



Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en



Original article

Electromagnetic fields from mobile phones: A risk for maintaining energy homeostasis?



Chandreshwar Seewooruttun^a, Thi Cuc Mai^{a,b}, Aurélie Corona^a, Stéphane Delanaud^a, René de Seze^b, Véronique Bach^a, Rachel Desailoud^c, Amandine Pelletier^{a,*}

^a PériTox (UMR I.01), UPJV/INERIS, University of Picardy Jules Verne, CURS, Chemin du Thil, 80025 Amiens, France

^b PériTox (UMR I.01), INERIS/UPJV, INERIS, MIV/TEAM, Verneuil-en-Halatte, France

^c PériTox (UMR I.01), UPJV/INERIS, University of Picardy Jules Verne, Department of Endocrinology, Diabetes Mellitus and Nutrition, Amiens University Hospital, 1, rondpoint du Pr Christian Cabrol, 80054 Amiens, France

ARTICLE INFO

Keywords:

Radiofrequency electromagnetic fields
 Thermoregulation
 Temperature
 Vasoconstriction
 Thermogenesis

ABSTRACT

In the world, there is a near ubiquitous presence of a low-intensity radiofrequency electromagnetic field (RF-EMF) radiation, due to telecommunications as mobile phones. However, their rapid expansion raises concerns about possible interaction with biological mechanisms. The RF-EMF safety guidelines recommended limits to protect against the thermal heating, the most recognized effect at high intensity levels with a known biophysical mechanism. Among all the effects studied, the impact of RF-EMF exposure on thermoregulation is one of the most important aspects of this research. This review aims to present the complex relationship between RF-EMF exposure and thermoregulation, at intensity levels below the threshold to produce thermal effects. In fact, most studies showed that RF-EMF exposure at 900 MHz seems to elicit physiological and biological effects similar to responses inducing by cold environment in two different rodent models. In this brief review, we will describe the effects and underlying mechanisms induced by RF-EMF exposure at low levels and discuss the potential implications for environmental health and safety.

© 2025 Elsevier Masson

SAS. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

1. Introduction

Wireless technologies are in constant evolution to improve telecommunications. Thus, the evolution from 1G to 5G has enabled the digital transition from basic mobile phones using GSM networks for basic text messaging, to modern smartphones using advanced cellular networks (4G LTE, 5G) for high-speed internet access, video streaming and storage services. This review will focus solely on radiofrequency electromagnetic fields (RF-EMF) emitted by wireless communication systems such as mobile phones. The wireless technology using RF-EMF has evolved over the past 20 years with an increase in the frequency bands used. Thus, frequencies used in earlier generations of mobile telecommunications, are conserved for the new ones. For example, frequency bands around 900 MHz which were initially deployed for 2G, are still used for 3G. With the expansion of wireless communication systems, data usage is also

rising, driving the need for advanced infrastructures like the fifth generation of cellular networks (5G). The 5G technology is the latest current evolution with major advances such as an enhance of connectivity, a decrease of latency and an increase of device density. The introduction of the frequency bands around 3.5 GHz has significantly contributed to these technological advancements. Due to the expansion of wireless technologies, human RF-EMF exposure has become increasingly prevalent nowadays with the widespread use of wireless technologies and the increasing number of smartphone users worldwide. However, this massive expansion has also raised major public concerns about the potential health risks related to RF-EMF exposure. For this reason, the investigation of the potential RF effects on health is a critical research field that is still relevant today. Thus, the European Union funded several projects (ETAIN, GOLIAT, NextGEM, SEAWave) and brought together multiple research teams with great expertise in RF, dedicated to the health-risk assessment related to 5G exposure [1].

This review aims to present the relationship between RF-EMF exposure and thermoregulation by distinguishing thermal effects from non-thermal effects. By presenting results from the literature, we seek to provide a comprehensive overview of the physiological

* Corresponding author at: PériTox (UMR I.01), UPJV/INERIS, University of Picardy Jules Verne, CURS, Chemin du Thil, 80025 Amiens, France.

E-mail address: amandine.pelletier@u-picardie.fr (A. Pelletier).

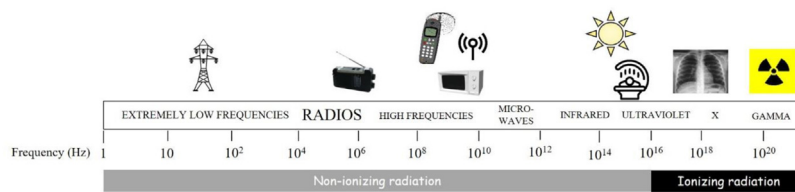


Fig. 1. Electromagnetic spectrum.

and molecular mechanisms through which RF-EMF radiation may influence the body's thermoregulatory functions and the potential implications for environmental health and safety. Before addressing these aspects, we will first present the physical properties of radiofrequency electromagnetic waves and their interactions with biological tissues.

2. What is radiofrequency electromagnetic fields?

Radiofrequency electromagnetic fields are electromagnetic waves which result from a combination of electric and magnetic fields perpendicular to each other and characterized by their wavelength, frequency, amplitude and intensity. These invisible waves carry energy and travel through space across various mediums, such as air, water, solid objects and biological tissues. Electromagnetic radiation is generally classified into two main categories as shown in the electromagnetic spectrum: ionizing and non-ionizing radiation (Fig. 1). Ionizing radiation carries sufficient energy to break chemical bonds and remove electrons from atoms and molecules creating ions. Highly energetic electromagnetic waves such as X-rays and Gamma rays are capable of ionisation. By contrast, non-ionizing radiation does not have enough energy to ionise atoms and molecules. RF-EMF are part of this category including radars for communication and security. These waves are also utilised in radiofrequency ablation (RFA) for cancer treatment such as liver, lung and kidney tumors [2]. RFA is a minimally invasive procedure which uses heat to destroy cancer cells, with few damages to surrounding healthy tissues.

2.1. Interaction between RF exposure and biological tissues

To understand the effects of RF-EMF exposure, it is essential to present the known interactions between RF-EMF and biological tissues. When radiofrequency (RF) waves interact with a medium, a portion of these incident waves will be reflected, some waves will be absorbed and the others waves will be propagated through tissues until they encounter an adjacent medium. In the case of biological tissues, RF waves cause dielectric heating through two main mechanisms: ionic polarisation and dipole rotation of water molecules. RF waves are a radiation energy without heat energy. However, upon interaction with biological tissues, a part of this radiation energy is transferred to the tissues, which will be converted into thermal energy by friction between rotating water molecules and/or moving charged particles [3]. The quantity of energy from absorbed RF radiation will depend on the physical properties of RF waves and the dielectric properties of the exposed tissues. The dielectric properties of target tissues depend on their permittivity and their conductivity. Permittivity affects the reflection, the propagation and the attenuation of RF waves within the biological material. The tissue's conductivity influences the level of radiation energy absorption and its efficient dissipation as heat. Conductivity is primarily influenced by the tissue composition and the distribution of water molecules and electrolytes. RF waves penetrate deeper into bone tissues than in muscle tissues due to the bone's higher permittivity. During RF exposure, bone tissue experi-

ences less heating than muscle tissue due to its lower water content and conductivity. Furthermore, RF waves penetrate deeper into bone than into muscle, as the bone's lower dielectric properties result in reduced absorption and attenuation of the electromagnetic radiation [4].

2.2. Specific absorption rate

To quantify the absorption of RF radiation energy by the body, the dosimetric parameter is the specific absorption rate (SAR). By definition, the SAR represents the quantity of electromagnetic power absorbed, in watt, per unit mass of tissue, in kilogram, (W/kg). This value can be determined for the whole body or for a specific region such as head or torso.

For many years, there was an ongoing debate on whether children absorb more RF radiation energy compared to adults when using wireless technologies. Despite the complexities in comparing RF energy absorption in different head models [5], there is no concrete evidence supporting this claim. Furthermore, the available dosimetry studies are quite heterogeneous and sometimes contradictory. Some studies showed that the head SAR is greater in children than in adults [6,7], others either found no significant difference [8–10] or opposite effects [11,12]. In fact, SAR variation is not age-dependent, but is attributed to the morphological and anatomical variations such as the thickness of the skull and surrounding tissues as well as the dielectric properties of the head [11,13]. The SAR variation between younger and older individuals is not massive [14].

3. Thermal effect of radiofrequency exposure

As explained previously, RF-EMF exposure can induce thermal effects by the absorption of radiation energy and the dissipation in heat through biological tissues. Thermal effects are defined as changes associated with heating of the whole body or an affected region sufficient to induce a biological effect. These effects are observed under specific conditions and are dependent on many factors such as ambient temperature, specific absorption rate, and exposure duration. The thermal effect is recognized by the scientific committee and RF safety exposure guidelines established by the International Commission on Non-Ionising Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE), propose exposure limits to protect against adverse health effects with a whole-body SAR of 0.08 W/kg for the general public and 0.4 W/kg for workers.

The threshold of thermal effect is 4 W/kg with a rise in core temperature during whole-body exposure of approximately 1 °C [15,16]. This level was defined from studies conducted on rodents and non-human primates in laboratories. For example, core temperature in rodents increased at 2.14 GHz RF-EMF exposure when SAR levels exceeded 4 W/kg. This was associated to stress responses and increased gene expression of some heat-shock proteins and heat-shock transcription factors [17]. Similar core body temperature change was observed in mice exposed to 1.95 GHz at SAR of 5 W/kg in the early phase of RF exposure [18]. Comparable increases

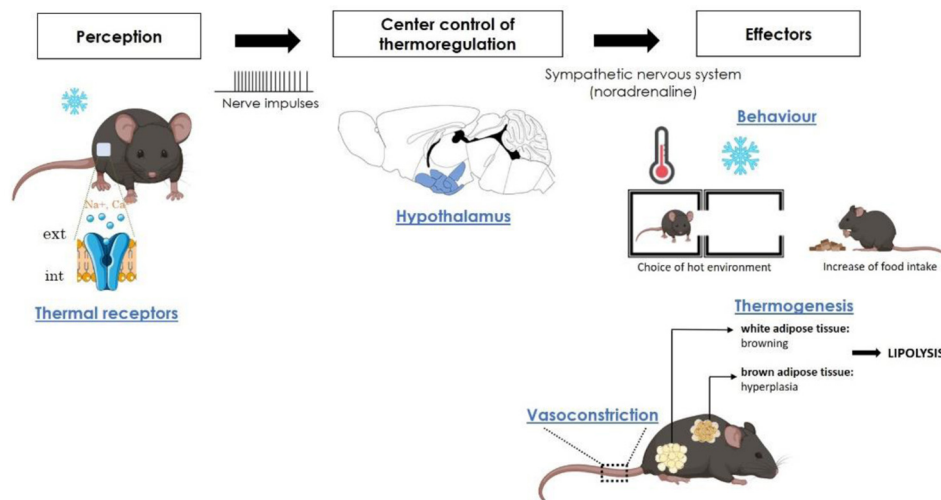


Fig. 2. Thermoregulation processes in cold environment: the cold sensation is detected by receptors which transmit information to the hypothalamus. In response, the sympathetic nervous system activates effectors such as vasoconstriction and behaviour to avoid a decrease of internal temperature, and thermogenesis in adipose tissues to produce heat.

in core body temperature were not easily produced in humans by RF-EMF exposure due to a more efficient thermoregulatory system. Eleanor Adair's research showed that volunteers had minimal skin temperature changes related to RF exposure at 100, 220, 450 and 2 450 MHz with SAR levels up to 7.7 W/kg without core temperature changes [19–21]. Localized heating was detected at 2 450 MHz when SAR reached 15.4 W/kg, leading to an increase in skin temperature by 4 °C with a few increase of core temperature.

4. Effects of low intensity radiofrequency exposure on thermoregulation

Previous studies for several decades were focused on carcinogenic and physiological effects related to the central nervous system, reproduction, immune system, endocrine system, cardiovascular system, . . . At low levels of RF-EMF exposure (SAR below 4 W/kg), the observed effects could be not due to an increase of body temperature. To explain these possible effects, other biological mechanisms have been considered: generation of free oxygen radicals, oxidative stress, genotoxicity, etc but none of them has been confirmed. In the current state of knowledge, the evidence of biological effects of RF-EMF at low levels remains poorly reproducible and controversial.

When exposed to cold or hot environment, the organism activates molecular and cellular mechanisms and physiological functions to regulate its internal temperature, such as sleep, locomotor activity, food intake or hormonal secretion. All these functions regulate energy inputs and outputs from the body to ensure the maintenance of energy homeostasis. The stability of internal temperature depends on thermolysis (heat loss) and thermogenesis (heat production). In cold environment, the cold sensation is detected by cold thermoreceptors which transmit information to the hypothalamus, the integrating center of thermoregulation (Fig. 2). In response, via the sympathetic nervous system, the hypothalamus activates effectors such as vasoconstriction and behaviour to avoid a decrease of internal temperature, and thermogenesis in adipose tissues to produce heat.

4.1. Physiological and behavioural thermoregulation

Over the past decade, several studies in rodents showed that RF exposure at low levels did not induce heating but, paradoxically, induced physiological and behaviour responses similar to

responses at cold exposure. Thus, after 5 weeks of 900 MHz exposure at 0.1 mW/kg, 23 h/24, RF-EMF exposed male rats (8 weeks old) had a lower tail temperature compared to controls with an ambient temperature of 31 °C [22]. There was no difference of core temperature at 31 °C between RF-EMF-exposed and control groups. The difference of tail temperature was not observed at 24 °C, an ambient temperature currently used in laboratory (Fig. 3A). The injection of prazosin, a post-synaptic antagonist of the α_1 -adrenergic receptor, induced vasodilatation in exposed animals indicating that the RF-EMF exposure maintained the vasoconstriction at 31 °C. This effect was not observed in non-exposed animals since the vasodilatation was already activated by the released of adrenaline at 31 °C. This inappropriate vasomotor tone in RF-EMF exposed animals was associated with a higher food intake to produce heat by thermogenesis [23,24]. The vasoconstriction allowed a conservation of heat and the food intake allowed a production of heat in cold environment, normally. A second study consisted in evaluating the thermopreferendum, the comfort ambient temperature, with similar RF-EMF exposure parameters. For this, animals had the choice between three ambient temperatures: 24, 28 and 31 °C [25]. RF-EMF exposed rats preferred an ambient temperature of 31 °C whereas non-exposed rats preferred 28 °C (Fig. 3B). Moreover, RF-EMF exposed rats maintained vasoconstriction at 31 °C (Fig. 3C). These results indicate that RF-EMF exposed rats felt cold (presence of vasoconstriction) and preferred a higher ambient temperature to warm up. These autonomic and behaviour responses avoid energy losses.

These previous studies showed that RF-EMF exposure at low level could disturb the homeothermy with an imbalance between heat loss and heat production/gain. Three mouse studies from two different laboratories, showed an increase of heat production during sessions of RF-EMF exposure [26–28]. The most recent study showed that the body temperature of mice exposed twice per day during one week at 900 MHz with a SAR of 0.16 W/kg, increased during RF-EMF exposure sessions and also, one hour after exposure, from the fourth day of exposure [26]. The increase of the internal temperature from the start of exposure and its decrease only at the end of this exposure shows a close causal relationship between exposure and thermal regulation (Fig. 3D). Moreover, the increase of body temperature could not be due to a higher energy absorption since the exposure intensity was too low. The possible explanation is an activation of thermogenesis, a process activated by the autonomic system to produce heat. This hypothesis was confirmed

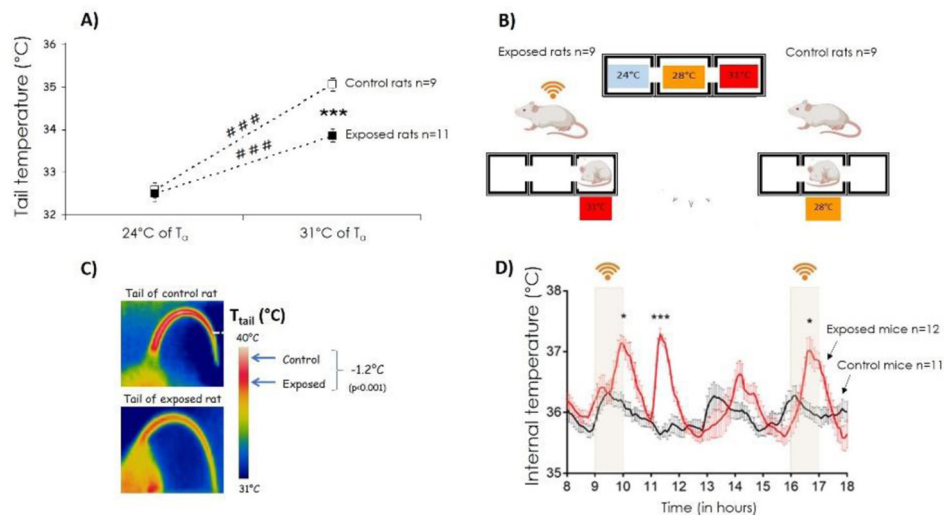


Fig. 3. Most important effects of 900 MHz exposure on: subcutaneous tail temperature measured by inserted probes (A, T_a : ambient temperature), comfort ambient temperature during light period (B) and cutaneous tail temperature measured by infrared camera (C) in rats after 5 RF-EMF exposed weeks and body temperature of mice after 4 RF-EMF exposed days (D).

by the same authors in RF-EMF exposed male rats (4 weeks old) which had higher plasmatic concentration of noradrenaline, a sympathetic neurotransmitter responsible of cold responses, and fatty acids, factors of lipolysis in thermogenesis after one week exposure to 900 MHz, compared to control rats [29].

4.2. Thermogenic mechanisms

4.2.1. Thermogenesis

Thermogenesis is a mechanism used to produce heat in organisms. This thermoregulatory process occurs at environmental temperatures below the thermoneutral range. The most important mechanism is the non-shivering thermogenesis with the implication of the adipose tissue. There are three types of adipose tissues: white adipose tissue (WAT), brown adipose tissue (BAT) and beige adipose tissue. The brown adipose tissue is the main effector of the non-shivering thermogenesis and it is stimulated by the sympathetic activation of β_3 -adrenoceptor. This activation triggers the activation of key thermogenic factors leading to heat production through the activity of uncoupling protein 1 (UCP1) in the mito-

chondria [30]. During cold exposure, the gene expression of UCP1, Peroxisome proliferator-activated receptor Gamma Coactivator 1- α (PGC1- α), Peroxisome Proliferator-Activated Receptor α (PPAR- α) and PPAR- γ is upregulated [30–32]. In regards to RF-EMF effects on BAT thermogenesis, few studies assessed cold-induced transcriptional changes. The only recent study on that aspect observed a significant downregulation of UCP1 in mice exposed to 900 MHz at SAR levels at 0.1 and 0.4 W/kg after 3 days of exposure [33]. However, these effects were not observed after 7 days of RF-EMF exposure under the same experimental conditions.

4.2.2. Hyperplasia of brown adipose tissue

Hyperplasia of BAT is a fundamental adaptive response to cold exposure characterised by the proliferation and differentiation of pre-adipocytes into mature brown adipocytes [34]. PR domain containing 16 (PRDM16) and other adipogenic markers such as CCAAT/enhancer-binding protein α (C/EBP- α) or C/EBP- β and PPAR- γ are involved in this process [35–37]. Few studies have explored RF-EMF effects on these adipogenic markers.

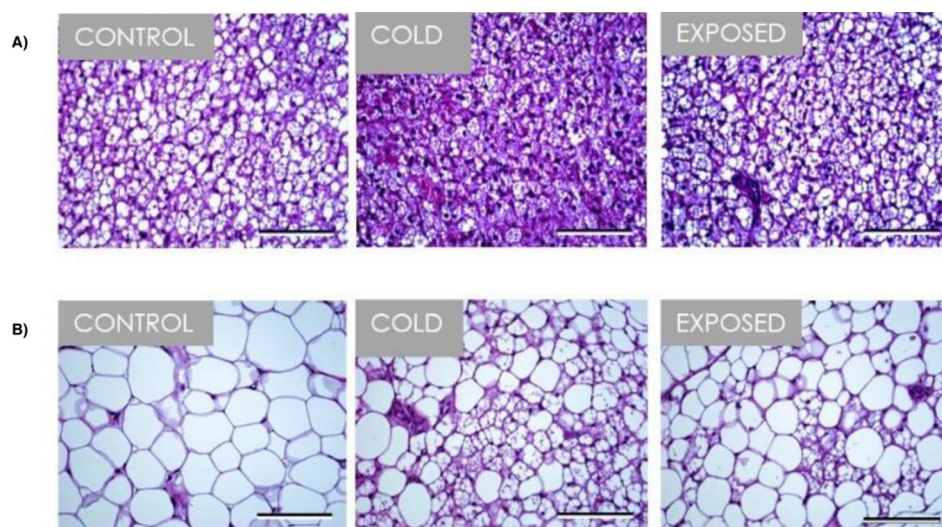


Fig. 4. Histological pictures of adipocytes (x200) in brown adipose tissue (A) and white adipose tissue (B) in non-exposed mouse (control), mouse exposed to 4°C of ambient temperature (cold) and mouse exposed to 900 MHz during one week (exposed).

In our laboratory, a recent study has shown a significant downregulation of PRDM16 and C/EBP- β in 3.5 GHz exposed rats compared to non-exposed animals [38]. Histological studies have also been carried out to compare the number of brown adipocytes and their individual size in BAT depots between non-exposed and RF-EMF exposed animals. Studies have shown that individual BAT depots can expand their mass in response to cold stress, either through the recruitment and proliferation of brown adipocytes (hyperplasia) or by adipocyte enlargement (hypertrophy). We observed a slight reduction in the mean size of brown adipocyte in both mice (Fig. 4A) and rats exposed to 900 MHz compared to non-exposed animals (unpublished data). Currently, no histological studies have been done to assess the effects of 5G radiofrequency effects (3.5 GHz) on BAT hyperplasia or hypertrophy.

4.2.3. Browning of white adipose tissue

Browning of WAT is a physiological phenomenon commonly observed during cold exposure. It is characterised by the conversion of white adipose tissue into beige adipose tissue, acquiring certain functional traits and characteristics similar to brown adipose tissue. UCP1 is expressed in beige adipose tissues as for other thermogenic genes such as PRDM16 and PPAR- α which are generally upregulated in beige tissues [39–42]. After 3 days of exposure, Maalouf et al. observed a significant downregulation of PPAR- α and an upregulation of PRDM16 in WAT of 900 MHz exposed mice at 0.1 W/kg [33]. After 1-week of exposure, PPAR- α was still downregulated, while PRDM16 showed a decrease in relative gene expression at the same SAR level [33]. Browning characteristics can also be histologically detected in white adipose tissue. They are characterised by an increase in UCP1 staining, multilocular small lipid droplets and mitochondrial biogenesis [42]. Our previous work highlighted the morphological and immunohistochemical evidence of WAT browning after short-term exposure to 900 MHz. In fact, an increase in UCP1 staining and a reduced white adipocyte size was detected in exposed mice compared to controls (unpublished data, Fig. 4B). In addition, a lower adipocyte area was observed even in rats after 900 MHz exposure during one week (unpublished data). The size of white adipocyte usually decreases during lipolysis and during the breakdown of the large central vacuole into smaller multilocular lipid droplets. In the literature, there are no studies addressing the effects of 5G exposure (3.5 GHz) on WAT browning.

5. Conclusion

In modern society, exposure to RF-EMF is very common and nearly impossible to avoid. Despite its major impact in driving technological advancements, it is important to address the growing public concern in regards to RF-EMF exposure. The thermal effects of high-intensity RF-EMF exposure ($\text{SAR} > 4 \text{ W/kg}$) are well documented in the literature. However, there is now emerging evidence that low-intensity RF-EMF exposure ($\text{SAR} < 4 \text{ W/kg}$) can also elicit thermoregulatory responses associated with a cold sensation. The present review highlights the behavioural thermoregulation associated with a cold sensation in rodents exposed to 900 MHz. We also provide molecular insights on RF exposure effects on different thermogenic mechanisms. The first results suggest that RF exposure primarily influences WAT browning rather than BAT thermogenesis, as reported by the up-regulation of UCP1 staining and reduced adipocyte size in WAT depots. In contrast, the cold-induced transcriptional changes on BAT thermogenesis were not observed after exposure to RF, although we detected increased plasma levels of noradrenaline, fatty acids in exposed rats. At short term, these adaptive responses do not seem to compromise homeostasis and

therefore the health of organisms, but what about the long-term consequences?

With the introduction of 3.5 GHz for 5G and early use of wireless technology by infants, further research is needed to determine these thermoregulatory effects. Investigating the peripheral tail temperature and thermal preference of 5G-exposed rats at different ages could provide valuable insights into their thermoregulatory responses. Additionally, the implication of the thyroid on these responses need to be more investigated. In fact, the hormones secreted by the thyroid regulate the basic metabolism and the processes implicated in lipolysis in adipose tissues to increase the production of energy in cells and heat by the thermogenesis.

Disclosure of interest

The authors declare that they have no competing interest.

References

- [1] Selmaoui B, Jamal L, Michelant L. Rapid Deployment of 5G Wireless Communication and Risk Assessment on Human Health: Quid Novi? *Bioelectromagnetics* 2025;46(4):e70005, <http://dx.doi.org/10.1002/bem.70005> [PMID: 40276940].
- [2] Shah DR, Green S, Elliot A, McGahan JP, Khatri VP. Current Oncologic Applications of Radiofrequency Ablation Therapies. *World J Gastrointest Oncol* 2013;5:71–80 [doi:10.4251/wjgo.v5.i4.71].
- [3] James SJ, James C. COOKING OF MEAT/Heat Processing Methods. In *Encyclopedia of Meat Sciences* (Second Edition); Dikeman, M., Devine, C. Oxford: Academic Press; 2014. p. 385–90 [ISBN 978-0-12-384734-8].
- [4] 'EMF-Portal | Radio frequency (10 MHz–300 GHz)'. Accessed: Feb. 18, 2025. [Online]. Available: <https://www.emf-portal.org/en/cms/page/home/effects/radio-frequency>.
- [5] Martínez-Búrdalo M, Martín A, Anguiano M, Villar R. Comparison of FDTD-Calculated Specific Absorption Rate in Adults and Children When Using a Mobile Phone at 900 and 1800 MHz. *Phys Med Biol* 2004;49:345–54, <http://dx.doi.org/10.1088/0031-9155/49/2/011>.
- [6] Hadjem A, Lautru D, Dale C, Wong MF, Hanna VF, Wiart J. Study of Specific Absorption Rate (SAR) Induced in Two Child Head Models and in Adult Heads Using Mobile Phones. *IEEE Transactions on Microwave Theory and Techniques* 2005;53:4–11 [doi:10.1109/TMTT.2004.839343].
- [7] Wiart J, Hadjem A, Gadi N, Bloch I, Wong MF, Pradier A, Lautru D, Hanna VF, Dale C. Modeling of RF Head Exposure in Children. *Bioelectromagnetics* 2005;Suppl7:S19–30, <http://dx.doi.org/10.1002/bem.20155>.
- [8] Bit-Babik G, Guy AW, Chou C-K, Faraone A, Kanda M, Gessner A, Wang J, Fujiwara O. Simulation of Exposure and SAR Estimation for Adult and Child Heads Exposed to Radiofrequency Energy from Portable Communication Devices. *Radiat Res* 2005;163:580–90 [doi:10.1667/rr3353].
- [9] Peyman A, Gabriel C, Grant EH, Vermeeren G, Martens L. Variation of the Dielectric Properties of Tissues with Age: The Effect on the Values of SAR in Children When Exposed to Walkie-Talkie Devices. *Phys Med Biol* 2009;54:227–41, <http://dx.doi.org/10.1088/0031-9155/54/2/004>.
- [10] Hadjem A, Conil E, Gati A, Man-Fai Wong M-F, Wiart J. Analysis of Power Absorbed by Children's Head as a Result of New Usages of Mobile Phone. *IEEE Transactions on Electromagnetic Compatibility* 2010;52:812–9 [doi:10.1109/TEMC.2010.2052810].
- [11] Beard BB, Kainz W, Onishi T, Iyama T, Watanabe S, Fujiwara O, Wang J, Bit-Babik G, Faraone A, Wiart J, et al. Comparisons of Computed Mobile Phone Induced SAR in the SAM Phantom to That in Anatomically Correct Models of the Human Head. *IEEE Trans Electromagn Compat* 2006;48:397–407 [doi:10.1109/TEMC.2006.873870].
- [12] Lee A, Choi H, Lee H, Pack J. Human Head Size and SAR Characteristics for Hand-set Exposure. *ETRI Journal* 2002;24:176–9 [doi:10.4218/etrij.02.0202.0202].
- [13] Christ A, Gosselin M-C, Christopoulou M, Kühn S, Kuster N. Age-Dependent Tissue-Specific Exposure of Cell Phone Users. *Phys Med Biol* 2010;55:1767–83, <http://dx.doi.org/10.1088/0031-9155/55/7/001>.
- [14] Wiart J, Hadjem A, Wong MF, Bloch I. Analysis of RF Exposure in the Head Tissues of Children and Adults. *Phys Med Biol* 2008;53:3681–95, <http://dx.doi.org/10.1088/0031-9155/53/13/019>.
- [15] De Lorge JO. Operant Behavior and Colonic Temperature of Macaca Mulatta Exposed to Radio Frequency Fields at and above Resonant Frequencies. *Bioelectromagnetics* 1984;5:233–46, <http://dx.doi.org/10.1002/bem.2250050211>.
- [16] Ziskin MC, Morrissey J. Thermal Thresholds for Teratogenicity, Reproduction, and Development. *International Journal of Hyperthermia* 2011;27:374–87 [doi:10.3109/02656736.2011.553769].
- [17] Ohtani S, Ushiyama A, Maeda M, Hattori K, Kunugita N, Wang J, Ishii K. Exposure Time-Dependent Thermal Effects of Radiofrequency Electromagnetic Field Exposure on the Whole Body of Rats. *J. Toxicol. Sci* 2016;41:655–66 [doi:10.2131/jts.41.655].
- [18] Sylvester E, Deng C, McIntosh R, Iskra S, Frankland J, McKenzie R, Croft RJ. Characterising Core Body Temperature Response of Free-moving C57BL/6 Mice to

- 1.95GHz Whole-body Radiofrequency-electromagnetic Fields. *Bioelectromagnetics* 2024;45:387–98, <http://dx.doi.org/10.1002/bem.22527>.
- [19] Adair ER, Blick DW, Allen SJ, Mylacraine KS, Ziriak JM, Scholl DM. Thermophysiological Responses of Human Volunteers to Whole Body RF Exposure at 220MHz. *Bioelectromagnetics* 2005;26:448–61, <http://dx.doi.org/10.1002/bem.20105>.
- [20] Adair ER, Mylacraine KS, Allen SJ. Thermophysiological Consequences of Whole Body Resonant RF Exposure (100MHz) in Human Volunteers. *Bioelectromagnetics* 2003;24:489–501, <http://dx.doi.org/10.1002/bem.10128>.
- [21] Adair ER, Mylacraine KS, Cobb BL. Partial-body Exposure of Human Volunteers to 2450MHz Pulsed or CW Fields Provokes Similar Thermoregulatory Responses*. *Bioelectromagnetics* 2001;22:246–59, <http://dx.doi.org/10.1002/bem.47>.
- [22] Pelletier A, Delanaud S, Décima P, Thuroczy G, de Seze R, Cerri M, Bach V, Libert J-P, Loos N. Effects of Chronic Exposure to Radiofrequency Electromagnetic Fields on Energy Balance in Developing Rats. *Environ Sci Pollut Res Int* 2013;20:2735–46, <http://dx.doi.org/10.1007/s11356-012-1266-5>.
- [23] Rothwell NJ, Stock MJ. Diet-Induced Thermogenesis. In *Mammalian thermogenesis*. Dordrecht: Springer Netherlands; 1983. p. 208–33 [ISBN 978-94-011-6032-2].
- [24] Saito M, Matsushita M, Yoneshiro T, Okamatsu-Ogura Y. Brown Adipose Tissue, Diet-Induced Thermogenesis, and Thermogenic Food Ingredients: From Mice to Men. *Front. Endocrinol* 2020;11:222 [doi:10.3389/fendo.2020.00222].
- [25] Pelletier A, Delanaud S, de Seze R, Bach V, Libert J-P, Loos N. Does Exposure to a Radiofrequency Electromagnetic Field Modify Thermal Preference in Juvenile Rats? *PLoS One* 2014;9:e99007 [doi:10.1371/journal.pone.0099007].
- [26] Mai TC, Delanaud S, Bach V, Braun A, Pelletier A, de Seze R. Effect of Non-Thermal Radiofrequency on Body Temperature in Mice. *Sci Rep* 2020;10:5724, <http://dx.doi.org/10.1038/s41598-020-62789-z>.
- [27] Arendash GW, Sanchez-Ramos J, Mori T, Mamcarz M, Lin X, Runfeldt M, Wang L, Zhang G, Sava V, Tan J, et al. Electromagnetic Field Treatment Protects Against and Reverses Cognitive Impairment in Alzheimer's Disease Mice. *JAD* 2010;19:191–210 [doi:10.3233/JAD-2010-1228].
- [28] Arendash GW, Mori T, Dorsey M, Gonzalez R, Tajiri N, Borlongan C. Electromagnetic Treatment to Old Alzheimer's Mice Reverses β -Amyloid Deposition, Modifies Cerebral Blood Flow, and Provides Selected Cognitive Benefit. *PLoS ONE* 2012;7:e35751 [doi:10.1371/journal.pone.0035751].
- [29] Mai TC, Braun A, Bach V, Pelletier A, Seze R. Low-Level Radiofrequency Exposure Induces Vasoconstriction in Rats. *Bioelectromagnetics* 2021;42:455–63, <http://dx.doi.org/10.1002/bem.22350>.
- [30] Golozoubova V, Cannon B, Nedergaard J. UCP1 Is Essential for Adaptive Adrenergic Nonshivering Thermogenesis. *American Journal of Physiology-Endocrinology and Metabolism* 2006;291:E350–7 [doi:10.1152/ajpendo.00387.2005].
- [31] Cannon B, Nedergaard J. What Ignites UCP1? *Cell Metabolism* 2017;26:697–8, <http://dx.doi.org/10.1016/j.cmet.2017.10.012>.
- [32] Chau P, Ryan Kt, Dalen E, Haugen KT. Timing of Acute Cold Exposure Determines UCP1 and FGF21 Expression - Possible Interactions between the Thermal Environment, Thermoregulatory Responses, and Peripheral Clocks. *Journal of Thermal Biology* 2024;124:103938, <http://dx.doi.org/10.1016/j.jtherbio.2024.103938>.
- [33] Maalouf J, Pelletier A, Corona A, Gay-Quéheillard J, Bach V, De Seze R, Selmaoui B. Dose- and Time-Dependent Effects of Radiofrequency Electromagnetic Field on Adipose Tissue: Implications of Thermoregulation and Mitochondrial Signaling. *IJMS* 2023;24:10628 [doi:10.3390/ijms241310628].
- [34] Bukowiecki L, Collet AJ, Follea N, Guay G, Jahjah L. Brown Adipose Tissue Hyperplasia: A Fundamental Mechanism of Adaptation to Cold and Hyperphagia. *American Journal of Physiology-Endocrinology and Metabolism* 1982;242:E353–9 [doi:10.1152/ajpendo.1982.242.6.E353].
- [35] Rosen ED, Hsu C-H, Wang X, Sakai S, Freeman MW, Gonzalez FJ, Spiegelman BM. C/EBP α Induces Adipogenesis through PPAR γ : A Unified Pathway. *Genes Dev* 2002;16:22–6 [doi:10.1101/gad.948702].
- [36] Darlington GJ, Ross SE, MacDougald OA. The Role of C/EBP Genes in Adipocyte Differentiation. *Journal of Biological Chemistry* 1998;273:30057–60, <http://dx.doi.org/10.1074/jbc.273.46.30057>.
- [37] Ahfeldt T, Schinzel RT, Lee Y-K, Hendrickson D, Kaplan A, Lum DH, Camarhort R, Xia F, Shay J, Rhee EP, et al. Programming Human Pluripotent Stem Cells into White and Brown Adipocytes. *Nat Cell Biol* 2012;14:209–19, <http://dx.doi.org/10.1038/ncb2411>.
- [38] Seewooruttun C, Bouguila B, Corona A, Delanaud S, Bodin R, Bach V, et al. 5G Radiofrequency exposure reduces PRDM16 and C/EBP β mRNA expression, two key biomarkers for brown adipogenesis. *Int J Mol Sci* 2025;26(6):2792, <http://dx.doi.org/10.3390/ijms26062792> [PMID: 40141434; PMCID: PMC11942954].
- [39] Jiang N, Yang M, Han Y, Zhao H, Sun L. PRDM16 Regulating Adipocyte Transformation and Thermogenesis: A Promising Therapeutic Target for Obesity and Diabetes. *Front. Pharmacol* 2022;13:870250 [doi:10.3389/fphar.2022.870250].
- [40] Machado SA, Pasquarelli-do-Nascimento G, Da Silva DS, Farias GR, De Oliveira Santos I, Baptista LB, Magalhães KG. Browning of the White Adipose Tissue Regulation: New Insights into Nutritional and Metabolic Relevance in Health and Diseases. *Nutr Metab (Lond)* 2022;19:61 [doi:10.1186/s12986-022-00694-0].
- [41] Kajimura S. Promoting Brown and Beige Adipocyte Biogenesis through the PRDM16 Pathway. *Int J Obes Supp* 2015;5:S11–4, <http://dx.doi.org/10.1038/ijosup.2015.4>.
- [42] Guo Y-Y, Li B-Y, Peng W-Q, Guo L, Tang Q-Q. Taurine-Mediated Browning of White Adipose Tissue Is Involved in Its Anti-Obesity Effect in Mice. *Journal of Biological Chemistry* 2019;294:15014–24, <http://dx.doi.org/10.1074/jbc.RA119.009936>.