How Electromagnetic Exposure can influence Learning Processes – Modelling Effects of Electromagnetic Exposure on Learning Processes

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Abstract

In the last years the public and often political discussion about eventually health hazard effects of high-frequency electromagnetic fields (above all of mobile-phones) on human beings is increasing. The further need of scientific studies to clear up possible effects becomes more and more obvious.

Actually, no one knows for sure how everyday electromagnetic exposure affects the learning and memory of insects, or other living organisms.

In recent years countless studies were initiated to examine the effect of high-frequency electromagnetic radiation on living organisms and cells. But – as far as we know - to this day there exists no adequate model of effect with specific relation to learning processes to explain the different, especially non-thermal effects. In this context we only want to mention the resonant stimulus of living organisms.

Keywords

Bioindicator, supersigns, honey bees, learning process, model of effect, non-thermal effects, structure of knowledge, resonant stimulation

Information-Theoretical Based Model

First of all we want to explain a specific model. It is based on an extended theory of supersigns, which was developed in the context of Educational Informatics.

The classical theory of supersigns deals with the mathematical modelling of the well known phenomenon of 'chunking'. Basically this theory assumes that the process of building supersigns, the superation, modifies the subjective information of a presentation, because of change of repertoire. According to the common basic assumption of a cybernetical based learning theory, learning is defined as a construction of an internal model. If a learning subject has built up an internal model of a fact means: The knowledge of that fact was built up.

On the other hand and following the same basic theory of information processing knowledge is caused by a process of superation. Summing up, the theories of artificial neuronal networks (as a model of brain) allow the idea of an internal representation of a structure of knowledge, reflected in physiological facts of the brain.

What transformations occur between different processing stages when electromagnetic exposition is influencing the learning processes?

What are the causes and consequences of these transformations?

To answer these questions with a computational perspective, we focus on the structure of knowledge instead of the 'hierarchy of knowledge' (see Stever, 2002), defined in the early theory of supersigns. This theory must be extended to develop a theoretical framework for examining electromagnetic exposition as an influencing factor of learning processes. In this sense the possibility of physical influences on the process of supersign development has to be taken into account.

In Stever & Kuhn (2003) we developed the cybernetical model of building supersigns based on a repertoire defined as ‘structure of knowledge’ and modifying the subjective information of a presentation while changing the repertoire.

A representation of knowledge, defined as a construction of an internal model of a fact, which has to be learned, can be formally signified as a pair of data ($\hat{W}$, $M(\hat{W})$). It can also be interpreted as a graph of a structure of knowledge. According to that, $M(\hat{W})$ symbolizes the union of the set of all possible morphisms to the set of different elements of knowledge $\hat{W}$:

$$M(\hat{W}) = \cup M_{i_1,i_2} = M(w_{i_1,i_2}) = \left\{ m_{i_1,i_2} \mid m_{i_1,i_2} : \begin{cases} \hat{W} \rightarrow & \hat{W} \\ w_{i_1} \rightarrow & w_{i_2} = m_{i_1,i_2}(w_{i_1}) \end{cases} \right\}$$

However this modelling neglects the possibility that physical influences of the outside world can induce effects on the process of developing supersigns. The effects of high-frequency electromagnetic fields on human beings, especially on their brain, can be interpreted as a repertory change in the construction of internal models. So the theory must be extended by the additional hypothesis that physical influences can change the process of superation. Therefore it is necessary to integrate additional parameters into the mathematical description of this process. The set of all finite sequences of connection with elements of $\hat{W}$ must be replaced by a set of all finite paths through the graph of the structure of knowledge

$$F_p(M(\hat{W})) = \bigcup_{n \varepsilon \mathrm{N}} \{ f_p : \mathrm{N}_n \to (\Pi, \hat{\mathrm{W}}, \mathrm{M}(\hat{\mathrm{W}})) \},$$

in which Π represents the set of all possible physical influences. So it is necessary to determine an optimal representation of the elements of knowledge and with that, an internal model of a fact for every $p \in \Pi$. In particular it has to be examined whether the physical influences change the process of superation itself. The way physical influences can act on this process is visualized through the possible parameter $p \in \Pi$.

In the following - after describing the physical facts of thermal and non-thermal effects - we want to illustrate how honey bees can be resonantly stimulated, and therefore, influenced non-thermally.

Physical Facts

Electromagnetic fields spread periodically in time and space. Hitting living organisms, they cause effects on molecular levels because there are charged particles within cells and tissue. These particles take up the energy of the electromagnetic field and transform it into energy of motion. Because of their motion, the charged particles bump against other particles, which are placed in the surrounding of the moving particles. By this transmitting of impulses the energy of motion is transformed into energy of heat.

These processes depend on both the frequency f of the electromagnetic field and the properties of the biological tissue, such as its electrical conductivity κ and its dielectric constant ε. The last two parameters depend also on the frequency of the electromagnetic field. Whereas the dielectric constant is decreasing when the frequency rises, the electrical conductivity of the biological tissue increases. This relation between the frequency and the electrical conductivity of the tissue resp. its dielectric constant is called relaxation. The phenomenon can be explained best with the exchange of energy between the electromagnetic field and polar molecules, such as dipoles. The dipoles are rotated by the periodically changing direction and field strength of the electromagnetic field (see Figure 1). The electromagnetic energy is transformed into energy of tension in the dipoles if the field strength is maximal. When the electrical field is turned back into the opposite direction, the dipoles are orientated into the opposite direction, too. So the energy of tension is transformed into energy of motion. Because of the friction thermal energy emerges. The characteristic time of this process is called time of relaxation τ.

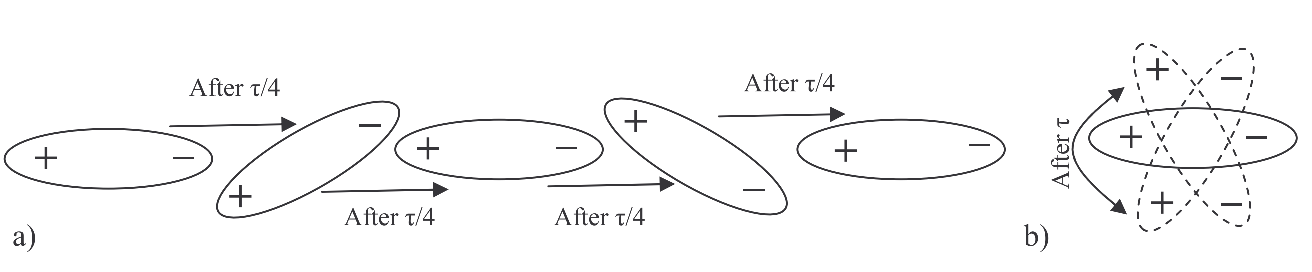

Figure 1: The process of relaxation: a) Dipole in different positions and b) the whole process in one picture

This transformation of electromagnetic energy into thermal energy is very efficient if the field is turned in the opposite direction after the dipoles reached their maximal orientation. So the optimal frequency of relaxation f_τ can be calculated with

$$f_\tau = \frac{1}{\tau}.$$

The frequency of relaxation of hydrous soluble protein molecules amount between 1 MHz and several GHz. When the frequency increases, the degree of the dipole-orientation decreases. This relation is described by the Debye-Equations:

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_0 - \varepsilon_\infty}{1 + \left(\frac{f}{f_\tau}\right)^2}$$

$$\kappa = \kappa_0 + \frac{(\kappa_\infty - \kappa_0)\cdot\left(\frac{f}{f_\tau}\right)^2}{1+\left(\frac{f}{f_\tau}\right)^2}.$$

Thermal Effects:

Physically the clearest and most explainable effect of high-frequency electromagnetic fields is the thermal effect. This effect describes the transformation of electromagnetic energy in thermal energy. This thermal energy is caused by the relaxation of rotation of the dipole-molecules. In this case the field strength is large enough to produce a maximal dipole-orientation. The orientated dipoles cause a frictional heat when they change their orientation. This effect depends on many parameters, e.g. the frequency, the field strength, the body mass, the body structure and the time of effect.

Non-Thermal Effects:

It is understood that high-frequency electromagnetic fields cause effects which can not be explained by thermal effects. So the discussion about non-thermal effects focuses on the question whether and under which circumstances they are biological relevant.

From physical view it is obvious that only such high-frequency effects are discussed first which are not covered by the thermal noise. The energy of this thermal noise amounts to 25 meV. So an effect with a smaller energy is not noticed by the biological tissue. But this limiting energy applies only to such biological tissue which can not be resonantly stimulated and to such radiation which frequency is not within the range of the frequency of resonance. If a biological tissue can be resonantly stimulated and the frequency of the radiation corresponds to the frequency of resonance of that tissue, biological effects can be caused by energies which are much smaller then 25 meV. So the resonance is one possible non-thermal effect, which will be explained in the following.

If an oscillation-able object – e.g. a protein molecule – is stimulated once, it performs a free oscillation. The frequency of this oscillation depends only on the property of this resonator. This frequency is called the self-frequency f_0 of the resonator. If an external energy source stimulates the resonator, it performs enforced oscillations with the frequency of the external source, the exciter. This frequency is called exciting frequency f_E. If the exciting frequency is in the range of the self-frequency of the resonator ($f_E \approx f_0$), the amplitude of the resonator-oscillation is maximal. This phenomenon is called resonance. So the frequency of resonance f_R corresponds with the exciting frequency and the self-frequency f_0 of the resonator when resonance arises: $f_R = f_E \approx f_0$.

A biological tissue absorbs maximal electromagnetic energy when the frequency of the radiation corresponds with the self-frequency f_0 of the biological tissue. This self-frequency depends on the proportions and the structure of the tissue. Every electromagnetic radiation with a strictly defined frequency f possesses also a strictly defined wave-length λ, which can be calculated with the equation

$$\lambda = \frac{c}{f} \text{ (}c\text{: speed of light; } c \approx 3 \cdot 10^8 \text{ m/s).} \tag{i}$$

To simplify the facts, we want to explain the self-frequency f_0 of an one-dimensional dipole molecule with the length l (see Figure 2). Its self-frequency f_0 depends on the length l of the dipole and can be calculated with equation (i):

$$f_0 = \frac{c}{l}. \tag{ii}$$

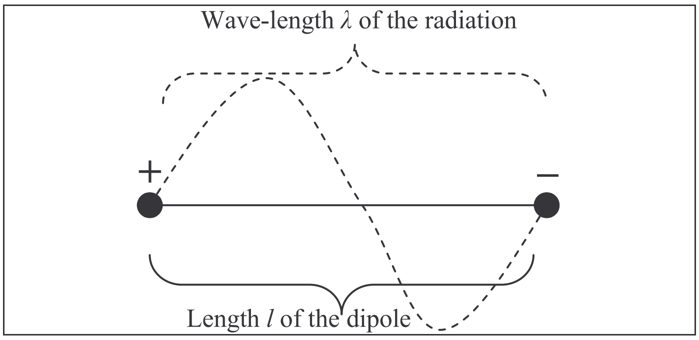

Figure 2: The wave-length λ to stimulate an one-dimensional dipole resonantly.

So the phenomenon of resonance occurs when the wave-length of the electromagnetic radiation is in the range of the properties of the biological tissue.

But because of the complexity of a biological tissue (multi-dimensional proportions, different types of molecules etc.) the frequency of resonance resp. the corresponding wave-length can hardly be calculated and often has to be estimated.

Honey Bees as Possible Bioindicator for Non-Thermal Effects

The function of the honey bee as a bioindicator for thermal effects was proved in details in Kuhn (2002, 2003). In this paper we want to show that bees can also serve as a bioindicator for non-thermal effects concerning their learning processes. With this knowledge it could be possible to study non-thermal effects of high-frequency radiation on the learning process of honey bees and transfer the results on human beings. This is possible because the brain structure of honey bees concerning learning processes is similar to that of human beings (Giurfa, 2003; Stever & Kuhn, 2003).

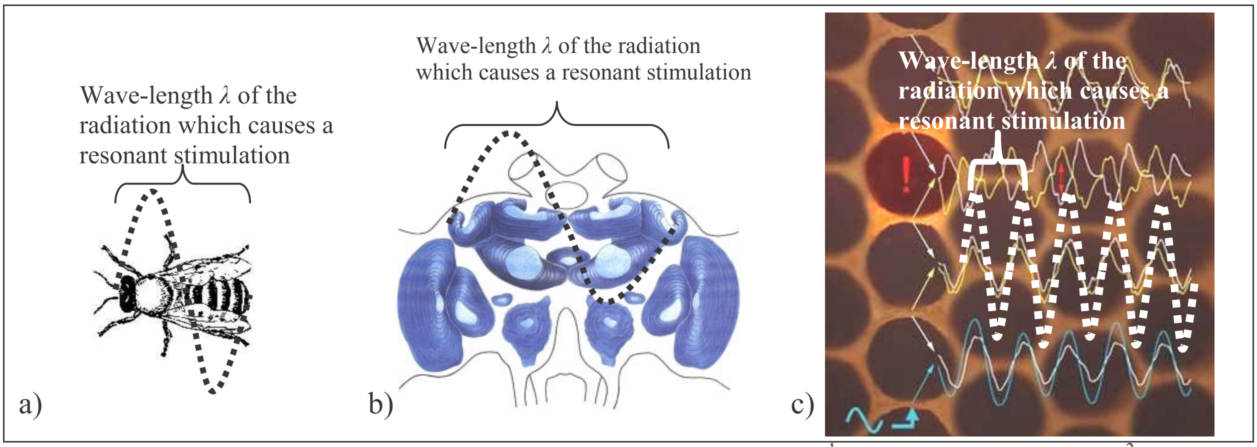

Figure 3: The resonant stimulation of an honey bee (a)), of a mushroom body[1] (b)) and of the honey comb[2] (c))

Honey bees can be influenced non-thermally in three ways:

First of all, the bee itself is a creature with a strictly defined shape. So this shape can be resonantly stimulated, when the wave-length – and so the frequency – of the radiation is in the range of the size of the bee (see Figure 3a)). As the honey bees' size is circa two centimetres ($l \approx 0{,}02$ m), the frequency of resonance f_S has to be up to 15 GHz (see equation (ii)). But honey bees can not only be resonantly stimulated by this strict frequency. Because their body is extensive, they can be stimulated by a broadband of frequencies, which borders have to be discovered experimentally.

[1] This picture of the honey bees' brain was found at www.neurobiologie.fu-berlin.de/mulan.html.

[2] This picture of the stimulation of the honey comb by waggle-dances was found at bild der wissenschaft online, Natur (03.12.2001).

In a second case, the mushroom bodies[3] in the brain of honey bees have also a strictly defined shape (see Figure 4). They are arranged symmetrically in the brain of the honey bee. Altogether their area amounts to circa $250 – 300 \cdot 10^{-9}$ m². The longest distance between the two exterior limiting points is circa 800 µm. So they can also be resonantly stimulated (see Figure 3b)). Because of their small size ($l \approx 800 \cdot 10^{-6}$ m), the frequency of resonance f_S is much higher (see equation (ii)), up to 375 GHz. But this value is very critical, because of the multi-dimensional properties of the mushroom bodies. The mushroom bodies are 3-dimensional objects, so the calculation is as complex as in the case of an one-dimensional object. Furthermore we have to take into consideration the properties of the mushroom bodies and of their surrounding, too. So the frequency of resonance f_S of these objects should be tested experimentally, too.

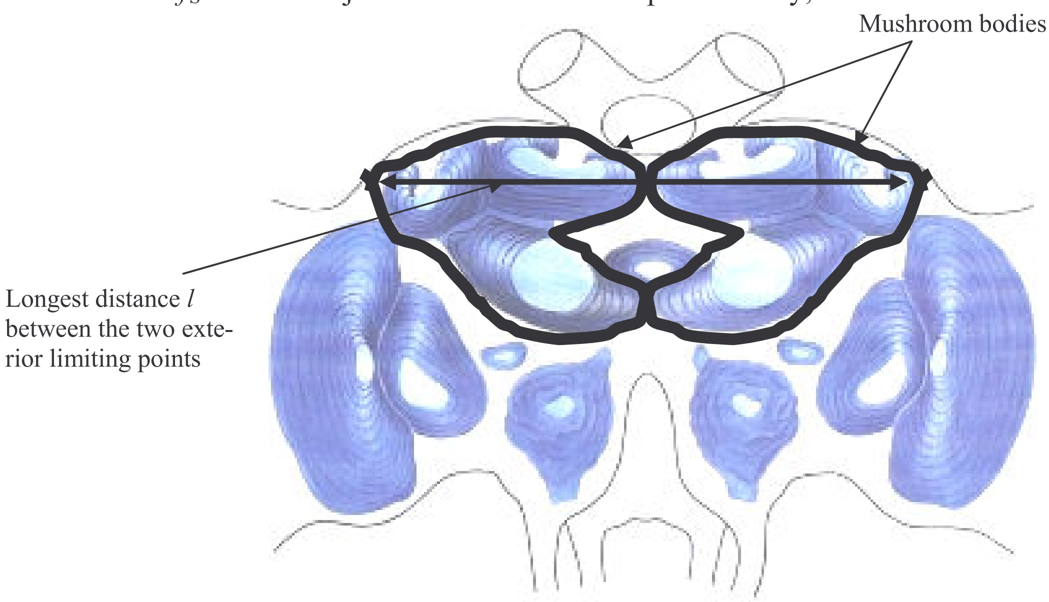

Figure 4: Cross-section of a honey bees' brain[4] (the bordered area marks the mushroom bodies).

[3] Neurobiological researches show that the change of the honey bees' actions is combined with modifications in certain areas of their brain, especially in such areas called mushroom bodies (Withers et al, 1993; Faber & Menzel, 2001). Therefore we want to consider these mushroom bodies as representations of internal models, which were the results of honey bees' learning processes. These internal models represent parts of the surrounding.

[4] This picture of the honey bees' brain was found at www.neurobiologie.fu-berlin.de/mulan.html.

Because of their complexity we can not exclude that they can be resonantly stimulated by an electromagnetic radiation with frequencies up to 2 GHz. So this frequency – the frequency of the GSM- and UMTS-mobile phones – has also to be taken into account.

The third way which describes a possible, non-thermal, resonant stimulation of the honey bees is outlined by the results of recent studies.

In addition to the well known theory of Karl von Frisch that honey bees communicate through waggle dances on the honeycomb, Nieh and Tautz discovered that dancing makes the honeycombs vibrate (Nieh & Tautz, 2000; Tautz et al, 2001). The frequencies of these vibrations are set in between 200 Hz and 300 Hz. As the honeycombs vibrate the information can be transported to honey bees which are located far away from the vibrating source. With the GSM-mobile-phones sending their information with a pulsed signal, we must consider the pure sending frequencies of 900 MHz and 1800 MHz as well as the pulsing frequency of 217 Hz. The frequency of the pulse corresponds to that of the waggle dance of the honey bee and so the dancing area could be resonantly stimulated by this pulsed frequency (see Figure 3c)).

So, in a first step the frequencies of resonance f_S of the honey bees' body (first way of a possible, non-thermal influence) and of the mushroom bodies (second way of a possible, non-thermal influence) have to be discovered experimentally. Then honey bees must irradiate with such frequencies. If these frequencies cause change in the honey bees learning ability (e.g. they forget the direction of the feed or they don't know how to construct their honeycombs), it is possible that our learning abilities can be influenced by these non-thermal stimulations, too.

Experimental Design and Results

Before testing the frequencies of resonance, we carry out a first explorative study to examine the effects of non-thermal stimulation (step zero).

We use the basis station of a DECT-mobile-phone. These basis-stations send out continually electromagnetic radiation with a sending-frequency $f_S \approx 1900$ MHz. So they also irradiate when the mobile-phone is out of order or is not in use. The average transmitting power P_S amounts to 10 mW, the peak power is 250 mW. The sending-signal is frequency modulated and it is pulsed with a pulsing frequency f_p of 100 Hz.

We have used only the basis station without the mobile-phone, so it has been in stand-by mode all the time. In this state the average transmitting power P_S amounts to 2,5 mW. We put the station at the bottom of a beehive, right under the honeycombs. So the station was placed within the beehive the honey bees have been able to touch the sending aerial all the time.

The study started in march 2003. We have observed that the honey bees have touched the sending aerial from the beginning, they did not avoid it. We haven't also been able to recognize a changing behaviour of the bees.

These observations can be explained in several ways. Either the frequency of resonance of the honey bees' body is not 2 GHz, and so the radiation of the DECT-basis-station doesn't stimulate them resonantly. Or the resonant stimulation does not change the behaviour of the honey bees. Furthermore the sending power has been very small. But it was too difficult to set the DECT-telephone in active process, because the mobile-phone had to be turned on all the time. Moreover we are exposed to this sending power in real life, so it is not necessary to use a higher sending power because it is unreal.

But this aspect should be taken into consideration in further research activities.

Conclusion, Outlook

Observations about the non-thermal effects of high-frequency electromagnetic fields are necessary because they have not been understood yet. So it is necessary to use a bioindicator which allows to examine such effects and to transfer the results on human beings. In this view honey bees can be useful because they can be stimulate non-thermally, namely resonant.

A first explorative study has not indicated a changing behaviour when the bees have been irradiated. But this fact can not assure that non-thermal effects do not influence honey bees. Rather in further studies the resonance frequencies of the honey bees' body and of their mushroom bodies have to be tested. Then the studies should differently use only these tested frequencies.

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