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Effects of exposure to nearby mobile phone base stations and mobile phone usage on human blood parameters

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ABSTRACT

The present study investigates the impact of RF-EMF (900 and 1800 MHz) emissions from mobile phone base stations (MPBS) as well as from mobile phone usage on the hematological parameters and stress markers of exposed individuals. Members of MPBS highly exposed ($N = 50$) and a reference group ($N = 51$) were tested using a complete blood count and two stress markers, amylase and cortisol. Different effects were found for different blood parameters, based on various combinations of exposure type, demographics, and lifestyle behaviors. Subsequent stepwise regression analysis revealed that exposure from MPBS contributed significantly to TLC, while various combinations of gender, age and power density contributed significantly to differential and absolute basophil counts and absolute monocyte counts. MPBS exposures contributed to absolute monocytes similar to smoking. Furthermore, hours of daily mobile phone exposure together with age contributed significantly to absolute and differential basophil counts and absolute lymphocyte counts. Of concern, almost a quarter of those with high MPBS exposures had basophil counts above the clinical reference limits, while over half of those with heavy daily mobile phone use (4 to 6 hours) had lymphocyte counts above the limits, and most were under 30 years old. While smoking and age contributed to amylase levels, no exposure variables contributed to amylase or cortisol levels. Altogether, there is an indication that RF-EMF from mobile phones and MPBS together with age and gender can differentially impact leucocytes, indicating biological stress and potentially affecting health. These results suggest the necessity for increasing awareness regarding adverse effects of RF-EMF exposures.

PLAIN LANGUAGE SUMMARY

This study aimed to test whether people who live closer to mobile phone towers (MPBS) and those with greater mobile phones use show any changes in their red and white blood cells, or to their stress hormones. Two groups of volunteers were recruited, a reference group of those living more than 300 m away, and a highly exposed group, living less than 60 m away from the closest MPBS. Blood samples were taken from both groups and analyzed. The strength of the radiofrequency signal from the MPBS in participants' homes was measured, and mobile phone use, lifestyle factors, and demographics that could affect the blood parameters were also recorded. Results showed that different white blood cells were affected by different combinations of gender, age, smoking, many hours of daily mobile phone use and high exposures from MPBS. Concerning effects on lymphocytes were found in a large group of residents under 30 years old with high daily mobile phone use (4 to 6 hours). These results indicate human biological systems are under stress from both mobile phone use and local mobile phone tower exposures, leading to potential health effects. Placement and signal strength from MPBS, and guidance regarding daily mobile phone use need to be informed by these results.

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KEYWORDS
Mobile phone base stations (MPBS); mobile phone use; power density; hematological parameters; leucocytes; amylase; cortisol

Introduction

The level of man-made radio-frequency electromagnetic radiation (RF-EMF) in the environment has increased globally in recent decades causing concerns about electromagnetic pollution (Bandara and Carpenter 2018). This change has primarily been brought about by the ever-expanding adoption and deployment of mobile and wireless communication/surveillance technologies, as well as the increased use of RF-EMF in medical applications. Issues regarding potential health effects

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on people residing near Mobile Phone Base Stations (MPBS) have also been intensifying as a result of the constant emissions of RF-EMF onto the general public. Multiple studies have demonstrated evidence of health risks associated with exposure to MPBS (e.g., Pachuau et al. 2015; Premlal and Eldhose 2017). MPBS emit radio-frequency signals as a long-term continuous source of whole-body exposure, which can alter biological systems by inducing non-thermal effects (Pandey and Yadav 2023). While the non-thermal effects of RF-EMF do not elevate body temperature to a level that damages tissue structure, they can still result in increased production of free radicals within tissues (Baliah et al. 2022) and oxidative stress, leading to DNA damage and an array of health effects (Yakymenko et al. 2016). Furthermore, RF-EMF has been categorized by the International Agency for Research on Cancer (IARC) as possible carcinogenic to humans (Group 2B) (Yadav and Singh 2023).

A number of studies have demonstrated a link between RF-EMF radiation from MPBS and health risks (Ali et al. 2021; Premlal et al. 2022). However, there has been controversy over whether base station exposures (that are typically far-field and low intensity but long-term) add any health effects on top of, or separate to, the biological effects from use of personal mobile phones (that are typically near field and more intense but intermittent) (Gandhi et al. 2015). For example, it has been shown previously that far-field 2.45 GHz Wi-Fi in isolation did not affect oxidative stress parameters in blood, while combined Wi-Fi and mobile phone exposures did increase these parameters (Bektas et al. 2020). On the other hand, Eskander et al. (2012) found decreases in hormone levels from either longer mobile phone exposures or longer-term MPBS (950 MHz) exposures.

Considering the current scientific evidence on the biological and health effects caused by RF-EMF, and the issues surrounding public safety, it is crucial to prioritize research that can objectively evaluate the potential negative impacts of RF-EMF. Studies using biological markers such as those in blood can provide such objective measures. Furthermore, investigating the effects of both mobile phone and base station exposures on the same population can help to ascertain whether one or both of these sources are having an effect on these objective markers.

Hazardous effects on blood cells in humans and experimental animals have been reported following RF-EMF exposures. These effects include changes in hematological parameters which vary according to the type of organisms, RF-EMF sources, exposure frequencies, intensities and duration (Jbireal et al. 2018). Changes in hematological parameters are implicated in an array of serious health conditions (Oni et al. 2011; Etim et al. 2014; Jbireal et al. 2018; Liu et al. 2023).

Changes observed in the blood parameters of laboratory-exposed rodents include: • A greater increase in white blood cells (WBC), mean corpuscular volume (MCV), blood platelets, and a greater decrease in red blood cells (RBC), hemoglobin (Hb), corpuscular hemoglobin (MCH), and corpuscular hemoglobin count (MCHC) (Aziz et al. 2010); • Decreased RBC, packed cell volume (PCV) and hemoglobin (Olajide et al. 2020); • Increases in red blood cells, attributed to the induction of a hypoxia-like state (Esfahani et al. 2007; Otitoloju et al. 2010; Sani et al. 2018) which is linked to heightened oxidative stress (Gautam et al. 2024); • Increased total leucocyte count (TLC) and monocytes (Al-Uboody 2015); • Higher WBC from 900 MHz mobile phone exposures (Ibraheim et al. 2020) and long-term 1800 MHz mobile phones exposures (Zosangzuali et al. 2021); • Increases numbers of eosinophils, basophils and monocytes from long-term 1800-MHz exposures (Sahoo et al. 2023); • Altered hematological parameters from magnetic field exposures (Purushothaman et al. 2013; Sani et al. 2018; Yahay et al. 2020).

Human studies have shown changes in blood parameters; e.g., Blood serum of workers highly exposed to microwave and TV transmission signals showed changes in a range of parameters including helper T-cell and killer T-cell lymphocytes (Dasdag et al. 1992). Human cell studies have also shown similar changes in blood parameters. For example, an *in-vitro* experiment found WBC to be significantly higher in cells exposed to 2.3–2.4 GHz mobile phone signals (Christopher et al. 2020).

Two psychobiological stress markers found in blood serum, amylase and cortisol, have also been found to be altered in rodents subjected to RF-EMF laboratory exposures: • A rise in the concentration of serum amylase in pancreatic tissue from 2.45 GHz exposures (Topsakal et al. 2017); • Elevated cortisol levels from long-term 900 MHz and 1800 MHz exposures (Shahryar et al. 2009; Shahabi et al. 2018), indicating oxidative stress from RF-EMF (Pagadala et al. 2023); • However, no significant variation was found in cortisol levels of male rabbits (Sarookhani et al. 2011).

Comparable results have also been found in human exposure studies: • Elevated activity of salivary amylase in individuals with frequent mobile phones use (Shivashankara et al. 2015); • Increases in cortisol levels of individuals exposed for 6 years or more to MPBS and mobile phones (Eskander et al. 2012); • Changes in both amylase and cortisol from 900 and 1800 MHz MPBS exposures (Augner et al. 2010); •

Elevated cortisol and other stress hormones in shift-workers highly exposed to RF-EMF (Vangelova and Israel 2005); • No increases in the cortisol levels of workers exposed to microwave and radio frequencies; however, other hormones showed affects (Dasdag et al. 1999); • Decreases in cortisol in men after 2 weeks of laboratory exposures with recovery after 4 weeks (Djeridane et al. 2008).

The above studies showing RF-EMF effects in animals and cells suggest that similar changes may occur in humans when exposed to RF-EMF perpetually. Furthermore, high mobile phone usage has been shown to have deleterious effects on health (Belyaev et al. 2019a; Noaman 2019). To answer concerns about health effects from exposures to MPBS (e.g., Vijay and Choudhary 2017) these studies need to be extended to real-world settings.

In a previous study, we investigated the effects of 900 and 1800 MHz RF-EMF exposures on individuals living close to MPBS (Zothansiama et al. 2017). The results showed an elevated frequency of micronuclei as well as increased levels of antioxidants shown in human peripheral blood lymphocytes. However, further investigations with appropriate laboratory tests are necessary. Subsequently, the present study aims to assess hematological parameters and stress markers associated with MBPS and mobile phone exposures, including absolute and relative counts of the five types of white blood cells (leukocytes) and two stress markers (amylase and cortisol).

Other stress factors that may also affect human health include lifestyle choices such as smoking, betel nut chewing, and tobacco chewing, as well as demographics. Males typically have more Hb and red blood cells than females (Grau et al. 2018; Daniyal et al. 2022). Females suffer from more life stress than males in India (Thibaut and Jhanwar 2020; Wakode et al. 2020) and are more vulnerable to environmental factors such as EMFs (Yakymenko et al. 2016) as well as chemical toxins (Butter 2006). Increasing age also results in more stress on the body (Chen et al. 2018). These factors all need to be considered in the study, so as to ascertain the relative effects of MPBS and mobile phone use over and above demographics and lifestyle choices.

We anticipated several outcomes from the investigation. Based on the literature, it was expected that levels of Hb and RBCs would be higher for males. The blood parameters and stress markers were also expected to differ between the highly exposed group living close to MPBS and a reference group living further away, as well as to differ between those with high and lower levels of mobile phone usage.

The direction of these differences was not anticipated for most parameters. Leukocytes, amylase and cortisol are all relevant to different aspects of the stress response. Amylase indicates activity in the Sympathetic-Adrenal-Medullary (SAM) system (Nater et al. 2006) which is the body's initial fight/flight response to stress. Cortisol is a measure of the secondary response to stress of the Hypothalamic-Pituitary-Adrenal (HPA) axis, that marshals the immune system and affects different leucocytes in different ways (Dhabhar et al. 2012). While these stress markers typically show higher activity from short-term stress, they may become under-reactive from long-term stress, due to exhaustion (Kudielka et al. 2009). Cortisol and amylase show different response patterns under chronic stress (Wolf et al. 2008). Gender, age, and lifestyle factors affect outcomes in different ways, with many unknowns (de Vente et al. 2015; Strahler et al. 2017). Therefore, no clear hypothesis can be made as to exactly how the blood markers will change with long-term high exposures to MPBS or mobile phones, or combinations of these factors with demographic and lifestyle factors such as gender and smoking. What is being hypothesized is that the blood parameters will show different response patterns for high versus low RF-EMF exposures from MPBS and mobile phones.

Materials and methods

Mobile phone base stations

The study was conducted in 2022 and 2023 in Aizawl city (23.8789° N and 92.8976° E). Ten mobile phone base stations erected in densely populated areas of the city and operating in two frequency ranges of 900 MHz and 1800 MHz were measured. Each base station had equilaterally positioned dishes and sector antennas so as to provide a 360° network coverage. The primary beam from each MPBS emitted RF radiation at a 20° angle (from the horizontal).

The city is located in hilly terrain, so that some dwellings are positioned horizontally in line of site of the towers. This configuration creates RF-EMF exposure at distances ranging from 1 to 20 m for all dwellings on the nearby slope, regardless of whether the towers are set up on rooftops or on the ground. Figure 1 illustrates the proximity of base stations to people homes and also how the base stations are placed on the hilly terrain.

Selection of participants

Around each mobile base station, a minimum of two people were sampled. Participants were recruited via door knocking of all houses around the towers, mostly in the evenings during both weekdays and weekends. The purpose of the study was described to the resident,



(a) (b)

Figure 1. (a) A base station located within 20 m of a residence, and (b) the undulating terrain with base stations emitting microwave range RF-EMF signals, both above some dwellings, but also beaming directly into others.

Table 1. Composition of selected base stations.

Base station	1	2	3	4	5	6	7	8	9	10
Disc-antenna (n)	6	4	5	4	1	6	8	5	9	4
Sector-antenna (n)	6	6	8	16	4	6	6	8	6	3
Power density (mW/m^2)	2.9–4.4	4.2–6.3	3.2–5.7	5.7–7.2	4.4–5.2	3.3–6.4	2.6–4.3	2.7–4.8	3.8–5.7	2.1–3.9
Electric field (V/m)	1.0–1.3	1.3–1.5	1.1–1.5	1.5–1.6	1.3–1.4	1.1–1.6	1.0–1.3	1.0–1.3	1.2–1.5	0.9–1.2

who was asked for their voluntary willingness to participate. If consent was given, a blood sample collection was conducted on a second visit by a trained nurse at a time that was convenient to the resident. This study was approved by the Human Ethics Committee, Mizoram University, Aizawl, India (No. MZU/HEC/2022/023).

The highly exposed group comprised 50 individuals over 18 years in good health and living within a 60-meter radius of a MPBS. Similarly, the reference group consisted of 51 individuals in good health who resided at least 300 meters away from any MPBS, matched to the highly exposed group in terms of gender and age. Participants were selected so as to ensure that the majority of their exposure came consistently from the local MPBS and not from work exposures, in the following ways. Participants who were included in the highly exposed group as well as about half of the reference group were those who stayed at home during the day due to being home-makers or unemployed. Furthermore, participants who were included in the reference group (i.e. living more than 300 m from the MPBS) were screened to ensure that they were not being highly exposed at work (i.e., that any MPBS near to their workplace was also more than 300 m away). Selection also ensured that there were no electric transformers, high voltage electrical power lines, radio transmitters, or television transmitters within 500 m of any of the participant's homes, so as to minimize any effects from these potentially confounding factors. Table 1 summarizes the characteristics of the ten MPBS.

Blood sample collection

A qualified nurse performed venipuncture to draw blood from the volunteers in both the highly exposed and reference groups. The nurse was hired to take blood samples, and was blind to the status of the participants in that she was not involved in the hypothesis, nor was she aware of the distance to the MPBS or its purpose in the study. Blood samples were taken around the same time of day, in the afternoon, for most participants. They were coded for anonymity and blinding purposes and then stored in a separate heparinized tube for further processing. Private laboratory technicians who were not aware of the study purpose assessed the coded CBC and serum assays. These analysts were thus

completely blinded to the exposure status of the participants. Details of the methods used for blood analysis are given in Appendix A.

Hematological parameters and stress-related biomarkers associated with RF-EMF exposure were assessed by using: (i) complete blood count (CBC), a highly appropriate and efficient laboratory test used to assess potential health hazards (Waris et al. 2021) and (ii) levels of amylase (an enzyme) and cortisol (a hormone) in blood serum, which are stress markers (Augner et al. 2010) that have been used in experiments related to effects of RF-EMF (see above).

A complete blood count (CBC) includes hemoglobin count, packed cell volume (PCV), RBC count, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin count (MCHC), red cell distribution width (RDW), platelet count and mean platelet volume. Importantly, a CBC also includes detailed information about leucocytes (white blood cells); i.e. total leucocyte count (TLC) and the absolute and differential counts of five types of leukocytes: neutrophils, lymphocytes (B cells and T cells), monocytes, eosinophils and basophils. The absolute leukocyte counts indicate the amount of each leukocyte in a given volume of blood (e.g. mm^3) in the sample. The differential leukocyte counts indicate what percentage each type of leukocyte contributes to the total count (based on all leukocyte types present).

Survey

A survey was used to collect data on demographics and behaviors, including years of mobile phone use, average daily mobile phone usage, years of residing near the mobile phone base station, distance of residence from the base station, and habits related to smoking, chewing of tobacco and betel nut, as well as alcohol consumption.

Power density measurements

Measurements for radio-frequency power density emitted by the base stations were taken in 50 houses, in the living room of each participant. A HF-60105V4 spectrum analyzer (Germany) was used for all RF measurements. Measurements were taken by a trained physicist competent in the use of the spectrum analyzer, who determined the average power density for the frequencies that were present (which was necessary because there is no official Indian government register for the region that describes tower placement and frequencies). Frequencies of 900 MHz and 1800 MHz were determined to be present in most residences, due to several towers being close by. The maximum recorded power density was 7.22 mW/m^2 (1.65 V/m) near base station number 5 (see Table 1). The safety limits for public exposure from mobile phone base stations are set to 0.45 W/m^2 (450 mW/m^2; 13 V/m) for 900 MHz and 0.90 W/m^2 (900 mW/m^2; 18.4 V/m) for 1800 MHz frequency as prescribed by the Department of Telecommunications, Ministry of Communications, Government of India, New Delhi guidelines (DoT 2013). The distance from each residence to the nearby MPBS was determined using a digital laser tape measure (Bosch, GLM).

Statistical analysis

The data for each variable (blood and serum markers and questionnaire responses) were subjected to between group t-tests so as to ascertain any significant difference between (i) the highly exposed and reference groups and (ii) levels of each of the demographic variables. Pearson`s correlation analysis was performed to determine the relationship between power density and the distance of residences from the base stations. Stepwise linear regression was used to investigate the extent to which exposures from MPBS, mobile phones, demographics and lifestyles factors predicted complete blood count and stress markers, by investigating both the unique contributions of these factors as well as combination effects. A p-value of less than 0.05 was considered statistically significant.

Results

Demographic and behavioral characteristics of the study groups

Table 2 depicts the demographic and behavioral characteristics of the highly exposed ($N = 50$) and reference groups ($N = 51$). All characteristics, such as age, gender, habit of chewing tobacco, smoking, alcohol consumption, or betel nut chewing, duration of mobile phone use and average daily use of a mobile phone were adequately matched between the highly exposed and reference groups, with the analysis showing no significant differences between groups.

As expected, the RF power density of the highly exposed group living within a perimeter of 60 m (average 4.6 mW/m^2; 1.3 V/m) was significantly higher than for the reference group living at least 300 m away from mobile phone base stations (average 0.05 mW/m^2; 0.14 V/m). For residences within 60 m of the base station, there was a negative correlation between distance from the base station and power density ($r = -0.67$, $p < 0.001$) (Figure 2).

Table 2. Power density statistics for the demographic and behavioral characteristics of the highly exposed and reference groups, with comparisons, showing no differences in characteristics between groups.

Characteristics		Highly exposed (*N*=50)			Reference (*N*= 51)					
		Category Descriptives		Power Density Descriptives (mW/m2)	Category Descriptives		Power Density Descriptives (mW/m2)			
	Category	N (%)	Mean (SD) [Min-Max]	Mean (SD) [Min–Max]	N (%)	Mean (SD) [Min-Max]	Mean (SD) [Min–Max]	*t*	X^2	*p*
Age (yr)	18–29	31 (65)	23.7 (3.4) [18–29]	4.8 (1.1) [2.1–6.7]	34 (67)	25.6 (2.2) [22–29]	0.05 (0.02) [0.02–0.09]			
	30–45	19 (36)	35.3 (4.5) [30–45]	4.8 (1.1) [2.6–7.2]	17 (33)	32.9 (3.7) [30–45]	0.04 (0.02) [0.02–0.09]			
	All	50	28.1 (6.8) [18–45]		51	28.0 (4.5) [22–45]		0.34		0.7
Gender	Male	27 (54)		4.9 (1.2) [2.6–7.2]	31 (61)		0.05 (0.02) [0.02–0.09]		0.19	0.7
	Female	23 (46)		4.6 (1.0) [2.1–6.3]	20 (39)		0.04 (0.02) [0.02–0.08]			
Tobacco chewing	Yes	12 (24)		4.6 (1.1) [2.6–6.3]	11 (22)		0.05 (0.02) [0.02–0.08]		1.72	0.2
	No	38 (76)		4.8 (1.1) [2.1–7.2]	40 (78)		0.05 (0.02) [0.02–0.09]			
Smoking habit	Yes	14 (28)		5.0 (1.3) [2.6–7.2]	23 (45)		0.05 (0.02) [0.02–0.09]		0.77	0.8
	No	36 (72)		4.7 (1.1) [2.1–6.4]	28 (55)		0.05 (0.02) [0.02–0.08]			
Alcohol	Yes	4 (8)		5.1 (0.9) [4.1–6.1]	3 (6)		0.03 (0.002) [0.03–0.04]		0.28	0.6
consumption	No	46 (92)		4.8 (1.1) [2.1–7.2]	48 (94)		0.05 (0.02) [0.02–0.09]			
Betelnut chewing	Yes	21 (42)		4.9 (1.3) [2.1–7.2]	24 (47)		0.05 (0.02) [0.02–0.09]		0.38	0.5
	No	29 (58)		4.7 (1.0) [2.7–6.7]	27 (53)		0.04 (0.02) [0.02–0.08]			
Family	Yes	13 (26)		4.9 (1.6) [2.1–6.7]	11 (22)		0.05 (0.02) [0.02–0.09]		0.10	0.8
cancer	No	37 (74)		4.8 (1.1) [2.6–7.2]	40 (78)		0.05 (0.02) [0.02–0.09]			
Mobile phone use (yrs)	≤10	27 (54)	6.7 (2.6) [3–10]	4.8 (1.2) [2.6–6.7]	24 (47)	8.3 (1.8) [5–10]	0.05 (0.02) [0.02–0.09]	−0.7		0.5
	>10	23 (46)	13.8 (2.5) [11–19]	4.8 (1.2) [2.1–7.2]	27 (53)	12.4 (1.4) [11–16]	0.05 (0.02) [0.02–0.09]			
	All	50	10.0 (4.4) [3–19]		51	10.5 (2.6) [5–16]				
Daily mobile phone use (hrs)	≤5	39 (78)	3.5 (1.3) [1–5]	4.8 (1.2) [2.1–7.2]	35 (69)	4.2 (0.8) [3–5]	0.05 (0.02) [0.02–0.09]	−2.0		0.07
	>5	11 (22)	6.1 (1.5) [6–10]	4.6 (0.8) [3.9–6.4]	16 (31)	6.9 (1.5) [6–10]	0.05 (0.02) [0.02–0.08]			
	All	50	4.3 (2.0) [1–10]		51	5.0 (1.6) [3–10]				
Years residing near base station	≤10	21 (42)	6.8 (1.7) [5–10]	4.2 (0.9) [2.1–6.1]	–	–	–			
	>10	29 (58)	15.5 (2.8) [12–20]	5.3 (1.0) [3.9–7.2]	–	–	–			
	All	50	11.8 (4.9) [5–20]		-	–	–			
Distance from MPBS (m)	1–20	23 (46)	10.0 (3.1) [5–17]	5.5 (0.9) [4.1–7.2]	–	–	–			
	21–40	15 (30)	29.5 (6.0) [21–40]	4.5 (0.6) [4.2–6.4]	–	–	–			
	41–60	12 (24)	44.2 (2.4) [41–48]	3.7 (0.8) [2.1–4.3]	–	–	–			
	All	50	24.1 (14.7) [5–48]		51	320.4 (183)				
Power density (mW/m^2)	All	50	4.8 (1.1) [2.1–7.2]		51	0.05 (0.02) [0.02–0.09]				

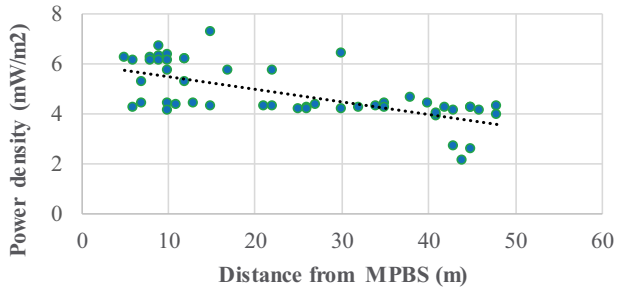


Figure 2. The relationship between power density and distance of residing for the exposed group living <60 m from the MPBS.

Overall, the intensity of exposures decreased as distance to the base station increased. However, there was some variation around this pattern (Figure 2). This was because some residences that are situated further away sit in direct line of sight of the MPBS, while others that are closer have other buildings partially blocking the signals. Moreover, some residences further away from the main MPBS may have had two or three towers beaming into their homes directly, giving a larger cumulative power density reading. Power density rather than distance was therefore used for the remaining analysis.

Changes in complete blood count (CBC) and exposure types

Table 3 provides an overview of where the blood cells and stress markers were found to be significantly different between the highly exposed and reference groups, for variations in mobile phone usage (years of use or daily exposure) and levels of high exposure to MPBS (≤ 4 mW/m^2 or >4 mW/m^2; ≤ 1.2 V/m or >1.2 V/m). Also shown are any differences between the high and low sub-categories of each of the two mobile phone usage variables, and between the two high exposure MPBS groups, that occurred for either of the exposed or reference groups.

The results shown in Table 3 reveal that various blood parameters showed significantly greater levels in the highly exposed group compared to the reference group. These differences occurred for total leukocyte count (TLC), differential basophils and neutrophils and absolute lymphocytes, monocytes and basophils, in those using mobile phones for ten years or more.

Similar differences occurred for total leukocyte count (TLC), differential basophils and absolute lymphocytes, in those using mobile phones for 5 hours per day or more (see Figure 3(a) for differential basophils).

Furthermore, for those who were highly exposed to MPBS only, residents who used mobile phones for more than 5 hours per day showed higher levels of MCV, differential basophils, and absolute lymphocytes, eosinophils and basophils than those who used their mobile phones for less time (see Figure 3(b) for absolute basophils).

In the MPBS exposed group only, the stress marker amylase was higher for those using mobile phones for 10 years or more. Similarly, in this group, some of the blood parameters were moderated by the power density of their RF exposures from the MPBS. Those exposed with >4 mW/m^2 (>1.2 V/m) had greater counts of differential lymphocytes and basophils as well as absolute lymphocytes and basophils, and higher levels of the stress marker amylase, than those with exposures that were ≤ 4 mW/m^2 (≤ 1.2 V/m).

The blood parameters for the highly exposed group only were not affected by the number of years that residents had been residing (when comparing 5–10 yrs versus 11- 20 yrs) or the distance from the base station when comparing 1–20 m, 21–40 m and 41–60 m. These null results are not shown in the table.

Overall, the results in Table 3 suggest that long-term and high mobile phone use together with higher MPBS exposures created stress responses and immune system changes. Supplementary document A provides full details of the above analyses, along with the normal reference ranges for each of the CBC parameters and the average CBC parameter values for each group-exposure characteristic combination. Supplementary document C provides the full illustrations of the corresponding interactions between group (MPBS highly exposed versus reference) and exposure characteristics.

Changes in CBC due to MPBS exposures, demographics and lifestyle behaviors

It is known from the literature that blood counts are influenced by age, sex and race; e.g., RBC associated blood parameters tend to take higher values in males than females, generally for those under 60 years of age (Qiao et al. 2014; Beeraka et al. 2023). Furthermore, age, gender and lifestyle factors have been shown to influence stress response patterns (Fukuda and Morimoto 2001; Novais et al. 2017). Therefore, as well as the experimental variables, potential effects of demographics and lifestyle were investigated.

Table 4 provides an overview of the blood and stress markers that were found to be significantly different between the highly exposed and reference groups, for the demographic and behavioral characteristics examined. Also shown are where any differences occurred between the two categories of the demographic or

Table 3. Summary of significant differences (red or orange) found in blood and stress markers between the highly exposed and reference groups, according to mobile phone or MPBS exposure type. Also shown are significant differences between the two categories of each of the exposure variables within the highly exposed (e) or reference groups (r).

Mobile phone usage and exposures	Total pop.	Mobile phone use (yrs)		Daily mobile phone use (hrs)		Power density (mW/m^2) (Exposed only)	
	All	≤ 10	> 10	≤ 5	> 5	≤ 4	> 4
Blood Marker							
Hemoglobin (g/dL)							
PCV (%)							
RBC Count							
MCV (fL)					e		
MCH (pg)							
MCHC (g/dL)							
RDW (%)							
TLC							
Segmented Neutrophil (%)							
Lymphocytes (%)							e
Monocytes (%)							
Eosinophils (%)							
Basophils (%)					e		e
Neutrophils							
Lymphocytes					e		e
Monocytes							
Eosinophils					e		
Basophils					e		e
Platelet count							
Mean platelet volume							
Stress Marker							
Amylase (U/L)			e				e
Cortisol (nmol/L)							

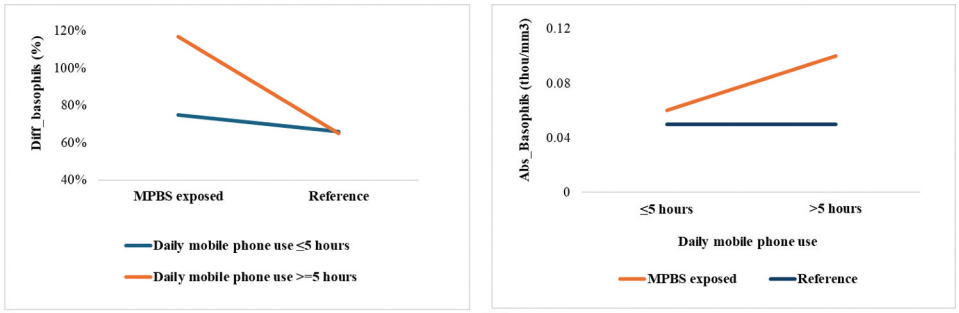
Key		
Significant differences between the exposed and reference groups.		(p ≤ 0.05
		(p ≤ 0.01)
		No diff.
Significant differences between the levels of a demographic (see note).	**e:** Within the MPBS highly exposed group, a significant difference between the two categories of the demographic (p ≤ 0.05).	
	r: Within the reference group, a significant difference between the two categories of the demographic (p ≤ 0.05).	

Note: Significant differences are always indicated in the column representing the category of the demographic that had the highest value; e.g. in the daily mobile phone use category, an 'e' or 'r' in the '>5' column indicates that blood marker levels for those using phones for more than 5 hours were greater than for those using mobile phones less than or equal to 5 hours, for the exposed (e) or reference groups (r).

behavioral variables within the highly exposed and reference groups separately.

Table 4 shows that CBCs varied with both demographics and lifestyle behaviors, with some interactions with exposure group. The MPBS highly exposed group had greater differential basophil counts than the reference group, irrespective of age group. However, age moderated the effect of exposure for some of the other blood parameters. The highly exposed group showed greater counts for absolute lymphocytes and basophils and higher amylase levels in those under 30 years, but greater counts for differential basophils, absolute monocytes and higher cortisol levels for those 30 years and over. In the highly exposed group only, the cortisol levels were higher for the older group than for the younger group.

Gender also moderated the effects of exposures on the blood parameters. In both the highly exposed and reference groups, males had overall higher RBC, Hb,



(a) (b)

Figure 3. (a) Variation of differential basophil counts between exposed and reference groups for higher and lower daily mobile phone use; and (b) Variation of absolute basophil counts between higher and lower daily mobile phone use for MPBS highly exposed and reference groups.

Table 4. Summary of significant differences (red or orange) found in blood and stress markers between the highly exposed and reference groups, according to demographic and behavioral characteristics. Also shown are differences between the two categories of the demographic or behavioral variables within the highly exposed (e) or reference groups (r).

Demographic/Behavior	**Age (yr)**		**Gender**		**Tobacco Chewer**		**Smoker**		**Alcohol**		**Betel nut**		**Family cancer**	
Category	18-29	30-45	M	F	Y	N	Y	N	Y	N	Y	N	Y	N
Complete Blood Count parameters														
Hemoglobin			e, r			e	e, r							
PCV			e, r			e	e, r				e, r			
RBC Count			e, r			e						e		
MCV			e, r				e, r		e, r		e, r			
MCH			e, r						e, r					
MCHC														
RDW				e										
TLC										e				
Differential Leukocyte Count (%)														
Segmented Neutrophils (%)														
Lymphocytes (%)														
Monocytes (%)			e, r						e					
Eosinophils (%)														
Basophils (%)			e, r											
Absolute Leucocyte Count														
Neutrophils														
Lymphocytes			r											
Monocytes			e, r				e, r							
Eosinophils			r								r			
Basophils			r											
Platelet count				e, r										
Mean platelet volume														
Stress Markers														
Amylase					e		r		e					
Cortisol		e					e							

Key		
Significant differences between the exposed and reference groups.		($p \leq 0.05$
		($p \leq 0.01$)
		No diff.
Significant differences between the levels of a demographic (see note).	**e:** Within the exposed group, a significant difference found between the two categories of the demographic ($p \leq 0.05$).	
	r: Within the reference group, a significant difference found between the two categories of the demographic ($p \leq 0.05$).	
Note: Significant differences are always indicated in the column representing the category of the demographic that had the highest value; e.g. in the Gender demographic the ' M' column is used to show where levels for males were significantly higher than for females in either the exposed (e) or reference group (r).		

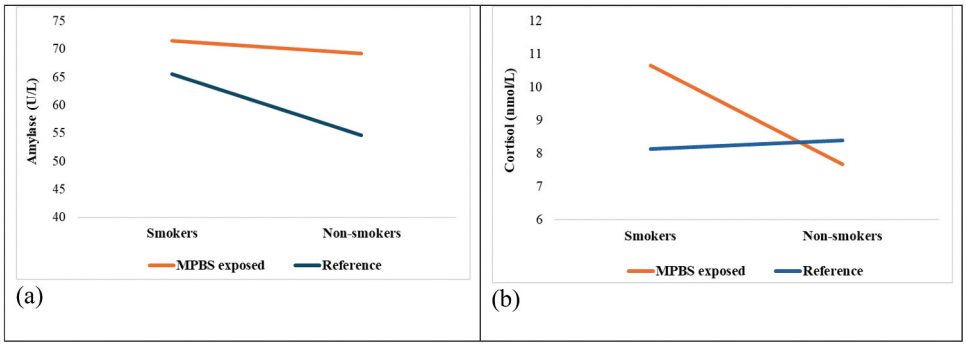


Figure 4. Variation between smokers and non-smokers for the MPBS highly exposed and reference groups for (a) amylase levels and (b) cortisol levels.

PCV, MCV and MCH, as predicted by the literature. However, highly exposed males had a significantly lower RDW than the females.

While males in both groups had higher counts than females for differential and absolute monocytes and differential basophils, it was only in the reference group that males had higher counts of absolute lymphocytes, eosinophils and basophils than females. For males only, those in the MPBS highly exposed group showed significantly higher absolute monocyte counts and amylase levels than those in the reference group. On the other hand, only the females showed higher TLC, and higher absolute and differential basophil counts in the exposed group as compared to the reference group. Furthermore, females in both groups had higher blood platelet counts. Thus, gender seems to interact with MPBS exposure in different ways for different blood parameters.

Tobacco chewers in the MPBS exposed group had higher mean platelet volume than those in the reference group. In the exposed group only, tobacco chewers had higher amylase levels compared to non-chewers. On the other hand, non-tobacco chewers in the highly exposed group had significantly higher Hb, PCV, and RBC counts than the tobacco chewers.

The pattern of results for smoking is similar to the pattern of results for males, in that smoking had effects on some of the blood and stress markers, irrespective of level of exposure to MPBS. Smokers in both the exposed and reference groups had higher levels of Hb, PCV, MCV and absolute monocytes than the non-smokers.

The results indicated that amylase levels were affected by exposure group separately from smoking. Exposed smokers showed elevated amylase levels compared to reference (unexposed) smokers. However, exposed non-smokers also had high amylase levels, notably higher than those of reference non-smokers and closer to the amylase levels of the exposed smokers (see Figure 4(a)).

In contrast, the pattern for cortisol only showed effects from both smoking and exposure group combined. Exposed non-smokers had lower levels than exposed smokers, aligning with the levels seen in both the reference group smokers and the reference group non-smokers (see Figure 4(b)).

On the other hand, differential and absolute basophils varied only for the non-smokers, where they were higher for the exposed group than for the reference group. Monocytes were higher in the MPBS highly exposed group for both smokers and non-smokers. Together these results suggest that smoking seems to interact with exposure to MPBS in different ways for different blood parameters.

The number of alcohol drinkers sampled in this study was very small (Table 2), and most of the highly exposed participants were non-drinkers, so that the alcohol results are more of an indication of the effects of MPBS exposures overall. Therefore, alcohol consumption was excluded from the remaining analyses.

Similar to smoking, betel nut chewers in both groups had significantly higher PCV and MVC levels than non-chewers. Betel nut chewers also had higher eosinophils in the reference group only. The MPBS highly exposed betel nut chewers showed higher levels than the reference chewers of Hb, RBC and absolute monocytes counts, while absolute and differential basophils and amylase levels were significantly higher in the highly exposed group for non-chewers.

The overlaps in the patterns of results shown above for the males, smokers and betel nut chewers, may be due to the fact that smokers and betel nut chewers were mostly male. This conjecture is confirmed by the significant Spearman's correlations between males and these lifestyle choices ($r_{gender,\ smoking} = 0.56$; $r_{gender,\ betel\ nut} = 0.38$, both $p < 0.01$).

Effects of MPBS exposure were influenced by family history of cancer for absolute monocytes only (Table 4). The full results of the demographic and lifestyle analysis

can be found in Supplementary document B, and the full set of graphs depicting the corresponding interactions can be found in Supplementary document C.

Overall, the results shown in Tables 3 and 4 suggest that greater exposure to RF-EMF affects white blood cell production, and that changes in blood parameters are due to a combination of exposure to MPBS and mobile phones, as well demographic and lifestyle factors.

Relative contribution of all variables to changes in blood parameters

The above descriptive analyses suggest that there were complex interactions between the various the demographic, behavioral and exposure variable factors investigated in this study, with overlaps between variables such as gender and smoking. In order to ascertain the important factors contributing to each of the blood markers, stepwise linear regression analyses were conducted. This type of analysis allows the most important factors to be found, by omitting factors that may appear to make an important contribution to outcomes, but only because they co-vary with other, truly important factors. Moreover, it lets the statistics inform as to which are the important factors, thereby reducing the bias of the researcher in modelling.

The blood parameters from Tables 3 and 4 that were most indicative of differences between highly exposed and reference groups were used as the outcome variables (i.e. TLC, absolute and differential basophils, monocytes, lymphocytes, amylase and cortisol). The exposure, lifestyle and demographics from Tables 3 and 4 that effected outcomes were also included as predictors. In addition, both variables describing mobile phone use (hours of daily use and years of use), exposure to mobile phone base stations power density (mW/m^2), and terms for the interactions of MPBS power density (mW/m^2) with age (years), gender and mobile phone use, as well as terms for the interactions of mobile phone use with age (years) and with gender were included as predictors.

Overall, this set of analyses investigated the differential contribution towards the blood parameters of exposure to MPBS and mobile phone usage, while also considering the contributions made by behavioral and demographic factors, plus any moderating effects of those factors on one another. The results are summarized in Table 5.

These results revealed that having greater MPBS exposures made it more likely that a resident would have higher counts of TLC, differential and absolute basophils, and absolute monocytes. Being male resulted in an even greater increase in monocyte counts than MPBS exposure alone (Figure 5(a)). Similarly, being over 30 years old resulted in an even greater increase in absolute basophils counts than MPBS exposure alone. Being a smoker made it more likely that a resident would have higher counts of absolute monocytes.

On the other hand, using a mobile phone for more hours per day made it more likely that a resident would have lower counts of differential and absolute basophils as well as absolute lymphocytes. The effects were moderated by gender; i.e., as daily mobile phone hours increased, females showed a greater rate of decline in differential and absolute basophils counts, while males showed a slightly greater rate of decline in absolute lymphocytes (Figure 5(b)).

Being a non-smoker or being 30 years or over made it more likely that a resident would have lower amylase levels; however, these factors dominated outcomes so that this stress marker showed no significant affects from exposures to MPBS or mobile phones. Similarly, cortisol levels showed no main effects or interactions with other factors

Table 5. Summary of demographics, behaviors, use of mobile phones or MPBS exposures that made a significant contribution to blood parameters or stress markers in the stepwise regression analyses.

Blood parameter	Proportion of total variance	Significant Contributing Factors	Description of the effects on the blood parameter
Total Leukocyte Count	5%	MBPS Power Density *	Increase with greater MPBS exposure
Differential Basophils	13%	MBPS Power Density ** Gender x Daily MP *	Increase with greater MPBS exposure Decrease with greater Daily MP use and females decline more rapidly
Absolute Basophils	18%	MBPS Power Density *** Age x Power Density ** Gender x Daily MP **	Increase with greater MPBS exposure and 30+ increase slightly more rapidly Decrease with greater Daily MP use, and females decline slightly more rapidly
Absolute Lymphocytes	8%	Gender x Daily MP**	Decrease with greater Daily MP use, and males decline slightly more rapidly
Absolute Monocytes	23%	MBPS Power Density *** Gender x Power density * Smoking **	Increase with greater MPBS exposure Males increase slightly more rapidly Smokers higher
Amylase^{+}	17%	Smoking *** Age **	Non-smokers higher Under 30 years old higher

Key: *p <0.05; **p <0.01; ***p <0.001 $^{+}$One outlier was removed from the amylase analysis.

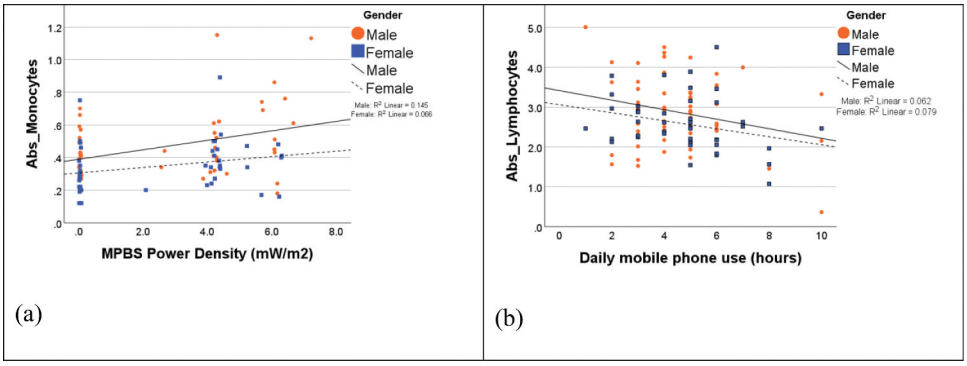


Figure 5. The moderating effect of gender on (a) the increase in absolute monocytes with increasing power density of exposure to MPBS and (b) the decrease in absolute lymphocytes with increasing hours of daily mobile phone exposure.

in the linear regression analysis. Even though amylase and cortisol had shown effects of exposures in the categorical analysis (Table 4) these were not apparent in the linear regression analysis that used continuous exposure values and that controlled for overlap between factors. Several of the cofactors present in this field study would have contributed to a wide range of individual variability in these stress markers.

Supplementary document D shows the full regression statistics and all graphs describing the main effects and interactions for the factors that were significant.

Blood parameters outside the reference limits

While some of the blood parameters in Table 5 were significantly altered by increasing exposure levels, it is more concerning when these parameters are found to be above or below the limits of their normal ranges (see Supplementary documents A and B). The blood parameters showing significant effects were therefore further investigated so as to determine what proportions of individuals lay outside the reference limits (Supplementary document E).

Of the MPBS highly exposed residents (living closer than 60 m to the MPBS) 24% (12) had absolute basophil counts above the upper limit, the majority of whom were under 30 years old. In addition, two individuals had absolute monocyte counts above the normal upper limit. On the other hand, 10% (5) residents living further than 300 m from the MPBS had absolute basophil counts above the normal upper limit. These results suggest that exposure to the MPBS altered absolute basophils, with about a quarter of the residents being affected, the majority of whom were under 30 years old.

The number of mobile phone users with absolute lymphocyte counts above or below the reference limits was also investigated for the exposed and reference groups combined (Supplementary document E). The data was divided into three daily mobile phone usage groups, and broken down by age group. The greatest usage group was made up of those using mobile phones for 4 to 6 hours a day. Of these, over 50% had absolute lymphocyte counts above the reference limits, the majority of whom were under 30 years old. Moreover, as daily mobile phone use increased, the proportion in each usage group showing excessively high absolute lymphocyte counts first increased but then decreased. In the highest usage group, one person using a mobile phone for 10 hours a day, had an absolute lymphocyte count below the reference limit. Figure 6 depicts the overall inverted U-shaped pattern that emerged from this analysis.

This non-linear mobile phone exposure-effect relationship may explain why the linear regression results for lymphocytes found a decline in WBC with increasing hours for mobile phone use (see Figure 5(b)); i.e., the relationship was better described by a non-linear inverted-U shape curve, but because there were more data points on the declining side of the curve, these dominated the linear regression line-of-best-fit.

If it is the case that a hormesis-type response curve is being described by the data, then this suggests that the effects of the more distant but long term MPBS exposures are akin to the closeup, shorter daily mobile phone exposures, in that both types of exposures show an increase in the immune response with increased exposures. However, as stress from mobile phone usage hours increases even more, a depletion of the immune response then occurs.

Discussion

This study was aimed at gaining a deeper understanding of the biological effects of RF-EMF on individuals residing in close proximity (within 60 m) to MPBS, in addition to any effects from their mobile phones. Assessing blood parameters is an important method for

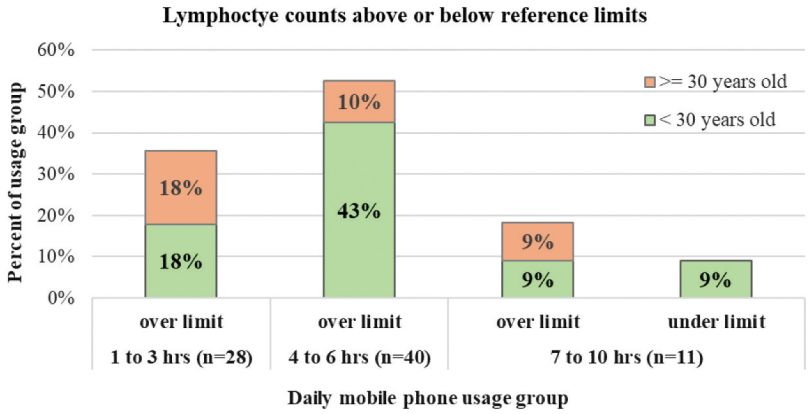


Figure 6. The proportion of each of three mobile phone daily usage groups with absolute lymphocyte counts above or below the reference limits, broken down by age group.

determining the health condition of an individual. Among the different blood parameters tested, differential and absolute basophils as well as absolute monocytes were found to be most indicative of greater exposures to MPBS while absolute lymphocytes were found to be most indicative of higher daily mobile phone exposures. These effects were moderated by combinations of demographics, behaviors and duration of exposures (Tables 3 and 4, and Supplementary document D). In particular, gender, age and smoking affected some of the blood parameters. Notably, power density from MPBS exposures had an influence on absolute monocytes similar to smoking (Table 5).

The effects from the long-term MPBS exposures on WBCs showed a linearly increasing pattern, while the effects of daily mobile phone exposures seem to be non-linear increasing then decreasing, suggestive of the immune system making a typical hormesis type of adaptive response to an external toxic stressor (Calabrese and Baldwin 2003). In the case of RF-EMF exposures, the immune response seems to vary with both strength of exposure (seen in both the MPBS and daily mobile phone use data) and duration of exposure (seen in the daily mobile phone use data), with an eventual decline in the immune response as exposures continue to increase.

Rather than suggesting that there are 'no consistent effects,' these results can be interpreted as suggesting that different blood cells respond differently to the different waveforms, intensities and durations of RF-EMF signals. Such non-linear responses have been described previously for a range of RF-EMF induced outcomes (Lai and Levitt 2022; Weller et al. 2025).

The levels of some of the white blood cell counts were found to be above the upper limits of their reference range. About a quarter of the highly exposed MPBS group were found to have absolute basophil counts above the upper limit, while over half of those using mobile phones for 4 to 6 hours a day were found to have absolute lymphocyte counts above the upper limit. In both cases, the majority were younger people less than 30 years of age.

The inconsistent results for cortisol and amylase results are supported by the literature describing complex interactions between demographics, lifestyle factors and stressors on amylase and cortisol (Novais et al. 2017). Age together with smoking were the main factors affecting amylase levels. These findings may nuance the understanding of previous results showing amylase enzyme increases among highly exposed individuals in a wide age range (18 to 67 years) (Augner et al. 2010), in students (8–24 years old) with high mobile phone use (Shivashankara et al. 2015), and in highly exposed younger rats (Topsakal et al. 2017).

Cortisol levels were not well explained by any of the factors studied, consistent with previous results showing no cortisol elevations in exposed workers from a wide age range (20–59 yrs; Dasdag et al. 1999). The null results of cortisol-EMF studies (including ours) may be due to the cross-sectional nature of the data collection, together with significant individual variation (Augner et al. 2010) based on the multiple complex moderating effects of the demographic and lifestyle factors on cortisol (Fukuda and Morimoto 2001; Kudielka et al. 2009). Similarly, the null results of a recent short-term provocation study (Verrender et al. 2025) may be due to individual variation in cortisol responses and recovery timing (Young et al. 2021). Indeed, when individual variation was minimized in a longitudinal study (1 to 6 years, within subjects) decreasing cortisol activity over time was evident, from both MPBS exposure and mobile phone use (Eskander et al. 2012). Overall, however, it appears that cortisol is not

a reliable biomarker for indicating stress-related effects of RF-EMF. In the current study, a wider range of blood parameters were tested, revealing significant hematological and immunological effects from exposures.

The MPBS blood parameter results emerging from this study corroborate the results of a related study conducted within the same hilly region of Mizoram, India, which investigated a range of health symptoms experienced by residents living nearby the MPBS (Sailo et al. 2025). A higher proportion of those living in closer proximity to the mobile base stations reported experiencing a range of health symptoms, including increased infections and allergies that were more prevalent in those under 40 years old. Given that elevated WBC counts are indicative of increased allergic reactions and inflammation, these two studies together suggest closer proximity to base stations is associated with an immune system under stress, in particular for residents under 30 years of age.

The results presented here also shed light onto the debate as to whether long-term far-field exposures from MPBS affect biological systems separately from the more intense near field exposures produced by personal mobile phones. The results indicate that the effects may be combinative, in that both exposure types have an effect on various white blood cells (Table 5). Also, there is a suggestion that the overall effects being observed may be due to a combination of a non-linear response to mobile phones, occurring as hours of daily exposures increase (Figure 6), combined with a linear response from chronic high-level MPBS exposures (Supplementary document D).

The non-linear effects suggested here from mobile phone use need to be investigated more fully in future studies by taking multiple blood samples within participants at regular intervals throughout the day as mobile phone hours increase. The possibility of similar effects from MPBS exposures will require much larger sample sizes than the current study, so as to allow for systemic investigations of the various combinations of waveform, intensity and duration.

The complexity of the results of this study may help to explain inconsistencies in the WBC literature, where some studies show increases and others show decreases from RF-EMF exposures. For example, higher RF-EMF exposures have resulted in increases in monocytes (Al-Uboody 2015) and WBC (Christopher et al. 2020), but also, decreases in WBC (Kumari et al. 2016; Sani et al. 2018). Our results have shown that some WBC increase while others decrease as a result of RF-EMF exposures, and moreover, non-linear hormesis-type responses may occur over time. Consideration of these factors in future work may help to unravel the mysteries.

An interesting finding was that MPBS exposures and mobile phone exposures affected different blood parameters in different ways, which is consistent with the literature describing how different leucocytes respond differently to stress (Dhabhar et al. 2012). Both MPBS and mobile phone exposures affected basophils, which release histamine to fight allergies and to respond to toxins (Schwartz et al. 2016). However, only MPBS exposures affected monocytes, in a manner similar to the effects of smoking (a known long-term low-level stressor that accumulates damage over time). Monocytes migrate from the blood into inflamed tissues, and transform into macrophages where they can create chronic inflammation (Coillard and Segura 2019). Monocytes were the only WBCs where the difference between the MPBS highly exposed and reference groups was moderated by family history of cancer (Table 4).

On the other hand, daily mobile phone exposures mostly affected lymphocytes, which underly the adaptive immune response, comprising T-cells and B-cells that are marshalled to fight pathogens and create antibodies, but which may be depleted after long-term stress (Alberts et al. 2002). Notably, T-cells develop in the thymus (Thapa et al. 2019a) close to where mobile phones signals radiate into the body.

Alterations in these WBC parameters typically indicate human systems under stress, leading to potential health problems. High levels of basophils and monocytes are indicative of acute stress, or of the immune system battling a pathogen, infection or an inflammatory allergic reaction (Siracusa et al. 2013; Kim et al. 2019) or chronic inflammation for certain hematologic disorders such as chronic myelogenous leukemia (Pincus and Abraham 2011). Very high levels of these white blood cells can be a sign of more serious conditions like leukemia or auto-immune conditions like rheumatoid arthritis (Syed and Pinals 1996; Riley and Rupert 2015). Lymphocytes usually decline with age (Müller et al. 2019), so that the decline seen here in the younger population is concerning.

The stress-based impact of RF-EMF on cellular health is linked to oxidative stress, which is known to be induced by EMR exposure as well as subsequent products of cell damage, including DNA and mitochondrial damage. Various products of stressed and damaged cells then trigger immune responses through the activation of DAMPS pathways (Patel 2018).

Future research is needed so as to further investigate which specific mechanisms and pathways may be responsible for the observed increases in the different WBCs, and the proposed increases in oxidative stress.

Possibilities for investigation include the activation of specific inflammatory signaling pathways (e.g., NF-κB, inflammasomes) or damage-associated molecular patterns (DAMPs) specifically within isolated monocyte and basophil populations from exposed individuals. Other pathways for investigation include (i) whether the observed increase in monocytes reflects a skewing towards a pro-inflammatory M1 phenotype due to RF-EMF induced oxidative stress; and (ii) whether the rise in basophils indicates a chronic, sub-clinical hypersensitivity reaction (measuring degranulation markers like histamine could clarify whether RF-EMF activates these pathways).

The finding that human lymphocytes respond to RF-EMF exposures may also be related to the recent discovery that lymphocyte T-cells are intrinsically sensitivity to blue and UV light, even at relatively weak intensities, given enough time (Phan et al. 2016). UV light and RF-EMF are both forms of non-ionizing radiation. It is therefore possible that these similarities cause lymphocytes to be directly responsive to RF-EMF. This possibility needs further investigation.

A limitation of this study was that it was cross-sectional in design, so that no long-term data was available to show cumulative changes over time. However, all of the highly exposed participants in this study had dwelt in their residence for more than five years, so we can assume with some degree of confidence that their blood parameter levels were based on cumulative responses to long-term MPBS exposures. Longitudinal studies are needed for accurately ascertaining long-term, cumulative effects on blood parameters.

A further limitation was that only single-point power density measurements were taken, so that the range of power density fluctuations over time is not captured in residences. Furthermore, in this real-world field study, it was impossible to separate out the effects of different frequencies, modulations or pulse rates on the individual blood parameters. Both dominant MPBS frequencies (900 and 1800 MHz) appeared in most residences. It is known that different signal characteristics differentially affect different cells, tissues and organs. For example, a month of daily 1800 MHz laboratory exposures had more of an effect on rat brains than 900 MHz exposures (Dasdag et al. 2023). However, a recent review has shown that both 900 MHz and 1800 MHz exposures have damaging effects on DNA (Weller et al. 2025). Therefore, it is possible that both frequencies present were affecting the blood parameters tested.

A further limitation of this study is that it did not assess the effects of exposure from blue-tooth headsets, WiFi modems or other personal or devices, that could have added significant amounts of noise to the data. In order to tease out the effects of the frequencies contributed by these sources, personal long-term dosimeters are recommended for future field studies. Furthermore, to assess future effects of 'polyfrequency' (McCredden et al. 2022), the current study could serve as a baseline comparison for investigating any changes that occur when 5 G frequencies (e.g., 700 MHz, 3.6 GHz and 5 GHz) are added to the Mizoram region in the future. It is also possible that there were higher millimetre wave frequencies being used for point to point, backhaul or satellite communications, which includes MWA and MWB signals in the 13 to 21 GHz range (Telecom Regulatory Authority of India 2023). However, monitoring equipment available to researchers does not measure these frequencies. The effects of frequency, modulation and duration on the blood parameters need to be systematically investigated in future studies using better equipment as it becomes available.

An important contribution of this study is the revelation of the extent of daily mobile phone use in the community, which is much greater than that noted in previous studies. For example, those classified as 'highly exposed' spent less than one hour per day on average talking on the mobile phone (Bektas et al. 2020). Similarly, those classified with 'strong' mobile phone exposures used their phones for more than one hour per day (Eskander et al. 2012). Importantly, Hardell et al. (2013) found a high-risk of brain tumors occurring in those who used their phones for a cumulative 2000 hours or more, which equated to about 40 minutes a day for ten years. The current study reveals how much daily mobile phone habits have changed since that time, in that most people are now spending between four to six hours per day using their mobile phones. The potential increased risk from greater time spent on the phone per day is exacerbated by revelations that everyday mobile phones violate the ICNIRP regulatory limits in their exposures to the head and body (Phonegate Team 2025).

The RF-EMF power density levels around MPBS values recorded in this study were in the range of 2 to 7 mW/m^2 (0.9 to 1.6 V/m), which are significantly lower than both the current ICNIRP safety limit for 900 to 1800 MHz of 4700 – 9000 mW/m^2 (41.2 – 58.2 V/m) as well as the present Indian Standard. However, biological effects were still found on residents living close by to MPBS, at levels 100 times lower than these safety limits. Furthermore, the emission levels recorded around the base stations in this study exceeded the much more conservative safety guidelines of 3 to 6 $\mu W/m^2$ (0.03 to 0.05 V/m) that have been proposed by the Bioinitiative Report (2012).

Conclusions

The present study indicates that exposures to RF-EMF from nearby mobile phone base stations at levels lower than government recommended public safety limit values, could lead to significant changes in blood cells for individuals highly and continuously exposed to MPBS with some potentially concerning results for basophils in those under 30 years old. Moreover, the study has revealed the high extent of use of modern mobile phone use in this community, with some concerning effects on lymphocytes for those under 30 years old.

Such changes are indicative of persistent stress occurring to human biological systems. These results should not be disregarded and must be considered as an important public health concern, in particular, for the vast numbers of residents living in close proximity to MPBS all over the world, and those using their mobile phones for many hours a day. Safety guidelines for the roll out of MPBS, and education on prudent use of mobile phones need to be developed as a priority for public safety.

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Disclosure statement

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Data availability statement

The article contains all the data necessary to understand the conclusions of this investigation.

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Appendix A (Blood Analysis)

Chemicals used

The ABX Pentra XL 80 reagents were purchased from HORIBA India Pvt. Ltd, New Delhi, India. The α-amylase EPS ver. 2 and Elecsys Cortisol II were purchased from Roche Diagnostic Pvt. Ltd (Mumbai, India).

Complete blood count

The Complete blood count was analysed using an automatic haematology analyzer (ABX Pentra XL80). The blood routine indicators included haemoglobin, packed cell volume (PCV), RBC count, mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean corpuscular haemoglobin count (MCHC), red cell distribution width (RDW), total leucocyte count (TLC), differential leucocyte count, absolute leucocyte count, platelet count and mean platelet volume.

Amylase level

Serum was obtained from whole blood by centrifugation at 2000 g for 10 min. The Amylase test was conducted using an enzymatic colorimetric assay recommended by IFCC (International Federation of Clinical Chemistry) using a commercially available kit (α-amylase EPS ver. 2, Mannheim, Germany). Briefly, the substrate 4,6ethylidene(G_7) pnitrophenyl(G_1) αDmaltoheptaoside (ethylideneG_7PNP) was cleaved under the catalytic action of αamylases. The G_2 PNP, G_3PNP and G_4PNP fragments so formed were completely hydrolyzed to pnitrophenol and glucose by αglucosidase. The colour intensity of the pnitrophenol formed is directly proportional to the αamylase activity. The activity of αamylase was then determined by measuring the increase in absorbance at 415 nm using Roche Cobas Integra 400^{+}.

Cortisol level

After collection of whole blood, serum was separated from the clot by centrifugation at 1000 g for 10 min. Cortisol level was measured via electrochemiluminescence immunoassay using a commercially available kit (Elecsys Cortisol II, Roche, Mannheim, Germany). Briefly, 10 µl of serum was incubated with a cortisol specific biotinylated antibody and a ruthenium complex labelled cortisol derivative. After addition of streptavidin-coated microparticles, the complex was bound to the solid phase through the interaction of biotin and streptavidin. The reaction mixture was then aspirated into the measuring cell where the microparticles were magnetically captured onto the surface of the electrode. ProCell M was used to remove the unbound substances and the application of a voltage to the electrode induced chemiluminescent emissions that were then measured by a photomultiplier (Cobas e 411 Analyzer).