malek *et al.,* 2015). Besides, the findings of this study are also similar to the results of several double-blind studies that did not validate non-thermal effects of radiofrequency electromagnetic radiations ranging between 385.25 MHz to 2100 MHz on the cognitive performance, such as digit symbol substitution task, digit span task, and a mental arithmetic task (Riddervold *et al.,* 2010).

Concerning the effects of gender, Pande *et al.* (2014) also did not find significant gender effects on 10 s and 60 s estimates while studying under constant routine conditions. This study did not find a zone-wise difference in subjects' frequency of overestimation, accurate estimation, or underestimation of short-interval time estimates using either time production or time reproduction methods. Further, in this study, the time of the day variability in the mean theta estimates of short-interval time was examined. In general, higher variability in estimating 10 s with time production and time reproduction methods was observed during afternoon than forenoon, irrespective of zones. However, variability in 30 s estimation was slightly different from that of 10 s. The time of day variability was discernible in the mean theta estimates of short-interval time, *i.e.,* 10 s and 30 s, but not in 60 s. Here, zone A was the only exception where variability in any one of the mean theta estimates was not detected. Earlier, Pande *et al.* (2014) documented variability in 10 s and 60 s intervals across the day and concluded that it has a covert endogenous basis.

Could it be speculated that the absence of variability in time estimates in zone A (higher E-Field) might be a consequence of exposure to a higher level of radiofrequency electromagnetic radiation? However, it is difficult to interpret the current results as there is a complete lack of peer studies for purposes of comparison. Studies on a large sample and along a longitudinal scale are necessary to validate this conjecture. Nonetheless, it has been reported that the effects of radiofrequency electromagnetic radiation on memory performance in humans fall largely in the realms of uncertainty (Brzozek *et al.,* 2018; Wu *et al.,* 2019). These uncertainties could be imputed to factors such as human error involving errors in data capture methodology, model structure, and communication between the researchers and the subjects (Brzozek *et al.,* 2018).

Based on the findings, it is concluded that radiofrequency electromagnetic radiation emanating from the base transceiver station did not produce any significant effects on the short-interval time estimates, one of the critical cognitive performances in humans. As far as human health is concerned radiofrequency electromagnetic radiation might produce adverse effects on the subjects living in the vicinity of base transceiver station. Further, time of the day variability in estimating the target short-interval time was discernible with zone A's lone exception. However, there is a need to initiate further confirmatory studies to underscore the possible non-thermal effects of radiations that emanate from base transceiver station installations on many other vital biological variables, including other cognitive functions in humans.

Acknowledgments

This research work is a part of the Doctor of Philosophy thesis of one of the authors (PC). The University Grants Commission, New Delhi, India, supported this work under the scheme of UGC-BSR for Junior and Senior Research Fellowship [Ref. No. 437-4/SLS/PRSU/2015; Date: 31/03/2015] to PC; UGC-DRS-SAP (Phase-III) scheme sanctioned to the School of Studies in Life Science, Pandit Ravishankar Shukla University, Raipur in the thrust area - Chronobiology [Grant No. F-3-2/2016/DRS-III (SAP-II)]; and Center for Translational Chronobiology (CTC) at School of Studies in Life Science, Pandit Ravishankar Shukla University, Raipur. We are thankful to all subjects for their voluntary participation in the study. We are also grateful to Dr. Jatin Nayak, former Professor of English at Utkal University, Bhubaneswar, India, for reading the manuscript critically and for editing the text of the manuscript with special reference to language, syntax, and grammar.

Add-on Information

Authors' contribution: P. Chandel: Conceptualization, Data curation, Formal analysis writing-original draf, writing-review & edition; **M.M. Singh:** Data curation; **A.K. Pati:** Conceptualization, Formal analysis, Writing-review & editing; **V. Choudhary:** Writing-review & editing; **A. Parganiha:** Conceptualization, Formal analysis, Writing-review & editing.

Research content: The research content of manuscript is original and has not been published elsewhere.

Ethical approval: The authors have followed and complied with the National Guidelines of appropriate authority for the use of plants or animals or humans used in the experimental study.

Conflict of interest: The authors reported no potential conflict of interest.

Data from other sources: Not applicable.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology.*

References

Abelin, T., E. Altpeter and M. Roosli: Sleep disturbances in the vicinity of the short-wave broadcast transmitter Schwarzenburg. *Somnologie*, **9**, 203–209 (2005).

Aschoff, J.: Human perception of short and long time intervals: Its correlation with body temperature and the duration of wake time. *J. Biol. Rhythms,* **13**, 437–442 (1998).

Australian Radiation Protection and Nuclear Safety Agency Regulation (2018). https://www.arpansa.gov.au/regulation-and-licensing

Berg-Beckhoff, B.G., M. Blettner, B. Kowall, S. Schmiedel, C. Bornkesse, U. Reis, P. Potthof and J. Schuz: Mobile phone base station and adverse health effects: phase 2 of a cross-sectional study with measured radiofrequency electromagnetic fields. *Occup. Environ. Med.,* **66**, 124–130 (2009).

Bouji, M., A. Lecomte, Y. Hode, R. De Seze and A.S. Villégier: Effects of 900MHz radiofrequency on corticosterone, emotional memory and neuroinflammation in middle-aged rats. *Exp. Gerontol.,* **47**, 444-451 (2012).

Brzozek, C., K.K. Benke, B.M. Zeleke, M.J. Abramson and G. Benke: Radiofrequency electromagnetic radiation and memory performance: Sources of uncertainty in epidemiological cohort studies. *Int. J. Environ. Res. Public Hlth.,* **15**, 592 (2018).

Buckus, R., B. Strukčinskienė, J. Raistenskis, R. Stukas, A. Šidlauskienė, R. Čerkauskienė, D.N. Isopescu, J. Stabryla and I. Cretescu: A technical approach to the evaluation of radiofrequency radiation emissions from mobile telephony base stations. *Int. J. Environ. Res. Public Hlth.,* **14**, 1–18 (2017).

Buonomano, D.V. and R. Laje: Population clocks: Motor timing with neural dynamics. *Trends Cogn. Sci.,* **14**, 520–527 (2010).

Fragopoulou, A.F., P. Miltiadous, A. Stamatakis, F. Stylianopoulou, S.L. Koussoulakos and L.H. Margaritis: Whole body exposure with GSM 900MHz affects spatial memory in mice. *Pathophysiology*, **17**, 179-187 (2010).

Gökçek-Saraç, Ç.: Effects of 2.1 GHz electromagnetic radiation on locomotor activity, recognition memory, and anxiety-related behavior in Rats. *Neurophysiology*, **52**, 261-266 (2020).

Hao, D., L. Yang, S. Chen, J. Tong, Y. Tian, S. Benhang, W. Shuicai and Z. Yanjun: Effects of long-term electromagnetic field exposure on spatial learning and memory in rats. *Neurol. Sci.,* **34**, 157-164 (2013).

Hutter, H.P., H. Mashammer, P. Wallner and M. Kundi: Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations. *Occup. Environ. Med.,* **63**, 307–313 (2006).

International Commission on Non-Ionizing Radiation Protection, Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 Ghz). *Hlth. Phys.,* **74**, 494–522 (1998).

Isgor, C., M. Kabbaj, H. Akil and S.J. Watson: Delayed effects of chronic variable stress during the peripubertal-juvenile period on hippocampal morphology and on cognitive and stress axis functions in rats. *Hippocampus*, **14**, 636-648 (2004).

Kim, J.H., J.K. Lee, H.G. Kim, K.B. Kim and H.R. Kim: Possible effects of radiofrequency electromagnetic field exposure on the central nerve system. *Biomol. Ther.,* **27**, 265–275 (2019).

Malek, F., K.A. Rani, H.A. Rahim and M.H. Omar: Effect of short-term mobile phone base station exposure on cognitive performance, body temperature, heart rate and blood pressure of Malaysians. *Sci. Rep.,* **5**, 1–5 (2015).

Matell, M.S. and W.H. Meck: Neuropsychological mechanisms of the interval timing behavior. *Bioessays*, **22**, 94–103 (2000).

Meo, S.A., M. Almahmoud, Q. Alsultan, N. Alotaibi, I. Alnajashi and W.M. Hajjar: Mobile phone base station tower settings adjacent to school buildings: impact on students' cognitive health. *Am. J. Mens. Hlth.,* **13**, 1–6 (2018).

Meo, S.A., Y. Alsubaie, Z. Almubarak, H. Almutawa, Y. AlQasem and R.M. Hasanato: Association of exposure to radio-frequency electromagnetic field radiation (RF-EMFR) generated by mobile phone base stations with glycated hemoglobin (HbA1c) and risk of type 2 diabetes mellitus. *Int. J. Environ. Res. Public Hlth.,* **12**, 14519–14528 (2015).

Narayanan, S.N., R.S. Kumar, K.M. Karun, S.B. Nayak and P.G. Bhat: Possible cause for altered spatial cognition of prepubescent rats exposed to chronic radiofrequency electromagnetic radiation. *Metab. Brain Dis.,* **30**, 1193-1206 (2015).

Pachuau, L., L. Sailo, Z. Pachuau and P.C. Lalngneia: RF radiation from mobile phone towers and their effects on the human body. *Indian J. Radio. Space Phys.,* **43**, 186–189 (2014).

Pande, B., A. Parganiha, P.K. Patra and A.K. Pati: Short-duration judgment in young Indian subjects under 30 h constant wakefulness. *Indian J. Exp. Biol.,* **52**, 559–568 (2014).

Pande, B. and A.K. Pati: Overestimation/underestimation of time: Concept confusion hoodwinks conclusion. *Biol. Rhythm. Res.,* **41**, 379–390 (2010).

Pande, B., R.D. Shindey, A. Parganiha and A.K. Pati: Interval timing as a function of methods of estimation-a study on cohorts of young Indians. *Bio. Rhythm Res.,* **44**, 469–483 (2013).

Pati, A.K. and B. Pande: Prospective judgment of short-intervals in a cohort of university students. *Natl. Acad. Sci. Lett.,* **36**, 191–199 (2013).

Randler, C.: Differences in sleep and circadian preference between eastern and Western German adolescents. *Chronobiol. Int.,* **25**, 565–575 (2008).

Riddervold, I.S., S.K. Kjaergaard, G.F. Pedersen, N.T. Andersen, O. Franek, A.D. Pedersen, T. Sigsgaard, R. Zachariae, L. Mølhave and J.B. Andersen: No effect of TETRA hand portable transmission signals on human cognitive function and symptoms. *Bioelectromagnetics*, **31**, 380–390 (2010).

Riddervold, I.S., G.F. Pedersen, N.T. Andersen, A.D. Pedersen, J.B. Andersen, R. Zachariae, L. Molhave, T. Sigsgaard and S.K. Kjaegaard: Cognitive function and symptoms in adults and adolescents in relation to RF radiation from UMTS base stations. *Bioelectromagnetics*, **29**, 257–267 (2008).

Santini, R., P. Santini, P. Le Ruz, J.M. Danze and M. Seignel: Survey study of people living in the vicinity of cellular phone base stations. *Electromagn. Biol. Med.,* **22**, 41–49 (2003).

Shahbazi-Gahrouei, D., M. Karbalae, H.A. Moradi and M.B. Ghahfarokhi: Health effects of living near mobile phone base transceiver station (BTS) antennae: a report from Isfahan, Iran. *Electromagn. Biol. Med.,* **33**, 206–210 (2014).

Singh, K., A. Nagaraj, A. Yousuf, S. Ganta, S. Pareek and P. Vishnani: Effect of electromagnetic radiations from mobile phone base stations on general health and salivary function. *J. Int. Soc. Prev. Communit. Dent.,* **6**, 54–59 (2016).

Singh, M.M. and A.K. Pati: Effects of radiation emanating from base transceiver station and mobile phone on sleep, circadian rhythm and cognition in humans-a review. *Biol. Rhythm Res.,* **47**, 353–388 (2016).

Singh, M.M., P. Chandel, A.K. Pati and A. Parganiha: Does exposure to radiofrequency radiation (RFR) affect the circadian rhythm of rest-activity patterns and behavioral sleep variables in humans? *Biol. Rhythm Res.,* 1-25 (2021). https://doi.org/10.1080/09291016.2021.1945788

Söğüt, Ö. and Ş. Karadeniz: Measurement of electromagnetic pollution in Adıyaman city centre. *Adıyaman University J. Sci.,* **7**, 89–108 (2017).

Wiedemann, P.M., F. Freudenstein, C. Böhmert, J. Wiart and R.J. Croft: RF-EMF risk perception revisited: Is the focus on concern sufficient for risk perception studies? *Int. J. Environ. Res. Pub. Hlth.,* **14**, 1–13 (2017).

Wu, Y., F.O. Hoffman, A.I. Apostoaei, D. Kwon, B.A. Thomas, R. Glass and L.B. Zablotska: Methods to account for uncertainties in exposure assessment in studies of environmental exposures. *Environ. Hlth.,* **18**, 31 (2019).