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Review

Schumann Resonances and the Human Body: Questions About Interactions, Problems and Prospects

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Featured Application: This review should strengthen the transdisciplinary dialogue between scientists for further studying the influence of the Earth's magnetic field on the human body. This review should draw attention to the issue among biomedical scientists and physicians.

Abstract: (1) Background: The interaction between the human body and the Earth's magnetic field at Schumann resonances (SRs) is one of the important fundamental questions of science that continues to be studied. The aim of this study was to create a working theoretical foundation for the interaction of the human body with SRs. (2) Methods: Extensive research was carried out in the literature with the aim of comprehensively presenting data on SRs and creating a working concept of their interaction with the human body. (3) Results: General data on SRs, a theoretical basis for justifying their interaction with the human body, possible mechanisms of influence and research results on the functioning of human internal organs were presented. (4) An interaction of the human body with SRs exists and has been scientifically proven. This interaction has been studied most significantly between SRs and the human nervous system. SRs affect functional indicators of the cardiovascular system: heart rate and blood pressure. Studying the influence of SRs on the course and pathogenesis of non-communicable diseases is a promising direction. Low-frequency SRs decrease the risk of developing acute myocardial infarction, and there is a tendency for them to promote cases of chronic kidney disease. SRs are an important external natural factor influencing the human body.

Keywords: non-communicable diseases; Earth's magnetic field; Schumann resonance; magnetoelectrochemical theory of metabolism; concept of synchronization

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1. Introduction

The study of aspects of the interaction of the human body with the Earth's magnetic field is relevant to modern fundamental science for two main reasons. The first reason is the scientific proof of the fact that the human body, at the micro level of its structure,

is formed by electromagnetic fields [1–3]. The quantum mechanical characteristics of subatomic molecular structures determine the occurrence of all chemical reactions of metabolism in the human body [4,5]. The chemistry of metabolic reactions in the human body is a secondary consequence of the dynamics of the electromagnetic states of the atoms of the molecules in the body and their subatomic structures [3,6,7]. Therefore, it is logical that the electromagnetic field structures that form the atoms of the molecules in the human body should respond to changes in the parameters of the external electromagnetic influence on them by changing their quantum mechanical characteristics. This interaction must obey the fundamental universal biophysical laws of nature. These aspects must be comprehended by fundamental science. Therefore, this is a new challenge for modern scientists. It is very important to study and understand these mechanisms of interaction between the human body and the Earth's magnetic field because the Earth's magnetic field is an important external component for the occurrence of magnetoelectrochemical processes in the phenomenology of biological life [8–12] and exerts a dynamic influence on the processes of cellular metabolism [13–15]. This demonstrates the relevance of continuing research in this area for fundamental science.

The second reason is based on the need to further study the fundamental mechanisms of the quantum level of the human metabolism to develop new approaches for the treatment and prevention of chronic non-communicable diseases (NCDs). Despite the significant progress of medicine in all its branches, modern human civilization has serious health problems in almost all populations on all continents [16–19]. NCDs are officially recognized as a global pandemic [20]. Over the past few decades, world science and the global community have been making efforts to solve the problem of NCDs. But success has not yet been achieved, and NCDs continue to be a challenge for global science and medicine [5,20–24]. Studying the fundamental mechanisms of interactions between the human body and the electromagnetic field of the Earth can reveal their participation in the occurrence and course of diseases of the internal organs of the human body. This may help improve knowledge of the pathogenesis of many pathologies of NCDs [25]. Accordingly, in the future, this may become the basis for creating new views on the treatment and prevention of NCDs, considering the natural dynamics of the Earth's chronobiological magnetic cycles. Perhaps in the future, based on this, it will be possible to use the artificial instrumental generation of frequencies of the Earth's magnetic field for the treatment and prevention of specific diseases. Therefore, it is important to continue to develop this scientific direction.

Studying the influence of the Earth's magnetic field on the human body is a very complex technical task. On the one hand, this research requires the presence of specific expensive technical equipment for recording and analyzing local changes in electromagnetic fields. On the other hand, a theoretical basis for the principles of describing and understanding the potential mechanisms of the influence of the Earth's magnetic field on the human body is still only being developed. This explains the imperfections in the methodologies of many studies conducted and their limitations. This is why, given the relevance and prospects of studying this scientific area for fundamental science, this review presents the results of a theoretical study on the conceptual integration of existing interdisciplinary and transdisciplinary knowledge in the fields of geomagnetism, magnetobiology, the physiology of the human body and medicine. The aim of the study is to create a working theoretical basis for the interaction of the human body with the Earth's magnetic field in the Schumann resonance frequency spectrum.

2. Materials and Methods

General scientific methods of theoretical research were used, such as dismembering and combining parts of the system under study, mental experience, logic, historical re-

search, analysis, induction, deduction and synthesis of knowledge. Theoretical methods of theory construction were used: ascent from the abstract to the concrete; generalization and abstraction; axiomatic, hypothetico-deductive and logical (rules of inference, formation of complex concepts from simple ones, establishment of the truth of complex statements, principles of formation of axiomatic theories, criteria for consistency, completeness and independence of systems of axioms and hypotheses) methods; and normative rules. Extensive research was carried out in the literature to elucidate the aspects and mechanisms of interaction between the human body and the Earth's magnetic field in the Schumann resonance frequency spectrum. This theoretical study was carried out by a transdisciplinary international team of scientists. The scientific team included mathematicians, biophysicists and medical scientists of various specialties.

3. Results

The concepts behind the results of the theoretical study are described as sections of the literature review.

3.1. Earth's Magnetic Field and Schumann Resonance Frequencies: Origin and Essence

As a result of theoretical research, it was conceptualized that from the position of modern biophysical knowledge, the natural electromagnetic environment of planet Earth is a single, whole, omnipresent, real formation, which is represented by electromagnetic fields [26]. For convenience of description, science has adopted a conventional division of the Earth's magnetic field into atmospheric magnetic fields and terrestrial magnetic fields [27]. However, the material of the Earth's surface and the lower ionosphere (60–130 km) are fairly good conductors, so the boundaries of electromagnetic fields are arbitrary and omnipresent. Only their physical local characteristics change depending on the localization of electromagnetic phenomena and the sources of their generation at a certain point in time. Magnetic fields do not have clear boundaries, forming a unique, single, integral, universal energy phenomenon [2]. This single magnetic field, as a universal phenomenon, can and does influence the existence of all material objects and biological life on planet Earth, being located everywhere.

To conceptualize knowledge about the interaction of the human body and the Earth's magnetic field, it is important to note the fact that the magnetic field of planet Earth is electromagnetic matter. Electromagnetic matter is a universal energy and information carrier [28]. All the energy and information from far and near outer space (from stars, nebulae, galaxies and other astronomical objects) come to Earth in the form of electromagnetic matter/radiation. The Sun is a powerful and comprehensive generator of electromagnetic radiation at various ranges and the main source of electromagnetic energy for the magnetic field of the Earth's atmosphere. Electromagnetic radiation from the Sun is the source of energy for all metabolic processes that occur on planet Earth [29]. Planet Earth is characterized by the heterogeneity of its electromagnetic field. The frequency range of electromagnetic processes on planet Earth ranges from 0 Hz (static fields) to 300 GHz. This natural frequency range of electromagnetic waves is the spectrum of the Earth's electromagnetic field. It includes, in increasing order, the frequencies of radio waves, infrared radiation, light radiation, X-ray radiation and gamma radiation [30]. Each band of the Earth's electromagnetic spectrum has a characteristic way of emitting and receiving waves [30]. For this reason, there are no sharp boundaries between different parts of the electromagnetic spectrum. The spectrum of electromagnetic radiation carries energy and information that affect the exchange of energy and substances in living biological organisms and have a specific biological significance for each range. The electromagnetic environment of planet Earth is formed by components such as the electromagnetic field of the Earth's

atmosphere, including local thunderstorm activity, air ionization due to corona discharges, solar radiation, resonance phenomena, etc.; planet Earth's own magnetic/geomagnetic field; electromagnetic fields of the biosphere (electromagnetic fields of all living organisms: prions, viruses, bacteria, plants, fungi, animals, humans); electromagnetic fields of the aquatic environments of the planet Earth; and now electromagnetic fields of technogenic anthropogenic origin. The electromagnetic environment of the Earth's surface is called the electromagnetic landscape [27]. It is this concept that is of greatest importance for systems medicine because it describes the total physical parameters of local electromagnetic landscapes that are the habitat for humans and affect the state of their health.

The electromagnetic environment of planet Earth arises due to the peculiarities of its planetary structure. The first fundamental feature is that planet Earth, from the point of view of physics, is a spherical capacitor. There is a constant potential difference between the Earth's surface and its atmosphere. This is due to the peculiarities of the organization of planet Earth and its atmosphere. On the one hand, the Earth's surface has high electrical conductivity and a negative charge. On the other hand, above the Earth's surface, there is an ionized, electrically conductive upper layer of the atmosphere, which is positively charged relative to the Earth's surface. This positive charge in the atmosphere arises due to the ionizing effect of solar radiation at high altitudes. Under the influence of solar radiation, a circular conductive layer appears in the atmosphere, which is called the ionosphere/plasmasphere. The plasmasphere can have a charge equal to hundreds of thousands and even up to millions of volts relative to the Earth's surface. The plasmasphere has high electromagnetic conductivity and is capable of reflecting short radio waves. Therefore, the plasmasphere is an inexhaustible generator and energy accumulator. In essence, this is a system of an "Earth capacitor", which is charged due to solar radiation/"solar wind"; in the upper layers of the atmosphere, ions are constantly formed from air molecules under the influence of the energy of solar radiation particles. When a thunderstorm/lightning strike occurs, the voltage slightly decreases and then increases again [31–33].

The second fundamental feature is that the surface of planet Earth, together with its plasmasphere, from the point of view of physics, is a spherical resonator [34]. The plasmasphere and the Earth's surface are impenetrable to several frequency ranges. This forms a so-called conventional "mirror cavity" above the surface of the planet in its atmosphere—a waveguide channel. It is these resonator properties that are the basic features that determine the specificity of electromagnetic variations in the Earth's magnetic field and form the so-called Schumann resonance frequencies. This is because electromagnetic waves are reflected from the Earth's surface and from the plasmasphere as from mirrors. As a consequence, electromagnetic waves, being reflected many times, circle the Earth. At the same time, they are characterized by behavior in accordance with the laws of physics: superimposed on each other, they can either be extinguished or reinforce each other—resonate. In such a resonator, waves of certain frequencies, repeatedly reflected from the layers of the plasmasphere and the Earth's surface, are capable of circling the globe more than once. If the electromagnetic wave arising in the cavity of the Earth's resonator, after circling the globe, again coincides with its own phase and enters resonance, then a so-called standing wave (soliton) is formed. Wave processes in the low (3 Hz–3 kHz) and very low (3–30 kHz) frequency ranges, as well as all types of electromagnetic radiation, are reflected from the Earth's surface and ionosphere [35,36]. Therefore, a certain characteristic pattern of low-frequency electromagnetic resonances constantly exists above the Earth's surface, which creates a certain local electromagnetic background with peaks at frequencies around 7.8, 14.3 and 20 Hz. These frequency peaks are called Schumann waves or Schumann resonances (SRs) [32,37–39].

N. Tesla was the first to describe the phenomenon of SRs. Later, when other scientists in different countries began intensively studying the plasmasphere, these resonant frequencies of the plasmasphere were measured with great accuracy [40]. In 1949, the German scientist Winfried Otto Schumann was first person who reported the existence of a spherical resonator on Earth—a plasmasphere with several fixed resonant frequencies. In 1952, Schumann published the first scientific paper on the existence of low-frequency resonances in a physics journal [41,42]. Studying electromagnetic fields in the Earth–ionosphere cavity, Schumann first theoretically predicted the existence of natural resonances in the ionosphere. Calculations he made based on the size of the Earth and its ionosphere initially showed the frequency of the Earth's fundamental resonance to be approximately 10 Hz. After performing numerous additional studies, it was experimentally determined that the exact frequency of the Earth is 7.83 Hz. Waves of this frequency are called Schumann waves. Schumann waves are standing electromagnetic waves of extremely low frequency in the atmosphere, the length of which approximately corresponds to the circumference of the Earth and is 38 thousand kilometers. They may have some variations in frequency ($\pm$0.2 Hz) and amplitude depending on the time of day, season and geography of the Earth's surface [43,44]. Schumann waves propagate at the speed of light in the spherical layer between the Earth's surface and the lower ionosphere and circle the Earth approximately eight times per second. Therefore, in science, the frequency of 7.83 Hz was called the fundamental frequency of SRs, and a number of scientists began to call it the "heartbeat frequency of the Earth". In addition to the fundamental Schumann frequency, the plasmasphere has other resonant frequencies, which are also referred to as SRs. Today, eight ultra-low-frequency Schumann waves are known. Their rounded frequency values are 8 Hz, 14 Hz, 20 Hz, 26 Hz, 32 Hz, 39 Hz, 45 Hz and 50 Hz [38,45].

The main source of waves for resonance and the occurrence of Schumann waves are various radio frequency bands that are formed as a result of lightning discharges in the Earth's atmosphere. At a given time, about two thousand thunderstorms occur on Earth: from 50 to 100 lightning strikes per second. The physical process of the formation of SRs can be described as follows. Lightning generates powerful electromagnetic radiation in almost the entire frequency range. But the "Earth–ionosphere" resonator from this "white noise" absorbs energy mainly at resonant frequencies due to the characteristics of its size. The plasmasphere receives constant energy pumping from lightning and converts all radiation into standing waves/solitons with Schumann resonance frequencies. Ultra-low-frequency waves (300 Hz–3 kHz) are received from the magnetosphere and ionosphere of the Earth's atmosphere in the form of so-called geomagnetic pulsations or ionospheric Alfven resonances that have no further influence along the geomagnetic field lines [35,43,44,46–49].

Thus, the Earth's magnetic field is formed through electromagnetic interactions between the Earth's surface and cosmic radiation. At the same time, the Earth's surface is under the constant influence of local atmospheric sources of electrical variations in lightning discharges and their result—SRs, which determine the contribution of the atmosphere to the local electrical landscape of the surface of planet Earth and influence living biological systems, including humans.

3.2. Magnetoelectrochemical Theory of Metabolism as a Fundamental Theoretical Basis for Justifying the Interaction of the Human Body with the Magnetic Field of the Earth

On planet Earth, the transfer of energy and information is also carried out using a magnetic field. But can the Earth's magnetic field affect the human body? What fundamental knowledge can justify the possibility of an influence of the Earth's magnetic field on the human body?

The theoretical biophysical justification for the validity of this concept for the human body is the magnetoelectrochemical theory of metabolism (2019–2025) [3,6,7,50]. This theory systematizes and extrapolates existing biophysical knowledge to the functioning of the human body at all hierarchical levels of its structure (from the subcellular level to the organismal level). The basic postulates were formulated [3,6,7,50], which became the final substantiation of the fact that the human body, at the micro level of its structure, is formed by electromagnetic field structures. Data from the standard model were extrapolated to ideas about the structure of the human body, and it became obvious that the human body, like all atoms on planet Earth, is also formed by fermions, bosons, etc. [51]. This theoretical research confirmed that the basis of the phenomenology of biological life is electromagnetic processes. At the same time, electromagnetic processes are fundamental for the implementation of the phenomenon of biological life at all structural levels of the human body, from the subatomic level to the organismal level. The quantum mechanical properties of the atoms of molecules determine their chemical structure and chemical reactivity. Biopolymer molecules become "alive" in vivo due to the generation and transmission of coherent electromagnetic energy in the form of solitons [3,52–54]. Electromagnetic biophotonic mechanisms are a component of intracellular communication and extracellular communication [5,28,55]. Biophoton signaling is involved in the formation of the morphogenetic field of organ tissue cells and is a component of non-chemical information transfer between organs and parts of the human body [56–58]. The biological life of cells, tissues and organs in the human body is connected and determined by the quantum mechanical state of membrane cellular structures and their generation of electromagnetic fields [59]; the cessation of the generation of electromagnetic processes in cell membranes leads to cell death. Therefore, according to biophysical knowledge, the cells of the human body and, accordingly, the tissues formed by the cells and the organs of living biological systems can be represented in the model of the resulting interfering electromagnetic wave packets, which have a specific constant frequency, subject to the normal course of metabolic/energetic processes in them [3,6,7,50]. The cells of the human body and the tissues and organs formed by the cells are integral quantum mechanical systems with periodic connections and a self-consistent morphological structure of organization. Membrane structures of cells oscillate and generate biological currents. This forms the electromagnetic field of the cells. As a quantum–mechanical result of the interaction of electromagnetic energy, a superposition of these fields arises in the millimeter wavelength range with a frequency of 10^{10}–10^{11} Hz [60]. In this case, a biological range of information and energy processes of the cellular phenomenology of life is formed at 10^{14} Hz and below. These are optical processes in the form of Davydov photons/solitons, which have a wavelength from >1 μm to 0 and an energy from <0.5 eV to 0. They have an intensity well below the energy levels of the ionization and excitation of atoms and molecules. They coincide with the optical region of the electromagnetic spectrum of the Sun [3,6,7,50]. An important fact is that electromagnetic waves are emitted by all atoms of substances in vivo. The human body is formed by atoms. Thus, the human body can be represented by a model of a conglomerate of electromagnetic field structures. The wave parameters of radiation from cells are described and classified according to two main characteristics: wavelength and the associated wave frequency. The wavelength parameter describes an electromagnetic wave according to the classical laws of physics. The "wave frequency" parameter describes the radiation according to the quantum laws of physics. Therefore, each cell of the human body in vivo is a source of electromagnetic oscillations and a complex of wave functions, the parameters of which are determined by the frequency–wave basis of the structural and metabolic processes occurring in it [3,6,7,50]. The biological role of water and the presence of biological anomalies in vivo are due to the unique quantum mechanical properties of water and the ability of

its molecules to form energy-intensive aqueous liquid crystal structures in the shape of a 30/11 spiral with semiconductor properties [61,62]. This explains the participation of water in the electromagnetic mechanisms of energy and information transfer without loss at the micro level of the human body structure in vivo [3,6,7,50].

Thus, the human body, formed by electromagnetic structures, functions and lives thanks to the occurrence of magnetoelectrochemical processes within it. When considering the human body from the perspective of modern biophysical knowledge, it becomes obvious that man is integrated into the general system of life and into energy exchange on planet Earth. Therefore, from the position of the concepts of the magnetoelectrochemical theory of metabolism, the human body at all levels of its hierarchical structure can be susceptible to the influence of the Earth's electromagnetic field, since, in essence, it is formed by electromagnetic field structures at the micro level of its structure.

3.3. The Concept of Synchronization of the Human Body and the Earth's Magnetic Field in the Schumann Resonance Frequency Spectrum

If we consider all the existing and scientifically proven facts of the electromagnetic aspects of the structure and functioning of the human body, then ideas about its possible synchronization with the Earth's magnetic field appear quite logical. Should everything in nature have a biological meaning? What biological meaning could there be in synchronizing the human body with the Earth's magnetic field?

It should be noted that the phenomenon of the synchronization of processes is a universal phenomenon in biology. Synchronization is observed in many living biological systems [63]. From a physical point of view, synchronization is a process of interconnection and mutual influence between objects/systems that fluctuate in time with a fixed phase relationship between them. That is, there must be some connection between objects leading to synchronization, as was, for example, established during the discovery of the phenomenon of synchronization in the 17th century by Christian Huygens (1629–1695) in an experiment with the pendulums of two clocks [64]. The oscillations of the pendulums of mechanical watches gradually became synchronized due to weak vibrations that were transmitted through a common support from one watch to another. The phenomenon of biological synchronization is an important mechanism of self-organization in complex systems. Due to interaction with the environment or the interaction of subsystems, this makes it possible to significantly reduce the degree of freedom of the biological system. The classical theory of synchronization uses the concept of the existence of an autonomous periodic generator. According to this scientific concept, if an external periodic force of the appropriate amplitude and frequency is applied to an autonomous generator, then this system will oscillate in phase with the external signal. Therefore, synchronization can be classified into frequency synchronization and phase synchronization [65,66]. If we theoretically consider the interaction of the electromagnetic field structures/processes of the human body with the electromagnetic field of the Earth, then we can postulate that during evolution, the human body adapted to become phase synchronized with the background electric fields of the atmosphere, the frequency characteristics of which were predetermined by SRs. In other words, SRs should be the natural factor through which the mechanism of the electromagnetic influence of the planet Earth on the course of magnetoelectrochemical metabolic processes in the human body is realized.

The logic of this conclusion is based on the following knowledge. Theoretically, the phenomenon of Schumann resonance has existed on planet Earth for billions of years, since the appearance of volcanic and thunderstorm activity. In the process of evolution, this maintained a natural background field of extremely low frequencies throughout the planet, with a certain maximum frequency with a fundamental mode around 8 Hz (as now proven and understood by science) [67]. The magnetic fields of the Earth are naturally

conducive to the existence of biological life [68]. It is logical that during evolution, especially in its early stages, SRs were the only constant electromagnetic fields available for such synchronization. SRs may have influenced early life forms that arose in the oceans, as extremely low-frequency waves with planetary wavelengths can penetrate hundreds of meters into the photic zone of the oceans (the sunlit upper layer of water). The estimated penetration depth of electromagnetic waves with a frequency of 8 Hz in sea water is 100 m [69]. Living organisms of the surface layer of water will be influenced by SRs in the same way as living organisms on the surface of the Earth. This is important for formulating the role of SRs as a biological electromagnetic factor participating in the evolution of life on planet Earth.

Schumann resonant fields in the atmosphere have a magnetic field amplitude that is calculated in picoteslas and are significantly weaker than the Earth's quasi-static geomagnetic field. The biological effects of such weak electromagnetic fields can be realized due to the occurrence of the phenomenon of stochastic resonance. When a nonlinear system is exposed to a weak, undetectable periodic signal, stochastic resonance occurs. This weak biological signal then becomes detectable due to the phenomenon of resonance between the stochastic noise and the weak deterministic periodic signal [70]. The periodic excitation mechanism and external noise interact with each other. In this case, the energy from the noise spectrum is transferred to a single frequency, consistent with the signal, and the amplitude of the external noise is adjusted to the internal properties of the biological system. Because of this interaction, a clear peak is formed in the power spectrum of the output signal, and the signal-to-noise ratio increases. Therefore, lightning-induced extremely low-frequency fields and SRs can act as signals perceived by biological systems through the phenomenon of stochastic resonance. Thus, SRs can be a constant source of electromagnetic influence, which over millions of years of evolution could influence the development of biological systems and largely determine the electrical activity of organisms.

Based on this knowledge, it is quite logical to assume the existence of a connection between the electromagnetic processes of the human body and the external electromagnetic fields of the Earth in the Schumann resonance frequency spectrum.

3.4. Studying the Influence of Schumann Resonance Frequencies on the Functioning of the Internal Organs of the Human Body

Research into the influence of Schumann resonance frequencies on the human body began at the moment of their discovery and continues in the present time, since the answers to many questions remain unknown and debatable. Conventionally, all studies conducted can be divided into the category of early studies and the category of modern studies. Early research was carried out with more primitive technical equipment and therefore became the historical basis for modern science.

The history of early research is reflected in detail in the article of Besser B.P. [40]. From the perspective of solving the problems of this review, the most significant early studies include the studies of W.O. Schumann [41,42], W.O. Schumann and H. Konig [71], J.R. Hamer [72], R. Wever [73,74], N. Kirmaier and H. Konig [75], R.J. Gavalas et al. [76], H.L. Konig [77], R.C. Franz et al. [78], E.R. Williams [79], D.D. Sentman [80], K. Schlegel and M. Fullekrug [81], M. Fullekrug and S. Constable [82], C. Price [43,44,83], V.P. Pasko et al. [84], M. Fullekrug et al. [85], etc. The results of these studies have varying degrees of reliability and validity. But they all indicate the influence of SRs on living biological organisms and the human body. They were unable to provide categorical conclusions regarding the mechanisms of influence of SRs on living organisms, but they substantiated the need to continue scientific research in this direction, confirming the existence of the Earth's magnetic field's influence on the human body in the frequency spectrum of SRs.

Technical progress and the era of digital technology have created modern, fundamentally new technical capabilities for recording the Earth's electromagnetic field and statistically processing large amounts of data. Therefore, all hopes for future discoveries regarding the mechanisms underlying the influence of SRs on the human body relate to modern research.

In the 21st century, the basic methodology for deciphering hidden information in brain signals has expanded [86]. There is an understanding of the creation of a unified methodology for studying SRs [87].

Fundamental knowledge about the Earth's magnetic field has increased. For example, there is an increased understanding of key aspects of the Earth's geomagnetic field, including dipole moment decay, changes in the South Atlantic anomaly and the positions of the magnetic poles, which are critical for effective space weather forecasting [88,89]. Progress has been made in modeling the magnetospheric magnetic field [90,91] and space weather [92]. This allows observational data to be combined with flexible models to better understand the dynamics of the Earth's magnetic environment. It has become possible to measure magnetic fields from geostationary orbit [93]. This has improved space weather monitoring and the scientific understanding of the interaction between near space and the Earth's magnetosphere. For modern science, the great importance of understanding the geomagnetic field of the Earth and its response to external influences is already obvious [94–96]. This forms a new paradigm of views on the entire problem of geomagnetism and all related transdisciplinary issues.

New opportunities have emerged for simultaneously recording the parameters of the Earth's electromagnetic field around the world. For example, the Global Coherence Monitoring System (GCMS) was created to measure the dynamics of the Earth's magnetic field and SRs. In 2008, the first "Maggie" magnetometer was installed in the United States. GCMS currently has a network of 12 magnetometers located in New Zealand, South Korea, Japan, Malaysia, India, South Africa, Saudi Arabia, Colombia, USA, Canada, Argentina and Lithuania [97]. The magnetometers are equipped with two ANT4 magnetic field detectors (Zonge Engineering Inc., Zonge International, 3322 E. Ft. Lowell Road, Tucson, AZ 85716, USA). The detectors are oriented north–south and east–west. Signals are digitized by a 24-bit data acquisition system with an average frequency of 130 Hz. The spectral power calculation is performed using the east–west component. A smooth response in the range of 0.01–300 Hz is ensured by the large bandwidth of the magnetometers. The measurement is carried out (according to the Nyquist theorem) only for frequencies up to 65 Hz [98]. The data acquisition equipment records Schumann resonance amplitude data in a time-locked manner using a global positioning system. These data are recorded on a central server. The methodology for measuring local Schumann resonance amplitude data is described in detail in [98,99]. This allows for an estimate of the Schumann Resonance Complexity Index (SRCI), which is calculated using a calibrated H-rank algorithm from the local magnetic field data recorded by each GCMS magnetometer [100]. This should improve the quality of research methodology in this scientific area. Thanks to the creation of this system, many scientists have received the technical opportunity to study the influence of the Earth's magnetic field and SRs.

Science has advanced in understanding many issues of geomagnetism and biomagnetism, but research into the interaction of the human body with the Earth's magnetic field at Schumann resonance frequencies is still far from achieving its ultimate goal. To date, aspects of the interaction between the human body and the Earth's magnetic field in the frequencies of the Schumann resonance spectrum have been studied in three organ systems of the human body: the nervous system, the cardiovascular system and the urinary system.

The results of these studies cannot yet be called exhaustive. Therefore, scientific research must continue.

3.4.1. Results of Studying the Interaction of Schumann Resonances with the Nervous System of the Human Body

The historical foundation of research on the interaction between the human body and the Earth's magnetic field was laid by the German doctor Herbert König. In 1952, he first discovered the fact that the main resonant frequency of the ionosphere, 7.83 Hz, coincides with the alpha wave range (7.5–13 Hz) of the electromagnetic activity of the human brain and scientifically proved it [71,101,102]. Modern research has confirmed and significantly expanded this scientific fact.

At the end of the 20st century, the relationship between SRs and brain activity was mathematically calculated. It was established that the resonant frequency for the human brain is approximately 10 Hz [103] and decreases depending on the increase in the size of the human skull [104]. Scientists from the University School of Electrical and Computer Engineering Melbourne (Australia), from the University of Alabama in Huntsville Electrical and Computer Engineering Dept Huntsville (USA) and from Custom Systems Pty Ltd. (Australia) in the period from 1984 to 2005 carried out studies on the resonant characteristics of human acupuncture meridians and their possible correlations with the rhythms of the human brain and Schumann resonance frequencies. Experimental results on the responses of human electrophysiological signals to "geomagnetic" and artificial environmental extremely low-frequency electromagnetic fields were compared. Frequencies between 8.8 and 13.2 Hz, which fall between the peaks of the SRs, were found to be mainly correlated with the analyzed human electrophysiological signals, and a correlation between the SR transfer function and human electrophysiological signals was proven. The researchers concluded that the human body absorbs, detects and responds to extremely low-frequency environmental electromagnetic field signals [104].

The study demonstrated the biological plausibility of the interaction of the Schumann resonance signal with the brain and changes in melatonin production [105]. The study confirmed that the electromagnetic fields of ultra-low-/extremely low-frequency waves of the environment interact with brain tissue at extremely low intensities, changing the flow of calcium ions, electroencephalogram results and reaction time. The brain cells use phase-locked loops to detect and respond to natural electrical signals in ultra-low-/extremely low-frequency waves. Laboratory experiments have confirmed that Schumann resonance frequencies alter reaction times in humans and monkeys. Human reaction times are also highly correlated with dose and Schumann resonance intensity, supporting this interaction. Ultra-low-/extremely low-frequency fields have also been found to reduce melatonin levels in animals and humans.

At the beginning of the 21st century, many parameters were established that detailed the connections between the human brain and the Earth's magnetic field. For example, in the right prefrontal sensor, theta activity (4–7 Hz) has a positive correlation with the strength of the Earth's atmosphere, an indicator of the strength of the steady state of the Earth's magnetic field [106,107]. Parahippocampal activity and bitemporal coherence were found to be positively correlated with the k-index, or the strength of geomagnetic displacement. However, the strength of the relationship between geomagnetic activity and right and left posterior temporal lobe coherence was the strongest for coherence at 7.81 and approximately 20 Hz. This corresponds to the first and third harmonics of SRs [108]. It has been proven that there is direct synchronicity between the magnetic processes occurring in the human brain and the Earth–ionospheric cavity. It was found that there are transient periods of "harmonic synchrony" that occur when calculating interchannel coherence between ultra-low-frequency magnetic activity originating in the

environment and the caudal RMS signal that is received from the brain. These periods of harmonic synchrony have a duration of approximately 200–300 ms, and they are a phenomenon of simultaneous coherence in the ranges of 7–8, 13–14 and 19–20 Hz [109,110]. It should be noted that a significant scientific contribution to the study of the influence of Schumann resonances on the human brain was made by scientists from Laurentian University (Canada). In 2012, Canadian scientist M.A. Persinger of Laurentian University applied the concept of scale invariance to the study and found that the current densities of action potentials that propagate along the axon are similar to the densities of lightning strikes. Persinger concluded that the supposedly fractal connections between the processes that occur in the brain are a reflection of the electromagnetic processes that take place on planet Earth [111]. From 2009 to 2013, a major study was carried out at Laurentian University on the statistical analysis of electroencephalogram data from the human brain and their connections with SRs [112]. Canadian scientists proceeded from the idea that the human brain is a functional dynamic dipole, which has a potential difference on the order of 10–30 mV and has a shape typical of an ellipsoid. In their opinion, therefore, a relatively fixed volume and surface area of the brain and a rostral–caudal volumetric velocity of ~4.5 m s^{-1} should generate constant standing waves with parameters very close to the fundamental Schumann resonance with a frequency of ~7.5 to 8 Hz. This is a resonant solution for the speed of light (3×10^8 m/s) and the fixed circumference of the Earth (4×10^7 m). It has been found that in many (but not all) individuals, electroencephalogram properties exhibit real-time differences in volume, three-dimensionality, coherence between spectral densities and power peaks with SRs. The researchers also concluded that these relationships are stable. The basis for this was the fact that for brain parameters, there were no statistically significant differences between the strength of the rostral–caudal, left–right comparison correlations or their power ratios for the entire sample and a random subsample of 10 respondents. Noteworthy is a study examining the connections between the emission of biophotons from the mouse brain and SRs [113]. It was found that the irradiation of mouse brain tissue with electromagnetic vibrations with frequencies close to the frequency of the first mode of the SRs shifts the maximum spectral density of biophotonic radiation at frequencies of 7.74 and 7.87 Hz. The level of magnetic field induction exceeded the background level of the SRs by 5–6 orders of magnitude. These data may be useful for extrapolation to the human body, since the fact that brain tissue is sensitive in vivo to the first-mode frequency is of interest for further research. Attempts have also been made to find connections between SRs and electroencephalogram data from sleeping people. A correlation was found between variations in the frequency of the second mode at 12–14 Hz and the frequencies of sleep spindles on electroencephalograms during the second stage of sleep (sigma rhythm) in humans [114].

In 2017, time-series correlation analysis revealed the response of the human autonomic nervous system to various dynamic changes in sunlight, cosmic rays and the surrounding magnetic field [115]. This study also revealed significant correlations between group measures of heart rate variability, Schumann resonance power and overall magnetic field changes. It was found that the participants' heart rate variability synchronized over the 31-day period in about 2.5 days, even though all the participants were in different locations. This was interpreted by the researchers as evidence that the daily functioning of the autonomic nervous system responds to changes in geomagnetic and solar activity, synchronizing with time-varying magnetic fields that are associated with SRs and geomagnetic field line resonances.

In 2018, a long-term study to investigate the relationship between solar and magnetic factors and the reactions of the autonomic nervous system to changes in solar and geomagnetic activity was carried out [116]. To achieve this, a group of participants under-

went weekly 72 h heart rate variability recordings over a five-month period. The study established correlations between geomagnetic and solar variables and measures of heart rate variability. The results of these studies established that the daily functioning of the autonomic nervous system responds to changes in solar and geomagnetic activity. The increase in solar wind intensity correlated with an increase in heart rate, and this was interpreted by the researchers as a biological response of the human body to stress. Increases in parasympathetic activity and heart rate variability were observed with increasing solar radio flux, cosmic ray flux and Schumann resonance power.

3.4.2. Results of Studying the Interaction of Schumann Resonances with the Cardiovascular System of the Human Body

Scientific research has aimed at identifying the relationships between SRs and generally accepted indicators of the functional activity of the cardiovascular system such as heart rate/pulse, blood pressure and heart rate variability.

In 2005, scientists from the Oriental Medical Center and Telecommunications University (Tokyo, Japan) and from the Chronobiology Laboratory of the University of Minnesota (USA) found a significant decrease in the group average values of diastolic blood pressure, systolic blood pressure, mean arterial pressure and pulse on days when an increase in SRs was observed. Disease-related illnesses had a negative correlation with the response of blood pressure, systolic blood pressure, diastolic blood pressure, mean blood pressure and double product to SRs. This led to the assumption that on days with elevated SRs, patients with lower blood pressure levels have better health. Health-related lifestyle had a negative correlation with the responses of blood pressure, diastolic blood pressure and mean arterial pressure to SRs. Gender differences were found: men had higher reactivity in blood pressure, diastolic blood pressure and mean arterial pressure compared to women [117].

In 2017, based on assessing the parameters of the intervals between heartbeats, an international team of scientists developed a new method for analyzing the degree of synchronization of the physiological state of the human body with changes in the Earth's magnetic field [118]. The results of the study confirmed the fact that slow rhythms of heart rate variability can synchronize with changes in local magnetic field data and that the degree of synchronization is influenced by the quality of interpersonal relationships.

In 2021, a global study was carried out to study heart rate synchronization with the Earth's time-varying magnetic field [99], which involved volunteers from California, Lithuania, Saudi Arabia, New Zealand and England. It was found that changes in geomagnetic conditions affect the rhythms of the brain and heart and the activity of the autonomic nervous system.

An alternative direction of research was the exploration of the influence of the Earth's magnetic field on the occurrence of diseases in the cardiovascular system. The idea of such studies was that in patients with NCDs, the body's adaptive reserves have been exhausted, and the stress of changes in the Earth's electromagnetic field will be a factor that will lead to an exacerbation or emergence of a life-threatening condition. For example, in 2023, the results of a five-year study examining the relationship between the Earth's local magnetic field and acute myocardial infarction were published [119]. The study results revealed significant long-term associations between the Earth's local magnetic field and acute myocardial infarction. SRs from SBeta (15–32 Hz) and SGamma (32–65 Hz) have been found to play an important role in establishing long-term relationships.

3.4.3. Results of Studying the Interaction of Schumann Resonances with the Urinary System of the Human Body

All organs in the human body are functionally united and influence each other's functioning. Therefore, the human body is a complex, interconnected, multi-hierarchical

functional system. This confirms the fact that pathologies of the kidneys and cardiovascular systems often occur simultaneously and have a combined progression. For example, the occurrence of acute heart failure is associated with acute kidney damage, and chronic kidney disease is present in more than 90% of patients with heart failure [120]. After reliable correlations were established regarding the influence of the Earth's electromagnetic field on the occurrence of myocardial infarction [119], a hypothesis arose about the possibility of the influence of SRs on the exacerbation of chronic kidney diseases. In 2023, a study was carried out on the correlation between episodes of kidney disease and SRs [121]. The study had several limitations and was exploratory. Its results are preliminary and justify the need for further research in this direction. The authors concluded that changes in SRs are correlated with episodes of kidney disease. A preliminary conclusion was made that the influence of the SRs on the pathogenetic mechanisms of kidney diseases is exerted in the opposite direction compared to that on cardiovascular diseases. But it is important to establish the correlation between SRs and kidney function. This may be another new and unexplored pathogenetic mechanism of NCDs and cardiorenal syndrome. In 2024, a theoretical study searched for new pathogenetic mechanisms of cardiorenal syndrome associated with the influence of the Earth's magnetic field and identified possible mechanisms [122]. The authors consider this direction promising for continued research because if SRs are synchronized with the activity of the nervous system and the cardiovascular system, then the kidneys, as organs associated with blood circulation, should also respond to changes in SRs.

3.4.4. Results of Studying the Interaction of Schumann Resonances with the Skin of the Human Body

It is well known that the skin of the human body exhibits electromagnetic heterogeneity. The study of the role and participation of the skin of the human body in the transmission of electromagnetic signals has long been another an important problem for fundamental science and medicine. Therefore, for future research, it is important to take into account that from 1984 to 2005, a transdisciplinary group of scientists from the University School of Electrical and Computer Engineering Melbourne (Australia), Custom Systems Pty Ltd. (Australia) and Engineering Dept Huntsville (U.S.A) carried out a series of studies on the electrical activity of the brain and skin and its interaction with SRs [123–128]. The reactions of electrophysiological signals of the human body to the influence of electromagnetic fields of extremely low frequencies, including SRs, were studied. Frequency passbands were established for skin areas with increased electrical conductivity properties, i.e., "meridians of traditional medicine", which were in the ranges and areas of SRs. Depending on the meridian and functional state of the study participant, reliable correlations of the interaction with SRs were observed [123–128]. Based on their results and existing data from other scientific studies at that time, the scientists concluded that it is typical for the human body to detect, absorb and respond to the influence of electromagnetic fields of extremely low frequencies, including SR frequencies [123–128]. The fact that the electrophysiological parameters of the skin changed when interacting with low frequencies and SRs allowed scientists to draw a parallel between the transmission of electromagnetic signals, areas of the skin with increased electrical conductivity properties/"meridians of traditional medicine" and the principle of the functioning of telecommunication systems [123]. Science is now making great progress in the study and understanding of the electromagnetic mechanisms of biological communication between cells. Therefore, this series of studies is important and should be rethought from the perspective of modern biophysical knowledge and considered when performing future clinical studies involving humans.

Table 1 presents a systematization of studies used in the review of publications studying the interactions of SRs with the human body that were carried out in the 21st century.

Table 1. Systematization of studies used in the review of publications studying the interactions of SRs with the human body that were carried out in the 21st century.

Scientific Direction of the Research	Reference Number of the Publication in the Review Reference List
Neurology *	[105,107–112,114,115,118]
Cardiology	[99,100,116–119]
Nephrology	[121,122]
Traditional medicine (electromagnetic parameters of the skin) *	[123]
General medicine	[30,98,105,106]

Note: *—There were studies carried out in the 20th century.

3.5. Conceptualization of the Mechanisms of Interaction Between the Human Body and the Magnetic Field of the Earth at Schumann Resonance Frequencies

Since there is evidence of the influence of SRs on the nervous system, cardiovascular system and kidneys, the possible mechanisms of these interactions with the human body were conceptualized.

The most obvious solution for the interaction of SRs and the brain is the forced resonance mechanism. In this case, the frequency of the forcing effect (for example, the frequencies of the first harmonic of the Earth's magnetic field) coincides with the natural frequency of the system (brain rhythms) [123,129]. It is possible that the frequency characteristics of SRs and brain rhythms coincide; this is a special case of general biological electromagnetic synchronization in the biosphere of planet Earth. This idea is inspired by the existence of another classic biological example of forced resonance: the response of the human body to a frequency of 40 GHz corresponds to the resonance of the tertiary structure of the deoxyribonucleic acid helix [130].

The direct effect of variations in the amplitudes of SRs can be mediated through the mechanism of reaction of nanocrystals of ferrimagnetic minerals in human cells, for example, with magnetite (Fe_3O_4). The presence of biogenic magnetite in the cells of brain structures and other human organs has been proven. The presence of biogenic magnetite in vivo in cells is a possible explanation for their sensitivity to weak magnetic fields and SRs. Therefore, the mechanism of ferromagnetism is a scientifically proven method of sensory transduction, which most scientists take into account in studies of human magnetoreception [68,123,131].

The connection between the regulation of the activity of the central nervous system and the activity of the cardiovascular system has been studied, scientifically proven and is generally known. Therefore, the possibility of the pathological activation of vascular reactions by an increasing level of frequencies in the low range (gamma) of the Earth's magnetic field was hypothesized. Similar reactions to an increase in low frequencies in the atmosphere can occur in patients with NCDs who have depleted the adaptation resources of the body against the background of pathological metabolic and morphological changes in the heart and blood vessels. This may explain the reason why an increase in the low-frequency contribution of the SRs was significantly associated with an increase in the number of myocardial infarctions [119]. A similar mechanism is confirmed by a theory regarding the existence of sensitivity in the nerve centers of cardiovascular regulation to changes in the electromagnetic field of the Earth [68,132]. This theory received experimental confirmation. The study revealed a significant negative correlation between baroreflex sensitivity, heart rate variability, blood pressure and increased geomagnetic field disturbances. In this study, baroreflex sensitivity was assessed by the response of blood pressure and heart rate to the intravenous administration of pharmacological agents—phenylephrine and nitroprus-

side. The clinical confirmation of this theory is the fact that an increase in mortality from myocardial infarction is associated with a decrease in baroreflex sensitivity [133].

The most reasonable mechanisms for realizing the interaction of the human body with the frequencies of the Earth's magnetic field should be considered reactions at the quantum level. Since all micro-level processes (nano level and deeper, <1 nm), subatomic structures, atoms, molecules, cell components and tissues are the result of electromagnetic interactions and exhibit the properties of frequency–wave duality, each atom, ion and molecule has a full individual spectrum of nuclear transitions, electronic transitions, rotations and vibrations. Therefore, they can have resonant responses to the same atmospheric frequency. The existence of bioeffective frequencies, which in the range of 0.3–30 Hz cause the resonance of bound ions, has been scientifically proven. In this concept, ions can be considered in the model of isotropic oscillators that have a charge. This mechanism may explain ion resonances that regulate the rate of biochemical reactions in the cells of biological organisms, which is known as cyclotron resonance [134–140]. The results of laboratory studies confirmed the role of ion cyclotron resonance mechanisms in the regulation of isolated myocardial cells [141].

The human body is a complex, multi-hierarchical system in which many micro- and macroscopic processes occur simultaneously. The existence of an organism is possible solely due to the close connection and coordinated functioning of the tissues of its organs and the systems of the whole organism. It is important to understand that this consistency is realized thanks to numerous oscillatory processes that occur at different levels of the structure of the body's vital systems [3,6,7,53–55,59]. The body is a self-oscillating nonlinear system. Various types of vibrations occur simultaneously in the human body: mechanical, electrical, acoustic, etc. In this case, the excitation of one type of vibration can cause the excitation of others. For example, the propagation of a nerve impulse leads to the mechanical contraction of muscle cells. Oscillatory processes in the human body can have an informational component and be part of systemic information processes. Thanks to this, the human body can transmit one signal to another, perceive vibration information of all types and react and adapt to changes in the external environment. An example is heart rate, the variability in which conveys information about the functional state of the body [137,138,142,143]. This idea implies the presence in the human body of a reaction system based on the principle of resonance with a nonlinear limitation of the increase in oscillations and with feedback between the energy source and the resonator. This requires continued research and is still under debate.

Almost all cells of the human body's organs come into contact with blood. Blood is a magnetically saturated medium that exhibits magnetic properties [122]. Blood contains red blood cells and hemoglobin, which contains iron atoms with non-zero magnetic moments. Therefore, Schumann resonances can affect the blood, changing the transport and distribution of ions and their membrane transport [122]. Accordingly, this will change the processes of electromagnetic generation in the membrane structures of cells, influence the depolarization of membranes and change the electrical potential of cells. It was found that in erythrocytes with membranes exposed to an electromagnetic field, changes in the transport of potassium and sodium ions occurred, and a decrease in electrical mobility and an increase in membrane permeability were recorded. In this case, their aggregation was activated. It has been proven that, due to the parallel orientation of the magnetic moments, the spontaneous magnetization of an array of particles causes the appearance of groups of particles with an ordered packing. Such a group, when moving in the vascular bed, can exhibit the behavior of a soliton-like object [144–146]. The observation of the reversible aggregation of erythrocytes can be explained by the formation of similar objects in the bloodstream. Blood plasma contains a large number of ions and has the property

of electrical conductivity. Electrical currents that are induced by moving red blood cells can cause increased plasma circulation around them and around each red blood cell. It is important that when red blood cells move, the magnetic field changes, and, in accordance with the law of electromagnetic induction, electric currents arise that tend to compensate for changes in the magnetic flux. The functions of many organs of the human body involve the passage of significant amounts of blood. Therefore, theoretically, this mechanism can influence their general electromagnetic state and responses to influences.

Studies [147,148] have confirmed the existence of the human magnetic sense, which is supposedly based on the quantum mechanical mechanism of magnetoreception. It has been proven that light-dependent magnetic orientation in humans occurs due to the resonant mechanism of the magnetic field. In one study, participants' magnetic orientation varied depending on the wavelength of incident light and was found to be dependent on blue light. It was concluded that these reactions could be mediated by a mechanism that is determined by the resonance of the magnetic field. This confirms the improvement or decrease in the ability to navigate using radiofrequency magnetic fields at the Larmor frequency and the dependence of these effects on the angle between geomagnetic fields and radiofrequency magnetic fields [147–150].

One study [121] put forward a hypothesis that may also explain the different degrees of response of different tissues in the human body to the influence of SRs. Tissue cells of different organs have fundamentally different atomic compositions. When interacting with external magnetic fields, an atom of each substance has individual biophysical characteristics of changes in the magnetic moments of electrons and nuclear atoms, which are predetermined by its quantum mechanical characteristics. Depending on what class of magnets the atoms of different chemical elements belong to, they will interact with the external magnetic field in different ways. Depending on the type of magnetic reactions, substances are classified as paramagnetic, diamagnetic or ferromagnetic. The atoms of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg) and oxygen (O) have paramagnetic properties. They are magnetized in the direction of an external magnetic field. Carbon (C), silicon (Si), hydrogen (H), sulfur (S), phosphorus (P), chlorine (Cl), iodine (J), bromine (Br) and copper (Cu) are diamagnetic substances that can be magnetized by an external magnetic field. It is important to note that 99% of the molecules in the human body are formed precisely by carbon, hydrogen and oxygen, which have the properties of diamagnetic materials. Therefore, it is believed that hydrogen is of great importance in responding to changes in external electromagnetic fields [3]. With an increase in the strength of the external magnetic field, an increase will occur in the oppositely directed magnetic moments of the elements of the paramagnetic and diamagnetic groups. Because of this, there will be an increase in the precessional effect of vibrations in the electronic orbits of individual atoms. The structures of the tissues of different organs contain different microelements and have different specific atomic compositions. Therefore, the total reactions of the moments of atoms forming molecules and cellular structures in different tissues and organs will be different. This may cause different functional responses of organs to changes in SRs.

As an important response mechanism in the magnetobiology of the human body, it is necessary to consider the secondary reactions of organs and systems to external electromagnetic influence by SRs. Therefore, as an option to explain the possible pathogenetic influence of the low-frequency (gamma) components of SRs, we can consider precisely the secondary reaction of the body's organ systems. This can be described as follows: Fluctuations in the frequencies and periods of the plasmaspheric resonator cause changes in the electron concentration in the plasmasphere. This synchronizes the body's rhythms and causes stochastic resonance. For example, resonance phenomena in the neurons of the brain cause an increase in frequencies in the gamma range. In response to this, a stress-adaptive

reaction of the body occurs with the activation of the hypothalamic–pituitary–adrenal axis. There is an increase in the production of glucocorticoids and catecholamines. The body's stress response is realized, which causes the activation of blood coagulation factors and increases the aggregation activity of blood cellular elements. All this leads to spasms of the microcirculatory vessels and a complete cessation of blood flow, which may occur in the capillaries. This can cause the development of ischemic lesions in the tissues of the brain and heart. This mechanism may explain the existence of a correlation between the increase in cases of acute myocardial infarction and periods of increases in low-frequency components of SRs [119].

3.6. Is There a Cause-And-Effect Relationship Between the Human Body and the Electromagnetic Field of the Earth at Schumann Resonance Frequencies?

A cause-and-effect relationship implies the presence of a correlation between the objects of study, but such a correlation does not imply the presence of a cause-and-effect relationship between them. Therefore, when assessing the results of studies on the interaction of SRs and the human body, it is important to correctly interpret this aspect. In modern science, one of the stages of proving the presence of a cause-and-effect relationship is to conduct a randomized controlled trial. The results of such studies of the interaction of the human body with SRs are not yet available and are a task for future research. Also, a weak point in proving the presence of a cause-and-effect relationship between SRs and the human body is the control of influencing factors. Unfortunately, the existence of a multifactorial, multilevel, complex external electromagnetic influence on the human body does not yet make it possible to carry out research taking into account all these factors. This is one of the limitations for such studies. Of course, all this gives rise to reasonable doubts and requires additional explanations.

So maybe there is no cause-and-effect relationship between the human body and SRs? Maybe these are just random correlations? However, with random correlations, there is never directionality, and it cannot be said that a change in one variable causes a change in another. A systematic analysis of existing studies on the influence of SRs on the electromagnetic activity of the brain [105–112,114,115,118,123,129] and heart [99,100,116–119,123,133] indicates the existence of a direction. When chronologically assessing the dynamics of changes in SRs, the established correlations indicate the existence of a time dependence. This confirms that a change in SRs as a cause leads to a change in activity indicators of the brain [105–112,114,115,118,123,129] and heart [99,100,116–119,123,133] as a consequence. Thus, a time direction also exists, and this is important evidence in favor of the existence of cause-and-effect relationships between the human body and SRs. Also, the presence of a cause-and-effect relationship is always supported by the existence of mechanisms for its occurrence. Modern scientific descriptions of the possible mechanisms underlying the influence of SRs on the human body exist and are described, although they continue to be discussed.

4. Discussion

A graphical summary of the working theoretical concept of knowledge about the interaction of the human body with SRs is presented in Figure 1.

In the center of Figure 1, there is a schematic representation of the hierarchical structure of the levels of the human body. Each subsequent level demonstrates the structure of the previous level. For example, an atom consists of a nucleus and spinning electrons; the nucleus consists of neutrons and protons; the protons are formed by quarks, etc. On the left is a conventional dimensional scale that shows to what depth "the human eye" needs to "plunge" to see it. Physics does not yet know what is deeper than 10^{-44} cm. Therefore,

for now, this is the end of the scale. A visual representation of the hierarchical structure of the human body is necessary for discussion and reflection on how and at what levels SRs can interact with it.

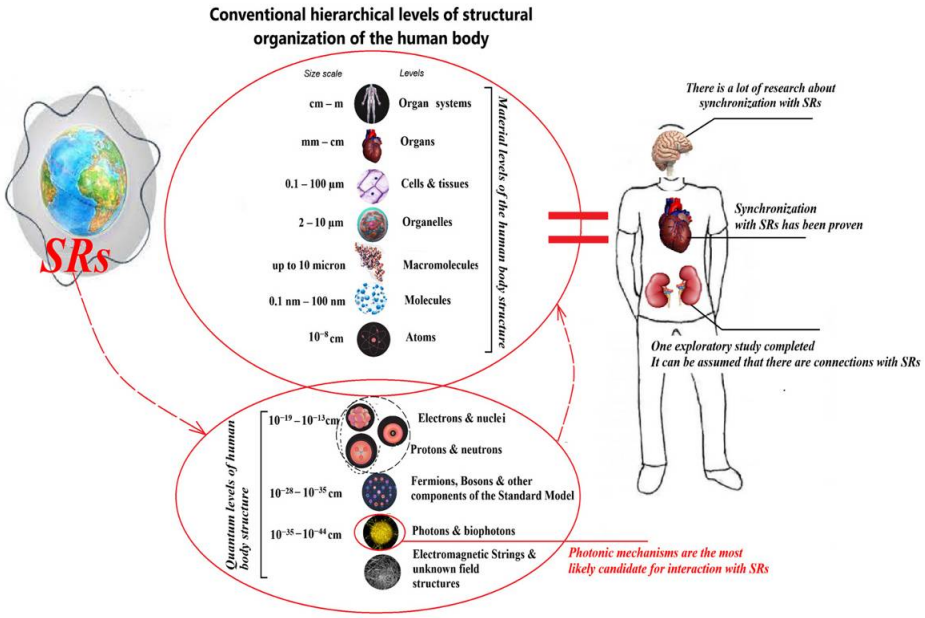

Figure 1. Graphical summary of the working theoretical concept of knowledge about the interaction of the human body and the electromagnetic field of the Earth in the frequency spectrum of Schumann resonances. Note: SRs are Schumann resonances; dotted arrows indicate influences.

The presence of magnetically sensitive receptors in the organs of the human body is debatable. Therefore, the interaction of SRs with the human body at the micro level of its structure can be considered plausible. The dotted arrow shows the influence of SRs on the quantum/energy-level components of the human body, which are circled in a red oval. We propose considering photon mechanisms as the most significant candidates for energetic interaction with the frequency spectrum of SRs. A logical theoretical argument for this is that the same type of energy state is found in SRs and photons. In both cases, this is magnetic energy/matter in the state of solitons and is capable of transferring information and energy without loss. Nowadays, ideas about the role of biophotons in the human body have expanded. They play key roles in intracellular communication and in information transfer between organs and segments of the body through the mechanisms of biophoton signaling [5,28,56,57]. Therefore, the working concept that the standing electromagnetic waves/solitons of SRs transmit information to standing electromagnetic waves/photons in the human body requires serious consideration and is promising. This is a new preliminary hypothesis. As part of the scientific discussion, we would like to note that there is scientific evidence that the transfer of energy in the human body is carried out using photons that are in a state of standing wave/solitons [5,28,56,57]. Biophotons are solitons inside the human body. SRs are solitons at the planetary level. SRs synchronize the functioning of the nervous system, and biophotons are carriers of electromagnetic energy and participate in the transmission of nerve impulses and the phenomenology of vision, or the phenomenon of visual images in humans [5,28,56,57]. Is this a coincidence? Or is it necessary to look for a pattern unknown to science? We believe that all interested scientists need to continue this research. Of course, currently, everything is very complicated in this matter. Scientists are waiting for the results of new research in quantum physics to understand this. Now, polaritonics, a narrow branch of the physics of light, may reach the forefront. This discipline studies the physics of liquid light. In 1958, American physicist and Nobel laureate John

J. Hopfield published a paper on excitonic polaritons [151] or, in other words, the quanta of "liquid light". Polaritonics is the study of photons that propagate within a crystalline material. It is important to note that their properties change completely within crystalline substances. In particular, they gain the ability to interact with each other. A photon, as a particle of light, has no mass. Biophotons inside crystalline structures acquire mass, and they acquire other characteristics (for example, dipole moments, etc.) comparable to the properties of a liquid. And this needs to be extrapolated in the future to the physiology of the human body as well. In the physics of the microworld, polaritonics is one of the rapidly developing branches. The exchange of photons between electrons forms the basis of quantum electrodynamics in the human body as well. Under the influence of the energy and information of electromagnetic waves of SRs, the quantum characteristics of the structural components of the quantum level of the human body change. This entails a change in the functioning of the structures of the human body at hierarchically higher material levels of its structure. The dotted arrow, which is directed to the oval with the material levels of the body structure, shows this influence. Objectively, this is registered as a fact of synchronization between the SRs and the functioning of the central nervous system, the autonomic nervous system and the heart rate of the human body.

SRs are an objectively existing natural phenomenon that affects the human body. Despite the significant theoretical and experimental research on SRs as a wave biophysical phenomenon, the study of their influence on the human body can still be considered insufficient. The presence of an interaction between the human body and SRs can be considered proven, but a full understanding of the essence of all the mechanisms underlying the influence of SRs on the human body requires continued scientific study. It is also necessary to continue clinical studies of the effects of SRs on organs and organ systems of the human body under normal conditions and in pathologies due to their limited number and the complete lack of research on many organ systems. In fact, science now has serious data on the interaction of the human nervous system with SRs. This is a significant foundation that justifies the great importance of SRs in the functioning of the human body because the brain is one of the most important structures for human life support. The presence of clinical data that confirms the existence of the influence of SRs on the occurrence of acute myocardial infarction and cases of kidney disease indicates that the Earth's magnetic field influences a functional state invisible to humans.

The progress of fundamental science and biophysics has created a theoretical basis for understanding the mechanisms of the possible influence of the Earth's magnetic field on the human body at the quantum level. The study and elucidation of the quantum mechanisms of cellular reactions when exposed to SRs certainly deserve the attention of modern scientists.

A serious scientific problem in the current stage of research on the influence of SRs on the human body is the lack of a unified protocol for the methodology of the research. The unification of approaches should be an important step for further research related to assessing the impact on the human body. The development of such approaches and clear promising parameters for the clinical assessment of effects will certainly increase the commitment of the global scientific community to conduct further research in this direction.

At the present stage of development of fundamental science, the question of the need for and importance of further transdisciplinary research on the existing connections between atmospheric electricity, SRs and biological systems is becoming increasingly relevant [150,151]. Of course, the field of studying the interaction of the electromagnetic fields of planet Earth, including SRs, and the human body is complex. However, the existence of a connection between atmospheric electricity, SRs, biology and human health makes it necessary to continue this research [152,153].

5. Conclusions

Based on the data from all the studies performed, which were available in the literature, it can be argued that there is a proven interaction between the human body and SRs. This interaction has been studied most significantly between SRs and the human nervous system. The available data provide grounds to tentatively assert the following: (1) the parameters of Schumann resonance signals and the electrical activity of the human body are interconnected; (2) SRs with spectral peaks at approximately 8, 14, 20, 26 and 33 Hz correspond to the electroencephalographic activity of the human brain in frequency and intensity, with an average magnetic field strength of about 1–2 picoteslas and an electric field strength of approximately 0.1–1 mV/m at an average thickness of the cerebral cortex of about 3 mm; (3) the human brain is sensitive to the effects of SRs and reacts to them by changing its functional state in accordance with the frequencies of impact; and (4) the autonomic nervous system of the human body is synchronized with the dynamics of SRs. SRs affect functional indicators of the cardiovascular system: heart rate and blood pressure. The ongoing study of the influence of SRs on the course and pathogenesis of NCDs is a promising direction. Existing evidence shows that low-frequency SRs decrease the risk of developing acute myocardial infarction, and there is a tendency for them to promote cases of chronic kidney disease. SRs are an important external natural factor influencing the human body, coordinating metabolic processes and the functional activity of its cells. It is necessary to take into account the importance of their physiological influence, as well as the possibility of the activation of pathogenetic mechanisms of NCDs.

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