



OVERVIEW

for a clearer picture

No. 3

**Does mobile communication
also have non-thermal
effects?**

Overview No. 3

Does mobile communication also have non-thermal effects?

Updated: 14 September 2026

Summary

The diagnose:funk publication series "Overview for a clearer picture" reports on the state of research into the health effects of non-ionising radiation from mobile communications. Its research into scientific studies draws on the databases www.EMFdata.org and www.EMF-Portal.de.

Overview No. 3 examines a principal justification for considering mobile phone radiation harmless: that statutory exposure limits protect against health risks, and that there is no evidence of non-thermal effects. However, European bodies and legal opinions now criticise the exclusion of studies showing non-thermal effects from risk assessment. This overview presents the debate over the thermal dogma from the 1950s to the present. In it, diagnose:funk documents 96 examples of studies showing non-thermal effects, scientifically challenging the protection offered by current exposure limits.

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1 Research findings and their assessment

For decades, research findings on non-ionising radiation from mobile communications have been interpreted differently. Governments and scientists who recognise only the thermal effects of mobile phone radiation consider it risk-free. They exclude hundreds of studies demonstrating non-thermal effects from risk assessment. This thermal dogma underpins the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and radiation protection policies in Western countries. In the former Eastern Bloc, legislation and protective measures were also based on non-thermal effects. This explains why their exposure limits are up to 500 times lower than those in the West.¹ Refusing to recognise non-thermal effects serves a political purpose: enabling the unrestricted expansion of mobile communications technology. In this working paper, we document peer-reviewed studies demonstrating non-thermal effects.

1.1 The military basis of today's protection rules: the thermal dogma

Early wireless technologies focused on military aviation and radio applications, such as radar and microwave communications. The development of radar technology used in the Second World War led to reports of biological effects in military personnel, prompting studies of the effects of microwave radiation on humans. The commissioned biophysicist Dr Herman Schwan worked for the US military-industrial complex and focused on the effects of electromagnetic fields (including RF) on biological systems. He proposed a protective exposure limit of $10 \text{ mW/cm}^2 = 100 \text{ W/m}^2$, justifying its use in the military (Foster, 2002, p. 17).² This value became the basis for exposure standards in the United States and Western countries. Schwan's dogma that only heat causes harm also became the foundation of today's ICNIRP guidelines for public protection. Since the 1950s, scientists calling for non-thermal effects to be considered have been sidelined in standard-setting bodies.

The dispute over recognising non-thermal effects continued to shape the debate from the 1950s onwards. Well-founded analyses are available. Accounts of this history, dominated by industry interests, include Tom Butler's 2020 report (University College York), Paul Brodeur's "Microwaves, the concealed danger" (1980), Nicholas H. Steneck's

1 Hecht K, Balzer HU (1997): Biological effects on humans of electromagnetic fields in the 0-3 GHz frequency range. Study of Russian literature from 1960-1996 commissioned by the Federal Ministry of Telecommunications, contract No. 4131/6304, 402, 14 November 1996.

2 Foster, K. R. (2002). Herman P. Schwan: A scientist and pioneer in biomedical engineering. Annual review of biomedical engineering, 4 (1), 1-27

standard work "The Microwave Debate" (1984), Martin Blank's "Overpowered" (2014), and Buchner/Rivasi's analysis of ICNIRP's connections.³

1.2 Thermal and non-thermal effects of LF-/RF-EMF absorption

Key statements on NTP



This montage illustrates the US confrontation between Dr Herman Schwan (right), representing the thermal dogma, and scientist Alain Frey, who, like the Russians, called for recognition of non-thermal effects (from "The Microwave Debate").

Thermal effects generally occur whenever radiation (LF-/RF-EMF) is absorbed. They consist of an increase in the temperature of the exposed material/tissue, unless heat-dissipating processes reduce or even reverse it. Put simply: the material warms up, perhaps only slightly. The greater the radiation intensity and the longer the exposure, the greater the temperature increase. For a given intensity and exposure duration, the degree of warming depends on the density, conductivity

and heat capacity of the exposed tissue. ICNIRP exposure limits protect only against this heating effect.

Non-thermal effects (or athermal effects) of absorbed radiation (LF-/RF-EMF) are biological effects that cannot be caused by any additional warming of the tissue (a side effect). This means that radiation intensity must be below the thermal threshold above which warming itself could cause such effects. Two examples:

1. UV radiation, radioactive radiation, X-rays and similar radiation can cause non-thermal effects through ionisation of atoms, because each photon's energy (= the smallest unit of EMF) is sufficient for this. The associated warming is minimal.

³ Butler, Tom (2020): A Report on the Non-Thermal Effects of Radio Frequency Radiation and the Adequacy of Health and Safety Guidelines to Protect Public Health, Online Paper

Michèle Rivasi, Klaus Buchner (2020): The International Commission on Non-Ionizing Radiation Protection:

Conflicts of interest, "corporate capture" and the drive to expand the 5G network, www.diagnose-funk.org/1701.

See also: The ICNIRP and Federal Office for Radiation Protection lobbying system - 5 analyses, www.diagnose-funk.org/1702

2. Mobile phone radiation (RF-EMF) can also cause non-thermal effects, even though each photon's energy is insufficient to ionise molecules/atoms.⁴ According to many studies, these effects involve stimulating unnecessary biological processes, such as irregular opening of ion channels in the cell membrane.

1.3 Mobile phone radiation is coherent, polarised and pulsed

Mobile communications fields can cause non-thermal effects because of their "structured form": their waves are coherent (i.e. the individual waves oscillate synchronously with a fixed phase relationship), polarised and pulsed.

This means that all electrically charged particles (electrons, atomic nuclei, ions) in the tissue, especially on the cell membrane and inside the cell, are forced to oscillate coherently. This produces various coherent polarisation effects (oscillating changes in distances between positively and negatively charged particles in molecules, atoms or space charges), as well as constantly changing orientations of dipole molecules. In particular, water dipole molecules are stimulated to rotate.

In addition to warming, this can generate alternating voltages superimposed on the biologically necessary voltage differences between the inside and outside of the cell, varying at the frequency of the incident field.⁵ If certain thresholds are exceeded, these interfering voltages can cause biological malfunctions (e.g. opening ion channels in the cell membrane). Radiation also leads, for example, to overproduction of free radicals in mitochondria and to oxidative cellular stress, a cause of inflammatory diseases. This mechanism has now been demonstrated in dozens of studies.

Put simply: structured/coherent fields have more ways of producing effects than unstructured fields. This reflects a principle familiar from everyday life, expressed in sayings such as "Together we are strong". Only when activities are structured/coordinated towards a common goal can they achieve effects otherwise unattainable.

Everyone knows the applause after a concert. When clapping is structured, i.e. everyone claps in rhythm (coherent clapping), it has a greater effect in encouraging an encore. A structured airflow, such as a smoke ring, can extinguish a candle that an equivalent unstructured gust could not. A

⁴ Klaus Scheler (2016): Polarisation: a key factor in understanding biological effects of low-intensity pulsed electromagnetic waves, umwelt-medizin-gesellschaft, supplement 3/2016, <https://diagnose-funk.org/1170>
 Klaus Scheler (2019): Common claims and specious arguments: "Mobile phone radiation has too little

energy to damage cells. Oxidative stress is implausible.": <http://www.diagnose-funk.org/1441>

⁵ J. H. Bernhardt (1995). Mobile communications and electrosmog. Biological effects of electromagnetic radiation. Phys. Bl, 51 (1995) No. 10, 947-950

magnetised piece of iron can act as a magnet only because its elementary magnets are all aligned, i.e. structured/ordered. As long as they are randomly oriented (unstructured), no macroscopic magnetic force exists.

1.4 Studies demonstrating non-thermal effects

The research has settled the question of whether non-thermal effects exist. This working paper documents a selection of 96 studies. They show how cellular cascades are altered, leading to pathological effects. Recognising these effects would require stricter safety rules and new exposure limits, as in the former Eastern Bloc. Authorities therefore engage in evasive manoeuvres to resist better protective rules and are retreating in the face of the research. Initially, they claimed that such non-thermal effects were impossible in principle, with radiation effects disappearing into thermal noise. Faced with many studies, they then had to admit that non-thermal effects exist. They now downplay them: they supposedly have no harmful health consequences and thus need not be included in risk assessment. Starkey (2016) documents the strategies used and the extent to which research findings are ignored.⁶

2 BfS adheres to the thermal dogma

Germany's Federal Office for Radiation Protection (BfS) cites ICNIRP guidelines and claims that biological damage involving health risks cannot occur below exposure limits. Studies demonstrating non-thermal effects are now devalued through the tactic of casting doubt, described by David Michaels, formerly deputy director of the US occupational safety authority, as a tool of risk deniers.⁷ A typical example is the BfS statement on the EU body SCHEER's current mobile communications analysis: "Evidence of non-thermal mechanisms from cell culture studies is classified as unclear ... SCHEER finds no consistent indications of possible non-thermal mechanisms of radiofrequency electromagnetic fields at the cellular level and rates the evidence overall as unclear. The BfS agrees."⁸ "Unclear" - a textbook example of casting doubt and relativising. With over 750 studies documented in our EMFData.org database,

6 Starkey SJ (2016): Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation. Published in: Rev Environ Health 2016; 31 (4): 493-503. German edition as a diagnose:funk Brennpunkt: Study demonstrates how exposure limits are legitimised through apparent science, 2017, <https://diagnose-funk.org/1163>

7 Michaels D, Monforton C (2005): Manufacturing uncertainty: contested science and the protection of public health and the environment, American Journal of Public Health | Supplement 1, 2005, Vol 95, No. S1. Download German translation: <https://diagnose-funk.org/1882>

8 <https://www.bfs.de/DE/themen/emf/kompetenzzentrum/berichte/berichte-mobilfunk/scheer.html>

most of which demonstrate non-thermal effects, the doubt-based argument of "uncertainty" is a brazen, politically motivated downplaying of risks.

3 Criticism of the thermal dogma by the International Commission on Biological Effects of EMF (ICBE-EMF)



This denial of non-thermal effects has always met with strong opposition. As early as 2007, Lutz/Adlkofer criticised the fundamentally false assumption that non-ionising radiation is harmless because it lacks the energy to break covalent bonds in cells. Ultimately, this theory treats the human body as a solid object:

"But this approach applies to inanimate matter. It can be used when a piece of wood, plastic or similar material is exposed. Living organisms undergo biological processes such as cell division and differentiation, which make molecules, especially DNA and RNA, very vulnerable. Chemical bonds are broken and new ones formed.

*DNA strands are opened and replicated, and new cells are formed. A much lower energy threshold may suffice to disrupt cellular processes. Indeed, it would be very difficult to define a lower energy threshold that rules out disruption of life processes for which molecular instability is a prerequisite."*⁹

This biologically based perspective is now supported by many studies, a selection of which we document below. Given ICNIRP's monopoly on interpreting research, its setting of exposure limits and its connections with industry and authorities, the International Commission on Biological Effects of EMF (ICBE-EMF) was founded in 2022. Its article demonstrates in 14 points that ICNIRP exposure limits are unscientific and offer no protection, making new limits necessary.¹⁰ This position is supported by the European Economic and Social Committee (EESC) opinion in the

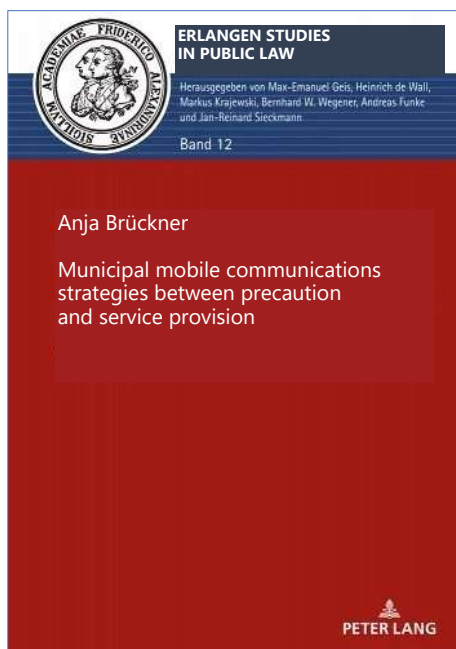
9 Josef Lutz / Franz Adlkofer (2007): Objections to current microwave radiation exposure limits, <https://www.emfdata.org/de/dokumentationen/detail?id=38>

10 ICBE-EMF (2022): "Scientific evidence invalidates health assumptions underlying the FCC (Federal Communication Commission, USA) and ICNIRP radiofrequency exposure limit determinations: implications for 5G", www.diagnose-funk.org/1937

EU Official Journal of March 2023.¹¹ The EESC calls for recognition of the entire research evidence, replacement of ICNIRP by an independent body, and new guidelines specifying: "Particular attention should be paid to non-thermal effects (1.11)."¹²

In a December 2025 letter to the US Senate, ICBE-EMF criticises the FCC for not scientifically reassessing its exposure limits since 1996. The commission also calls for updated limits based on the extensive research on non-thermal effects and long-term health risks.¹³

3.1 Legal criticism of excluding non-thermal study findings from risk assessment



In Germany, lawyers also sharply criticise excluding studies of non-thermal effects from risk assessment. In her dissertation "Municipal mobile communications strategies between precaution and service provision" (2022),¹⁴ lawyer Anja Brückner demonstrates that the federal government ignores research findings on non-thermal effects of mobile phone radiation and commissions insufficient research of its own. Exposure limits therefore fail to reflect the research, offer no protection and are untenable. Brückner criticises the federal government's "inaction" in fulfilling its "duty to improve" (p. 52) the limits, meaning that "the required protection objective cannot be achieved" (p. 50).

More at: <https://diagnose-funk.org/2109>

¹¹ Download the EESC opinion: www.diagnose-funk.org/1828

¹² Ibid.

¹³ Download the letter: <https://icbe-emf.us17.list-manage.com/track/click?u=d38ad5dbc84c6563aba160d5f8&id=319453bada&e=e4fd201beb>

¹⁴ Anja Brückner: Municipal mobile communications strategies between precaution and service provision, ©2022. Dissertation, 194 pages, series: Erlanger Schriften zum Öffentlichen Recht, Volume 12

4 Studies demonstrating non-thermal effects



Diagnose:funk documents a selection of studies (as of August 2026) demonstrating non-thermal effects. They are recorded in our database www.EMFdata.org and linked here through their database identification numbers (IDs).

Notes

1. Studies are arranged in ascending order of publication year within the different endpoints.
2. Nineteen studies appear more than once because they cover several endpoints simultaneously.
3. Quotations come from study reviews by the ElektromogReport editorial team or from the authors' original abstracts.
4. The individual endpoints were assigned by EMF-Portal.

4.1 Reviews

ID 575: Belyaev I et al. (2005): Nonthermal Biological Effects of Microwaves: Current Knowledge, Further Perspective, and Urgent Needs. Review. In addition to known dependencies on frequency and modulation, available data indicate that non-thermal microwave effects depend on exposure intervals and coherence time, polarisation, genotype, sex, physiological and individual factors, the static magnetic field, stray electromagnetic fields and cell density during exposure. They further suggest that exposure duration may be more important for non-thermal microwave effects than energy density.

ID 366: Starkey SJ (2016): Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation. [Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation], Rev Environ Health 2016; 31(4): 493-503

ID 162: Yakymenko I et al. (2016): Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation. Review. Microwaves are a strong oxidative stressor for

living cells. All studies were conducted at field strengths below the thermal threshold (exposure limits).

ID 531: Belpomme et al. (2018): Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective. [Thermal and non-thermal health effects of low-intensity non-ionising radiation: an international perspective]. Review. Summarises evidence of cancer following EMF exposure and identifies other diseases or pathological conditions, such as Alzheimer's disease or reduced fertility, demonstrably associated with excessive exposure to weak EMF. The authors also focus on electromagnetic hypersensitivity (EHS) in children and adults, and cognitive and behavioural problems in children resulting from increasing exposure. Discusses non-thermal mechanisms, particularly EMF-induced free radical production and epigenetic and genetic mechanisms.

ID 796: Zhao X et al. (2021): The non-thermal biological effects and mechanisms of microwave exposure. Review. [The non-thermal biological effects and mechanisms of microwave exposure], Int J Radiat Res 2021; 19 (3): 483-494

Hinrikus H et al. (2023): Limiting exposure to radio-frequency radiation: the principles and possible criteria for health protection. International Journal of Radiation Biology. 2023 Aug 3;99(8):1167-77. <https://doi.org/10.1080/09553002.2023.2159567>

ID900: Torkan A et al. (2025): Effects of Mobile Electromagnetic Exposure on Brain Oscillations and Cortical Excitability: Scoping Review. [Effects of mobile electromagnetic exposure on brain oscillations and cortical excitability: scoping review]. Despite extensive research over the years, gaps remain in the literature requiring further investigation, particularly regarding 5G as a new technology. This concerns the non-thermal effect, which occurs at exposures below current thermal thresholds. (...) Various non-thermal mechanisms in which electromagnetic fields interact with biological processes at the cellular level can explain these effects.

ID910: Weller SG et al. (2025): A scoping review and evidence map of radiofrequency field exposure and genotoxicity: assessing in vivo, in vitro, and epidemiological data. [A scoping review and evidence map of radiofrequency exposure and genotoxicity: assessing in vivo, in vitro and epidemiological data]. Findings from the evidence review suggest that medium- to long-term RF-EMF exposures, particularly at low intensities, may cause genetic damage through non-thermal mechanisms such as increased free radical formation and oxidative stress.

4.2 DNA damage, genotoxicity, gene/protein expression (general)

ID 55: Lopez-Martin E et al. (2002): The action of pulse-modulated GSM radiation increases regional changes in brain activity and c-Fos expression in cortical and subcortical areas in

a rat model of picrotoxin-induced seizure proneness. Changes in behaviour (seizures), EEG and neuronal c-Fos expression. None of the radiation treatments caused tissue warming, so thermal effects can be ruled out.

ID 59: Diem E et al. (2005): Non-thermal DNA breakage by mobile-phone radiation (1800 MHz) in human fibroblasts and in transformed GFSH-R17 rat granulosa cells in vitro. Induced DNA damage cannot be due to thermal effects. DNA strand breaks were determined by means of the alkaline and neutral comet assay. [...] Therefore we conclude that the induced DNA damage cannot be based on thermal effects.

ID 248: Lee S et al. (2005): 2.45 GHz radiofrequency fields alter gene expression in cultured human cells. We observed no significant increase in heat-shock gene expression. These findings suggest that 2.45 GHz RF fields can alter gene expression in cultured human cells through non-thermal mechanisms.

ID 124: Ferreira AR et al. (2006): Ultra high frequency-electromagnetic field irradiation during pregnancy leads to an increase in erythrocytes micronuclei incidence in rat offspring. An in vivo mammalian cytogenetic test, the micronucleus (MN) assay, was used to examine chromosomal damage in erythrocytes of rat offspring exposed during embryogenesis to a mobile phone's non-thermal UHF-EMF. Result: Genotoxic responses in haematopoietic tissue during embryogenesis.

ID 28: Belyaev I et al. (2009): Microwaves from UMTS/GSM mobile phones induce long-lasting inhibition of 53BP1/gamma-H2AX DNA repair foci in human lymphocytes. Effects on chromatin conformation and inhibition of 53BP1/gamma-H2AX DNA repair foci formation in human lymphocytes from hypersensitive and healthy individuals, depending on carrier frequency and signal type (non-thermal range).

ID 97: Gerner C et al. (2010): Increased protein synthesis by cells exposed to a 1,800-MHz radio-frequency mobile phone electromagnetic field, detected by proteome profiling. Cellular response as an athermal effect: significant increase in protein expression in Jurkat cells and human fibroblasts, and to a lesser extent in activated human leukocytes.

ID 100: Campisi A et al. (2010): Reactive oxygen species levels and DNA fragmentation on astrocytes in primary culture after acute exposure to low intensity microwave electromagnetic field. Production of reactive oxygen species and DNA fragmentation in primary astrocyte cultures; ROS production (oxidative stress) and DNA breaks were significantly increased after 20 minutes of pulsed radiation exposure. This is a non-thermal effect.

ID 334: Chavdoula ED et al. (2010): Comparison of biological effects between continuous and intermittent exposure to GSM-900-MHz mobile phone radiation: Detection of apoptotic cell-death features. In our earlier experiments, continuous daily exposure for 6 minutes over 5 days to GSM-900 MHz and DCS-1800 MHz (Digital

Cellular System) mobile phone exposure led to a substantial decline in the insect's reproductive capacity, defined by the number of F(1) pupae. This decline was found to be non-thermal and correlated with an increased percentage of induced DNA fragmentation in egg-chamber cells during early and mid-oogenesis.

ID 242: Jorge-Mora T et al. (2011): The Effects of Single and Repeated Exposure to 2.45 GHz Radiofrequency Fields on c-Fos Protein Expression in the Paraventricular Nucleus of Rat Hypothalamus. The paraventricular nucleus may be sensitive to 2.45 GHz microwave exposure at non-thermal SAR values.

ID 380: Misa-Agustino MJ et al. (2015): EMF radiation at 2450 MHz triggers changes in the morphology and expression of heat shock proteins and glucocorticoid receptors in rat thymus. Significance: The findings suggest that non-ionising subthermal radiation changes endothelial permeability and thymus vascularisation and acts as a tissue-modulating agent for Hsp90 and GR.

ID 183: Gustavino B et al. (2016): Exposure to 915 MHz radiation induces micronuclei in *Vicia faba* root tips. Genotoxic effects in broad bean (*Vicia faba*) seedlings. Thermal effects are unlikely, since the plants were maintained at a constant 20-22°C.

ID 23: Molla-Djafari H, Schiessl K, Allgemeine Unfallversicherungsanstalt AUVA, Schmid G, Kundi M, Knasmüller S, Mosgöller W (2016): ATHEM-2. Athermal effects of electromagnetic field exposure associated with mobile communication. All exposures in this project used intensities that ruled out concerning heating. The observed effects are therefore described as athermal or "non-thermal". Specific indications of athermal effects on DNA existed long before ATHEM-2 began. Intermittent exposure (e.g. 5 minutes "on", 10 minutes "off", so the field is effectively "on" for only one-third of the exposure period) produced a higher DNA break rate than continuous exposure over the same duration. This clearly demonstrates that RF-EMF-induced DNA impairment does not correlate solely with the amount of electromagnetically induced heat energy, and thus occurs independently of heat (= athermal). Long before the project began, international literature described how radiofrequency electromagnetic field exposure can correlate with DNA lesions even at intensities in the athermal range.

ID 551: Panagopoulos DJ et al. (2019): Chromosome damage in human cells induced by UMTS mobile telephony radiation. DNA damage that cellular mechanisms could not repair, indicating genotoxic/bioactive effects of mobile phone radiation. The scientists demonstrated that thermal effects played no role.

ID 553: Grasso R et al. (2020): Dynamic changes in cytoskeleton proteins of olfactory ensheathing cells induced by radiofrequency electromagnetic fields. The study investigated non-thermal effects on cells of the olfactory mucosa caused by radiofrequency electromagnetic fields that

alter the envelope of the electromagnetic wave. Result: At the longest exposure duration of 20 minutes, sample temperature increased by less than 0.35°C, allowing the scientists to rule out thermal effects.

ID 588: Gulati S et al. (2020): Effects of different mobile phone UMTS signals on DNA, apoptosis and oxidative stress in human lymphocytes. Investigation of non-thermal effects of three different UMTS frequency bands on human lymphocytes. The researchers found relatively low but statistically significant induction of DNA damage at 1977 MHz.

ID 608: Othman H et al. (2021): Exposure to 2.45 GHz radiation triggers changes in HSP-70, Glucocorticoid Receptors and GFAP biomarkers in rat brain. Dysregulation of HSP-70 and GCR caused by repeated 2.45 GHz exposure. Thermal effects were ruled out.

ID 614: Said-Salman et al. (2021): Effects of Wi-Fi Radiofrequency Radiation on Carbapenem-Resistant *Klebsiella pneumoniae*. The study examined the effects of non-ionising radiation acting non-thermally on microbial virulence, particularly the emergence of multidrug-resistant bacteria. Result: Non-linear responses of *Klebsiella pneumoniae* cells to the antibiotics gentamicin and colistin. Exposure of cells to 2.45 GHz radiation from a Wi-Fi router for 24 hours caused morphological changes in bacterial cell membranes.

ID 758: Capucci U et al. (2022): WiFi Related Radiofrequency Electromagnetic Fields Promote Transposable Element Dysregulation and Genomic Instability in *Drosophila melanogaster*. These findings strongly suggest that EMF can induce TE activation (TE = transposable elements, parts of DNA) through a molecular mechanism independent of Hsp70 induction. This allows possible thermal RF-EMF effects on transposon dysregulation to be ruled out.

ID931: Kim et al. 2026: Electromagnetic field-inducible in vivo gene switch for remote spatiotemporal control of gene expression. EMF stimulation triggers pronounced rhythmic calcium oscillations, enabling highly selective, bio-orthogonal gene regulation. We identified cytochrome b5 type B (Cyb5b) as an essential mediator, probably acting as an EMF sensor (= non-thermal effect).

ID910: Weller et al. (2025): See page 11

ID847: Gulati S et al. (2024): Evaluation of oxidative stress and genetic instability among residents near mobile phone base stations in Germany. [Evaluation of oxidative stress and genetic instability among residents near mobile phone base stations in Germany]. Human RF-EMF exposure is restricted to prevent thermal effects in tissue. However, at very low intensities, non-thermal biological effects such as oxidative stress, DNA or chromosomal aberrations, collectively termed genomic instability, may occur after a few hours.

Panagopoulos DJ et al. (2026): Recording the extremely low frequency pulsations of wireless communication electromagnetic fields. *Electromagnetic Biology and Medicine*, 1-10;

<https://doi.org/10.1080/15368378.2026.2654072>. The damage is caused by low-frequency timing/pulsing. The authors write that "non-thermal EMF bioeffects are induced by ELF/ULF pulsation, modulation and variability, rather than the standalone (unmodulated) RF-EMF carrier waves, which can only produce warming at sufficiently high intensities that rarely occur in the environment." The scientists identify ion oscillation at voltage-gated ion channels as the mediating mechanism, principally responsible for the non-thermal biological effects of mobile communications and Wi-Fi.

ID 944: Gelenli Dolanbay E et al. (2026): Prenatal 3.5 GHz radiofrequency exposure induces renal histological changes and DNA damage in 6-month-old rats. Thermal effects were also considered in the SAR simulations; however, neither computational nor experimental analyses indicated conditions of thermal overload.

4.3 Tumour risk and tumour promotion

ID 517: Yakymenko I et al. (2010): Risks of carcinogenesis from electromagnetic radiation of mobile telephony devices. Review. Significant metabolic changes in living cells exposed to weak (non-thermal) electromagnetic fields.

ID 436: Lerchl A et al. (2015): Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans. Although animal experiments are generally not directly transferable to humans, the findings strongly indicate that the tumour-promoting effects of lifelong RF-EMF exposure can, in principle, occur at intensities supposedly too low to cause thermal effects.

ID 942: Kundi M, Hutter H-P (2026): Interpretation of epidemiological studies on the relationship between mobile phone use and cancer. [Assessment of epidemiological studies on the relationship between mobile phone use and cancer].

4.4 Oxidative stress

ID 115: Yu Y et al. (2008): Effects of exposure to 1.8 GHz radiofrequency field on the expression of Hsps and phosphorylation of MAPKs in human lens epithelial cells. Possible induced stress response in human lens epithelial cells (LECs) from non-thermal RF exposure. The appearance of p-ERK1/2 and p-JNK1/2, together with Hsp up-regulation, suggests that non-thermal RF exposure can induce the stress response in human LECs.

ID 100: Campisi A et al. (2010): See page 12

ID 729: Pilla AA et al. (2012): Electromagnetic fields instantaneously modulate nitric oxide signaling in challenged biological systems. This study aimed to show that a non-thermal pulse-modulated RF signal configured to modulate calmodulin (CaM) activation by accelerating Ca^{2+} binding kinetics produces an immediate, almost

threefold increase in nitric oxide (NO) in dopaminergic MN9D cultures ($p < 0.001$). Result: According to the authors, this is the first report of a real-time effect of non-thermal electromagnetic fields (EMF) on NO release from stressed cells. This effect could be useful in treating acute postoperative or chronic pain, for example in osteoarthritis.

ID 214: Jelodar G et al. (2013): The prophylactic effect of vitamin C on induced oxidative stress in rat testis following exposure to 900 MHz radio frequency wave generated by a BTS antenna model. The findings show that 900 MHz radiation from base stations caused oxidative stress in rat testes (non-thermal effect).

ID 152: Sefidbakht Y et al. (2014): Effects of 940 MHz EMF on bioluminescence and oxidative response of stable luciferase producing HEK cells. Oxidative stress in transgenic human embryonic kidney cells, followed by an antioxidant response. SAR was well below 2 W/kg, averaging about 0.09 W/kg (temperature rise 0.07 ± 0.03 , 0.02 - 0.1°C , non-thermal effect).

ID 205: Akbari A et al. (2014): Vitamin C protects rat cerebellum and encephalon from oxidative stress following exposure to radiofrequency wave generated by a BTS antenna model. The findings suggest that the radiation causes oxidative stress in encephalon and cerebellar tissue (non-thermal effect).

ID 707: Liu K et al. (2014): The Protective Effect of Autophagy on Mouse Spermatocyte Derived Cells Exposure to 1800 MHz Radiofrequency Electromagnetic Radiation. The study examined biological RF effects on the male reproductive system and whether RF exposure could induce autophagy in mouse spermatocytes. Although 4 W/kg is a relatively high radiation dose, thermal effects can be ruled out. Result: Autophagy may play an important role in preventing apoptotic cell death under RF exposure stress. A significant increase in DNA damage was found after exposure at 4 W/kg, but not at lower doses.

ID 179: Gürlü HS et al. (2014): Increased DNA oxidation (8-OHdG) and protein oxidation (AOPP) by Low level electromagnetic field (2.45 GHz) in rat brain and protective effect of garlic. This study examined whether garlic has a protective effect when non-thermal microwaves from a Wi-Fi system, at SAR 0.02 W/kg or 3.68 V/m, damage DNA, lipids and proteins in rat brain tissue and blood plasma. The public SAR exposure limit is 0.08 W/kg. Result: Oxidative stress in blood and brain; garlic may mitigate this effect.

ID 414: Othman H et al. (2017): Postnatal development and behavior effects of in-utero exposure of rats to radiofrequency waves emitted from conventional WiFi devices. These rat experiments examined how daily non-thermal 2.45 GHz exposure from an ordinary Wi-Fi device affecting foetuses in the womb subsequently influences offspring development after birth. Result: Various adverse effects on offspring from exposure of the mothers to 2.45 GHz Wi-Fi frequencies.

ID 710: Marjanovic Cermak AM et al. (2017): In vitro non-thermal oxidative stress response after 1800 MHz radiofrequency radiation. Transient oxidation-reduction imbalance in fibroblast cells after adaptation to the experimental conditions used.

ID 711: Marjanovic Cpanagermak AM et al. (2017): Oxidative stress response in SH-SY5Y cells exposed to short-term 1800 MHz radiofrequency radiation. Disruption of the redox balance in neuroblastoma cells and damage to lipids and proteins from short-term non-thermal RF exposure.

ID 703: Li R et al. (2018): The Protective Effect of Autophagy on DNA Damage in Mouse Spermatocyte-Derived Cells Exposed to 1800 MHz Radiofrequency Electromagnetic Fields. The study aimed to determine the mechanism and role of RF-EMF-induced autophagy in mouse spermatozoa. Although SAR 4 W/kg is relatively high, it remains below the threshold for thermal effects. Result: A significant increase in DNA damage was found after exposure at 4 W/kg, but not at lower doses.

ID 595: Choi J et al. (2020): Continuous Exposure to 1.7 GHz LTE Electromagnetic Fields Increases Intracellular Reactive Oxygen Species to Decrease Human Cell Proliferation and Induce Senescence. The study examined non-thermal effects of 1.7 GHz LTE radiation on the growth of different human cells in vitro. Thermal effects were ruled out through a sophisticated cooling system. Result: Reduced cell division in all cell types studied during continuous exposure to 1.7 GHz LTE radiofrequency radiation for 72 hours, at SAR1 = 1 W/kg and SAR2 = 2 W/kg.

ID 560: Singh KV et al. (2020): Effect of mobile phone radiation on oxidative stress, inflammatory response, and contextual fear memory in Wistar rat Environmental Science and Pollution Research. Oxidative stress in the brain: Although radiation emitted by mobile phones is far below intensities producing thermal effects, recent scientific literature has demonstrated that long-term exposure can cause damage through non-thermal pathways. Reactive oxygen species (ROS) and their effects currently provide the most convincing mechanisms for explaining non-thermal RF-EMF effects, particularly in the brain.

ID 596: Delen K et al. (2021): Effects of 2600 MHz Radiofrequency Radiation in Brain Tissue of Male Wistar Rats and Neuroprotective Effects of Melatonin. The study investigated non-thermal effects: the degenerative effects of 2600 MHz radiation (histology, oxidative damage and apoptosis), and melatonin's effects on the cerebral cortex, hippocampus and astrocytes in male rat brain tissue. Result: Statistically significant decreases in brain-tissue GSH, GSH-Px and SOD concentrations, and significant increases in MPO, MDA and NOx concentrations.

ID 686: Zosangzuali M et al. (2021): Effects of radiofrequency electromagnetic radiation emitted from a mobile phone base station on the redox homeostasis in different organs of Swiss albino mice. Investigation of possible effects of exposure below

thermal levels from a mobile phone base station on selected oxidative stress parameters in the brain, heart, kidneys and liver of Swiss albino mice. Result: Oxidative stress triggered by RF exposure from mobile phone base stations may have harmful effects on the mouse brain.

Schuermann D, Mevissen M (2021): Manmade Electromagnetic Fields and Oxidative Stress - Biological Effects and Consequences for Health. Int. J. Mol. Sci. 2021, 22(7), 3772; <https://doi.org/10.3390/ijms22073772>

ID 651: Pooam M et al. (2022): Exposure to 1,8 GHz radiofrequency field modulates ROS in human HEK293 cells as a function of signal amplitude. Significant increase in ROS in the nucleus and cytoplasm of HEK392 cells after 15 minutes of non-thermal 1.8 GHz field exposure.

ID 859: Gurhan H, Barnes F (2024): Frequency-Dependent Antioxidant Responses in HT1080 Human Fibrosarcoma Cells Exposed to Weak Radio Frequency Fields. With an applied RF field strength of only 20 nT, this study adds to the growing evidence suggesting that low-intensity electromagnetic fields exert biological effects through non-thermal mechanisms.

ID 912: Lai H, Levitt BB (2025): Radiofrequency radiation-induced gene expression. [Gene expression induced by radiofrequency exposure]. Forty gene expression effects were observed at SAR below 0.4 W/kg (non-thermal effect).

4.5 Cells, cell function and cell viability

ID 167: Esmekaya MA et al. (2011): Mutagenic and morphologic impacts of 1.8 GHz radiofrequency radiation on human peripheral blood lymphocytes (hPBLs) and possible protective role of pre-treatment with Ginkgo biloba (EGb 761). Increased mutation rate in peripheral blood lymphocytes, reduced cell viability and altered cell morphology; EGb 761 may reduce these effects. The transmitting antenna was positioned vertically above the lymphocytes. No temperature differences existed between exposed and sham-exposed samples, so no thermal effects were present.

ID 304: Vojisavljevic V et al. (2011): Low intensity microwave radiation as modulator of the L-lactate dehydrogenase activity. L-lactate dehydrogenase enzyme activity can be modulated by specific frequencies of weak microwave exposure. This finding may support the hypothesis that weak microwaves induce non-thermal effects in biomolecules.

ID 729: Pilla AA et al. (2012): See page 15

ID 710: Marjanovic Cermak AM et al. (2017): See page 17

ID 711: Marjanovic Cermak AM et al. (2017): See page 17

ID 703: Li R et al. (2018): See page 16

ID 550: Imani M et al. (2019): Morphological Changes Induced By Extremely Low-Frequency Electric Fields. Morphological changes possibly based on calcium-channel mechanisms. The effects were non-thermal.

ID 733: Said-Salman IH et al. (2019): Evaluation of Wi-Fi Radiation Effects on Antibiotic Susceptibility, Metabolic Activity and Biofilm Formation by *Escherichia Coli* 0157H7, *Staphylococcus Aureus* and *Staphylococcus Epidermis*. Antibiotic resistance, motility, metabolic activity and biofilm formation were measured to investigate non-thermal effects on different pathogenic bacterial strains (*Escherichia coli* 0157H7, *Staphylococcus aureus* and *Staphylococcus epidermis*). Result: The findings suggest that Wi-Fi exposure stresses bacteria, increasing antibiotic resistance and motility in *Escherichia coli* 0157H7 and promoting biofilm formation by *Escherichia coli* 0157H7, *Staphylococcus aureus* and *Staphylococcus epidermis*.

ID 725: Yamazaki S et al. (2020): Propagation of (THz) Irradiation Energy through Aqueous Layers: (Demolition) of Actin Filaments in Living Cells. The study investigated the effects of terahertz (THz) radiation on deep human-body tissue. Although the THz laser slightly increased the medium's temperature, the authors do not regard this as a thermal effect because the increase was marginal. Result: Demonstration of the potential of THz waves as an invasive method of altering protein structure in living cells.

ID 686: Zosangzuali et al. (2021): See page 17

ID 652: Echchgadda I et al. (2022): Changes in the excitability of primary hippocampal neurons following exposure to 3.0 GHz radiofrequency electromagnetic fields. Significant changes in neuronal activity, i.e. excitability of embryonic hippocampal cells, 15 minutes after the end of 60-minute exposure (through non-thermal means).

ID890: Seewooruttun et al. (2025): See page 22

ID 929: Jangid P et al. (2026): Radiofrequency radiation-induced changes in Leydig cell function. Our findings show that non-thermal RF electromagnetic radiation exposure impairs morphology, proliferation and cell-cycle regulation in TM3 Leydig cells in a frequency- and time-dependent manner.

4.6 Microwave effect (non-thermal mechanism)

ID 221: Hinrikus H et al. (2015): Microwave effect on diffusion: a possible mechanism for non-thermal effect. A possible mechanism for a non-thermal effect: Microwaves rotate dipolar water molecules and cause high-frequency changes in hydrogen bonds between water molecules, altering their viscosity and increasing diffusion.

4.7 Blood and biochemistry

ID 128: Busljeta I et al. (2004): Erythropoietic changes in rats after 2.45 GHz nonthermal irradiation. Disrupted maturation and proliferation of red blood cells and formation of micronuclei in erythropoietic cells after non-thermal exposure.

ID 53: Cespedes O et al. (2009): Effects of radio frequency magnetic fields on iron release from cage proteins. Rates of iron chelation with ferrozine are reduced by a factor of up to three in the proteins (non-thermal effect).
ID 884: Žura N et al. (2025): Short-Term In Vitro Exposure of Human Blood to 5G Network Frequencies: Do Sex and Frequency Additionally Affect Erythrocyte Morphometry?

4.8 Glands and hormones

ID 769: Mai TC et al. (2021): Low-Level Radiofrequency Exposure Induces Vasoconstriction in Rats. The authors examined the effects of low-level 900 MHz RF (SAR 0.35 W/kg) on rat tail-skin temperature (Ttail). Result: Indications that radiofrequency exposure below the thermal threshold may affect mammalian thermoregulation.

ID 929: Jangid P et al. (2026): See page 18

4.9 Testes/sperm, fertility

ID 31: Desai NR et al. (2009): Pathophysiology of cell phone radiation: oxidative stress and carcinogenesis with focus on male reproductive system. Review: Cell function may be disrupted by non-thermal radiation from commercially available mobile phones.

ID 420: Shahin S et al. (2014): 2.45-GHz microwave irradiation adversely affects reproductive function in male mouse, *Mus musculus* by inducing oxidative and nitrosative stress. Twelve-week-old mice were exposed to weak non-thermal 2.45 GHz microwave radiation (CW for 2 hours/day for 30 days, power density = $0.029812 \text{ mW/cm}^2 = 0.29812 \text{ W/m}^2$ and SAR = 0.018 W/kg). Result: Significant decrease in sperm count and viability, together with decreased diameter and degeneration of the seminiferous tubules.

ID 546: Yu G et al. (2019): Long-term exposure to 4G smartphone radiofrequency electromagnetic radiation diminished male reproductive potential by directly disrupting Spock3- MMP2-BTB axis in the testes of adult rats. Adverse effects on testicular health and sperm quality. The radiation emitted by the 4G smartphone did not increase the experimental animals' body temperature, ruling out thermal effects.

ID 647: Kim S et al. (2021): Effects of mobile phone usage on sperm quality - No time-dependent relationship on usage: A systematic review and updated meta-analysis. Systematic review/meta-analysis: Evidence that mobile communications effects are based on non-thermal

effects. If thermal effects were greater than non-thermal effects, people keeping their phones in trouser pockets would show a significant reduction in sperm parameters, because thermal effects require immediate contact to warm the tissue. (Background: subgroup analysis of storage location showed no significant differences.)

ID 883: Jha N et al. (2025): Effects of 700MHz radiofrequency radiation (5G lower band) on the reproductive parameters of female Wistar rats. The authors stress that non-thermal effects may pose reproductive health risks even below current exposure limits.

ID948: Vijay S et al. (2026): The Effect of 2.45 GHz Radiofrequency Electromagnetic Radiation on Components of the Hypothalamic-Pituitary-Gonadal Axis in Male Rats. According to the authors, increased GnRH with unchanged kisspeptin indicates a kisspeptin-independent, non-thermal effect.

ID 947: Syed Taha SMA et al. (2026): Testicular heat-shock protein expression in rats following 3.5 GHz and 24 GHz RF-EMF exposure. These findings suggest that low exposure to RF-EMF relevant to 5G can alter molecular stress responses in testicular tissue even without obvious histological damage (= non-thermal effect).

4.10 Embryo/foetus, embryogenesis

ID 124: Ferreira AR et al. (2006): See page 11

ID 746: Tsybulin O et al. (2012): GSM 900 MHz Microwave Radiation Affects Embryo Development of Japanese Quails. Indications of athermal effects on embryogenesis. The authors suggest that the stimulatory effect of low radiation doses on embryonic development may be explained by hormesis triggered by reactive oxygen species (ROS).

ID 414: Othman H et al. (2017): See page 16

4.11 Eyes

ID 115: Yu Y et al. (2008): See page 15

4.12 Brain, brain metabolism and brain activity

ID 792: Salford LG et al. (2007): Non-thermal effects of EMF upon the mammalian brain: the Lund experience. [Non-thermal effects of EMF on the mammalian brain: the Lund experience]. Published in: Environmentalist 2007; 27 (4): 493-500

ID 422: Sinha RK et al. (2008): Neural Network-Based Evaluation of Chronic Non-Thermal Effects of Modulated 2450 MHz Microwave Radiation on Electroencephalogram. Minor

effects on sleep EEG, open-field behaviour and thyroid hormones (T3, T4 and TSH) in an animal model.

ID 242: Jorge-Mora T et al. (2011): See page 13

ID 698: Kesari KK et al. (2013): Effect of 3G Cell Phone Exposure with Computer Controlled 2-D Stepper Motor on Non-thermal Activation of the hsp27/p38MAPK Stress Pathway in Rat Brain. The study investigated the effect of 3G mobile phone exposure using a computer-controlled 2-D stepper motor on non-thermal activation of the HSP27/p38MAPK stress-signalling pathway in rat brains. Result: Impaired brain function and various neurological disorders.

ID 205: Akbari A et al. (2014): See page 16

ID 160: Bragin DE et al. (2015): Increases in microvascular perfusion and tissue oxygenation via pulsed electromagnetic fields in the healthy rat brain. Increased microvascular cerebral perfusion through a nitric oxide-dependent signalling pathway. Exposure: SAR = 40 mW/kg (well below the thermal threshold).

ID 199: Sirav B et al. (2016): Effects of GSM modulated radio-frequency electromagnetic radiation on permeability of blood-brain barrier in male & female rats. Increased blood-brain barrier permeability, possibly with sex-specific differences. SAR is reported as 0.02 W/kg, far below the thermal threshold.

ID 560: Singh KV et al. (2020): See page 17

ID 887: Narayanan SN et al. (2025): Possible effects of radiofrequency electromagnetic radiation on contextual fear conditioning, hippocampal perivascular space, apoptosis and adrenal gland microarchitecture in rats. The study suggests that chronic non-thermal mobile phone radiation exposure significantly altered fear memory, accompanied by structural changes in the hippocampus and adrenal cortex.

ID 889: Lameth J et al. (2025): Repeated Head Exposures to a 5G-3.5 GHz Signal Do Not Alter Behavior but Modify Intracortical Gene Expression in Adult Male Mice. All SAR values are below ICNIRP exposure limits and in the non-thermal range.

ID 902: Bodin R et al. (2025): Altered development in rodent brain cells after 900 MHz radiofrequency exposure. This study examines the effects of non-thermal RF-EMF exposure levels in the 900 MHz mobile phone range on rodent neurological development.

ID890: Seewooruttun C et al. (2025): 5G Radiofrequency Exposure Reduces PRDM16 and C/EBP β mRNA-Expression, Two Key Biomarkers for Brown Adipogenesis. Paradoxically, low-intensity non-thermal RF-EMF may interfere with mammalian thermoregulation.

4.13 Memory, learning and behaviour

ID 119: Regel SJ et al. (2007): Pulsed radio frequency radiation affects cognitive performance and the waking electroencephalogram. Reduced response speed and increased accuracy in a working-memory task; increased EEG spectral power density in the 10.5-11 Hz range (alpha-wave activity): non-thermal effect.

ID 264: Sinha RK et al. (2008): Chronic non-thermal exposure of modulated 2450 MHz microwave radiation alters thyroid hormones and behavior of male rats. Changes in thyroid hormones and behaviour through chronic non-thermal exposure.

ID 157: Deshmukh PS et al. (2015): Cognitive Impairment and Neurogenotoxic Effects in Rats Exposed to Low-Intensity Microwave Radiation. Effects on the brain: significantly increased DNA damage and Hsp70 protein expression. The study shows that low-intensity microwave radiation at 900, 1800 and 2450 MHz (non-thermal effect) harms rat brains, evident in reduced performance in learning, memory and spatial orientation.

ID 552: Narayanan SN et al (2019): Radiofrequency electromagnetic radiation-induced behavioral changes and their possible basis. Increasing numbers of publications indicate possible non-thermal biological effects of RF electromagnetic radiation (RF-EMR) on the brain and behaviour.

ID 558: Broom KA et al. (2019): Early-Life Exposure to Pulsed LTE Radiofrequency Fields Causes Persistent Changes in Activity and Behavior in C57BL/6 J Mice. Persistent changes in activity and behaviour. Because behaviour was measured several weeks after exposure, simple explanations such as perceptual disturbances or thermal effects are untenable, as are unknown environmental stressors.

ID 652: Echchgadda I et al. (2022): See page 19

ID 692: Hinrikus H et al. (2022): Possible health effects on the human brain by various generations of mobile telecommunication: a review based estimation of 5G impact. Review: The majority of studies (68 of 73) used exposure levels below the official ICNIRP limit of 2 W/kg (non-thermal).

ID 887: Narayanan et al. (2025): See page 22

ID 900: Torkan A et al. (2025): Effects of Mobile Electromagnetic Exposure on Brain Oscillations and Cortical Excitability: Scoping Review.

4.14 Plants and animals

ID 233: Baranski S et al. (1972): Histological and histochemical effect of microwave irradiation on the central nervous system of rabbits and guinea pigs. This study examined whether prolonged, repeated microwave exposure at power densities that do not raise temperature (i.e. athermal doses) can cause histological or histochemical changes in the exposed animals' CNS. Result: Morphological lesions, a proliferative

response in glial cells and reduced acetylcholinesterase and succinate dehydrogenase activity.

ID 161: Tafforeau M et al. (2002): SIMS Study of the Calcium deprivation step related to epidermal meristem production induced in flax by cold shock or radiation from a GSM telephone. Calcium deprivation (analogous response: a combination of touch, wind or drought). 900 MHz radiation is not a natural environmental influence to which plants are adapted, but a plant can respond without experiencing a thermal effect (1 mW/cm², temperature increase < 0.2°C after 2 hours = non-thermal effect).

ID 746: Tsybulin O et al. (2012): See page 21

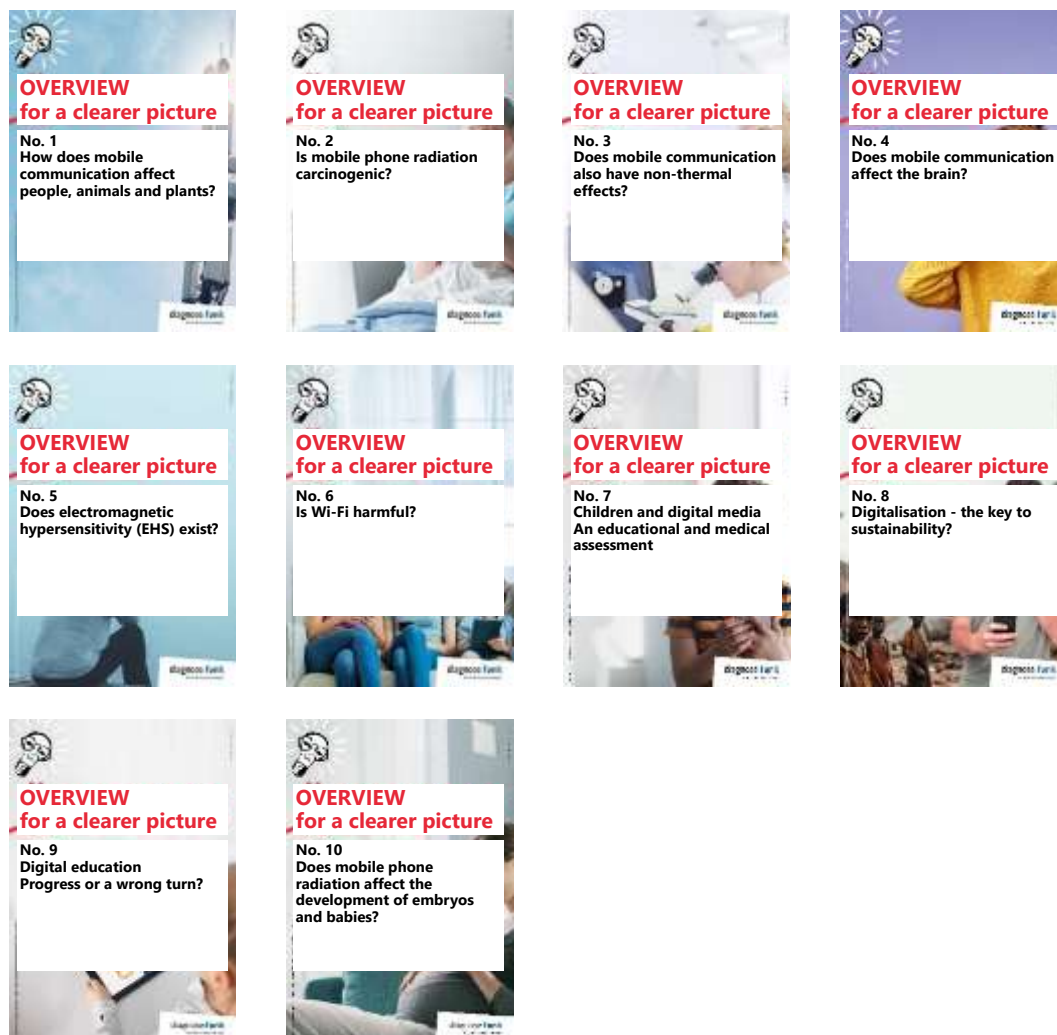
ID 489: Gremiaux A et al. (2016): Low-amplitude, highfrequency electromagnetic field exposure causes delayed and reduced growth in *Rosa hybrida*. Delayed and reduced growth in *Rosa hybrida*. Measurements of plant energy absorption from RF-EMF under these exposure conditions (SAR 7.2×10^{-4} W/kg) indicated that this biological response was probably not attributable to a thermal effect.

ID 504: Halgamuge MN et al. (2017): Review: Weak radiofrequency radiation exposure from mobile phone radiation on plants. The review examined the hypothesis that weak non-thermal electromagnetic fields affect living plants. Result: Various physiological or morphological changes across 169 experiments in the 45 included publications under short-term exposure (up to 13 weeks).

ID 686: Zosangzuali et al. (2021): See page 17

ID 769: Mai TC et al. (2021): See page 20

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