

Article

The Influence of an Electromagnetic Field at a Radiofrequency of 900 MHz on the Behavior of a Honey Bee

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Abstract: The development of wireless technology and the desire to improve communication electromagnetic fields (EMFs) of various frequencies have become common across the honey bee's foraging landscape. There has been discussion for many years about the possible impact of electromagnetic fields on living organisms. Artificial radio fields emit frequencies ranging from 100 kHz to 300 GHz. The presented research aimed to demonstrate the influence of the radiofrequency electromagnetic field (RF-EMF) with a frequency of 900 MHz on the behavior of honey bees in laboratory conditions. For this experiment, we used wooden cages to house honey bee workers immediately after they emerged. Bee workers were divided into control and experimental groups. Bees in the control group were not exposed to RF fields, while the experimental groups were exposed to 900 MHz electromagnetic fields of different intensities and durations of exposure. Bees' behavior was analyzed with an appropriate computer program. Behavioral analysis of bees was performed immediately after exposure and seven days after exposure. Our research has shown that the radio field (900 MHz) affects the behavior of bees compared to the control group, although not all results are statistically significant. Significant effects were observed seven days after exposure in walking, flight, and individual contact. However, it is worth extending the study to include the impact of an RF-EMF on the expression of genes responsible for bee behavior.

Keywords: behavior; honey bee; RF-EMF; 900 MHz



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1. Introduction

With technological advancements and the growing demand for wireless communication, artificial electromagnetic fields (EMFs) have emerged as a new potential source of stress for honey bees. Among EMFs, radiofrequency electromagnetic fields (RF-EMFs) have gained particular attention in recent years, emitting frequencies ranging from 100 kHz to 300 GHz [1]. However, one of the most commonly used frequencies is 900 MHz. It is utilized worldwide in mobile communications and is known for its long operating range and better penetration through infrastructures [2,3]. According to the European Parliament directive (2013/35/EU) of 26 June 2013, the maximum permissible exposure to radio fields is determined based on frequency. The most widely recognized guidelines for electromagnetic field exposure limits are those established by ICNIRP [4]. The activity of radio fields and microwaves depends on the frequency and typically ranges from 6 to 61 V/m.

In recent years, studies have investigated the effects of radio fields on insects, including the honey bee. Most of these studies provide evidence of the harmful effects of EMFs on their bodies. Panagopoulos et al. (2004) report that a RF of 900 MHz reduces reproductive capacity by 50–60% in fruit flies [5]. Bozorgmanesh and Kowkabi (2023) analyzed the effect of electromagnetic waves from cell phones (at 900 MHz) on a phenomenon called CCD (colony collapse disorder) [6]. CCD is characterized by a rapid decline in the number of bees in a colony with no signs of disease [7]. The authors confirm that the 900 MHz radiofrequency electromagnetic field interferes with the navigation system of honey bees, preventing them from finding their way back to the hive. Similar conclusions were reached by [8–10]. Balmori (2015) also confirms that 900 MHz radiofrequency electromagnetic fields induce behavioral changes not only in higher animals but also in insects (e.g., ants, honey bees, bumblebees, butterflies), primarily by disrupting their orientation in the field [11].

There is limited data on how radio fields influence honey bee fundamental behavior. In laboratory studies, behavioral analysis typically assesses the basic behaviors of the honey bee. Such behaviors include walking (time spent moving), flight (moving with wings), individual contact (including trophallaxis and mutual grooming), self-cleaning (grooming of body surfaces), and immobility (time the bee remains motionless) [12,13]. Still, we do not have enough knowledge about the impact of 900 MHz on honey bee behavior. Studying the behaviors of the honey bee in controlled laboratory conditions is essential for understanding the underlying mechanisms that drive these activities. The behaviors selected for investigation—flight, walking, grooming, social contact, and immobility—play critical roles in the maintenance of colony health and individual fitness. Analyzing flight can provide insights into the cognitive and sensory capabilities of honey bees. Research has shown that honey bee flight is influenced by environmental factors, social interactions, and even neurological processes [14]. Understanding these behaviors can inform us about pollination efficiency and navigation strategies. Walking is fundamental for foraging and colony activities. Studies have indicated that locomotion is affected by factors such as age, experience, and environmental stressors [15]. Investigating walking behavior under controlled conditions helps isolate variables that may impact honey bee movement and efficiency. Grooming is critical for maintaining hygiene within the colony, and it plays a vital role in disease resistance [16]. Observing grooming behaviors in the lab can help clarify the mechanisms by which honey bees mitigate disease spread and manage external parasites. Honey bees are highly social insects, and their interactions significantly influence colony dynamics. Laboratory studies can simulate various social conditions, allowing researchers to explore the effects of social contact on behavior, stress responses, and colony cohesion [17]. Immobility can result from various stressors and is an important behavior in analyzing environmental and chemical exposures. Studying this in a lab setting can yield insights into how stressors affect overall bee health and function. The laboratory study of these behaviors not only enhances our understanding of honey bee biology but also informs conservation efforts and agricultural practices. Controlled experiments allow for precise manipulation of variables, leading to clearer, actionable findings. Changes in these fundamental behaviors are really dangerous for honey bee survival. This is the main motivation for this research. Hence, the purpose of the present study was to investigate whether an 900 MHz radio field affects selected behaviors (walking, cleaning, personal contact, flight, and immobility) of the honey bee worker. In addition, we investigated whether possible changes will be visible immediately after exposure or only after some time (long effect).

2. Methodology

2.1. Research Material

The research material consisted of worker western honey bees of the Carniolan honey bee (*Apis mellifera carnica*), which were obtained in 2024 from 1 bee colony located in the apiary of the Wrocław University of Life Sciences (51°06′49.5″ N 17°08′45.1″ E). Frames with brood on the 20th day of development were transported to the laboratory and placed in an incubator, the conditions were similar to those in the hive (temperature 34.5 °C ± 0.5 °C and humidity 70% ± 5%). After the worker bees emerged, they had ad libitum access to beebread and carbohydrate (1 mol/dm³ sugar syrup and honey on frames) food. Honey bee workers were distributed randomly in cages.

2.2. Experimental Design

After emerging, the honey bee workers were transferred to wooden cages (200 × 150 × 70 mm) with two food dispensers (5 mL each) and then were divided into 1 control and 9 experimental groups. Each group (experimental and control) consisted of 7 cages, and each cage contained 50 honey bee workers. The bees in the control group were fed a 1 mol/dm³ sucrose solution administered ad libitum. One-day-old bees were used for the experiment and after the appropriate exposure time to the EMF, the remaining bees continued to be fed a 1 mol/dm³ sucrose solution administered ad libitum until the seventh day after exposure.

Bees in the experimental groups were exposed to 900 MHz electromagnetic fields with intensities of 12 V/m, 28 V/m, and 61 V/m for 15 min, 1 h, or 3 h each (Table 1). The control group was not exposed to an RF field. The name of the test groups was the intensity of the RF field and the duration of exposure (e.g., 12V/m15′1D-RF-EMF exposure with an intensity of 12 V/m for 15 min for bees on the one day of exposure, 12V/m15′7D-RF-EMF exposure with an intensity of 12 V/m for 15 min for bees seven days after exposure.). Bees labeled “1D” represent bees on the one day of exposure, while “7D” represent bees seven days after exposure.

Table 1. All experimental groups.

Groups		Experimental Groups Exposed to 900 MHz															Control Groups	
Intensities		12 V/m					28 V/m					61 V/m					C	C
Exposition time		15′	1 h	3 h	15′	1	3	15′	1 h	3 h	15′	1	3	15′	1 h	3 h	0	0
Days after exposure		1	1	1	7	7	7	1	1	1	7	7	7	1	1	1	1	7

2.3. Radio Field Generation

The RF-EMF source consisted of a panel antenna connected to an amplifier fed by a 900 MHz radio frequency generator with narrowband FSK (frequency shift keying) modulation. Cages with bees exposed to RF-EMF radiation were placed in free space in the far-field conditions of the antenna, i.e., in the lobe area of the main antenna. The cages were positioned to prevent electromagnetic coupling between the antenna and cage and between cages. The cages containing the bees were placed at three fixed points with field strengths of 61 V/m, 28 V/m, or 12 V/m (Figure 1).

Measurement of E-field distribution in the research area was carried out with an NBM-520 S/N C-0062 m with an EF-1891 S/N A-0335 probe calibrated by an accredited calibration laboratory AP-078 (calibration certificate LWiMP/W/082/21). Measurements were performed by the accredited testing laboratory LWiMP AB-361. E-field inhomogeneity in individual exposure areas did not exceed ±12% for 61 V/m, ±9% for 28 V/m, and ±5% for 12 V/m. The variation in E-field strength during the measurement period did not

exceed $\pm 3\%$ and was controlled by monitoring the power delivered to the antenna and controlling the field strength in the exposed area.

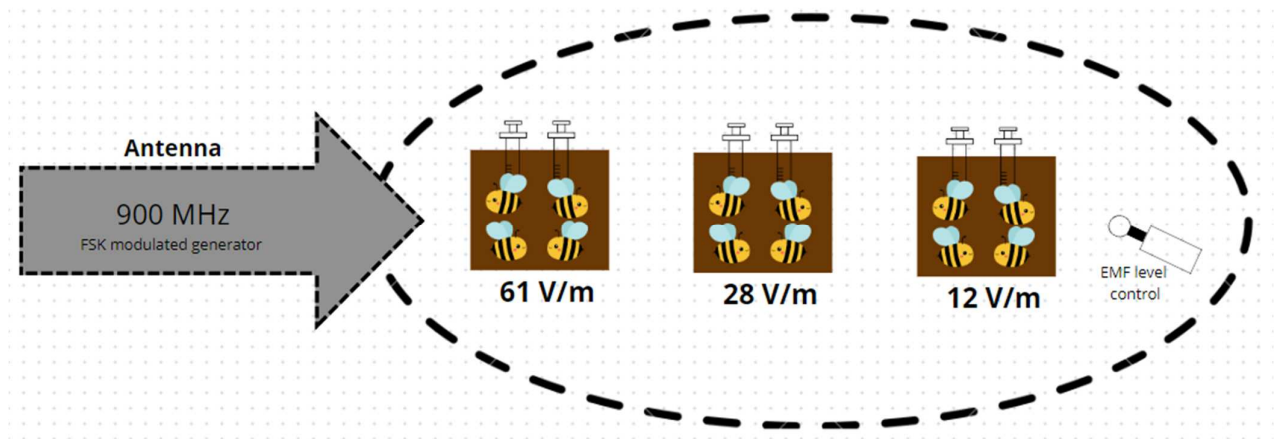


Figure 1. RF-EMF exposure diagram.

2.4. Behavioral Assessment

Immediately after the end of the exposure, 12 bees were randomly selected from each group, taken from randomly chosen cages, and placed under the glass lid ($20 \times 20 \times 20$ cm) to record behavior. A camera (SONY HDR-CX240E, Tokyo, Japan) was placed above the lid to record bee behavior (Figure 2). Three bees were analyzed in one recording (4 videos per group). The length of the recording was 360 s (of which the first 60 s was for adaptation to the change in environment and 300 s was used for proper analysis). After the specified time, the bees were replaced.

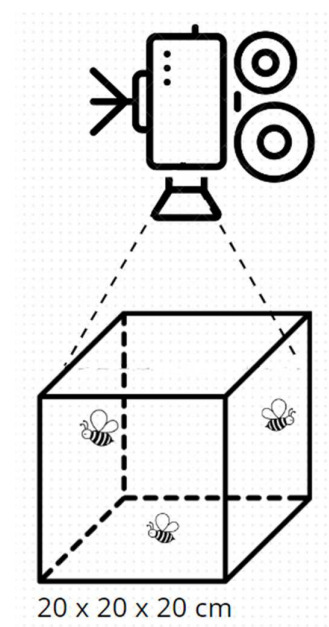


Figure 2. Schematic of the bee behavior analysis area.

The behavioral analysis was performed offline using Noldus Observer XT 9.0 software, Wageningen, The Netherlands). Five basic behaviors characterizing the honey bee's motor and social activities were selected for analysis: walking—specifically movement between the walls of the vessel; flight—wing movement and flying between the walls of the vessel; individual contact—direct interactions between two individuals, including trophallaxis and grooming (such as cleaning of the antennae, tongue, head, and thorax);

and immobility—periods during which the bee remained completely still and did not engage in any activity. Even though 1-day-old bees have not yet developed the ability to fly, the behavioral analysis evaluates flight activity as wing movement and movement between walls, which tests the general motor skills of the insect's body. The behavioral assessment consisted of a subjective assessment of the activities performed by the bee based on the recording. Initially, the behavioral analysis using Noldus Observer XT 9.0 software consisted of creating a corresponding design in the analyzer environment. The design of the behavioral evaluation scheme used a mutually exclusive type of behavior. The design did not use behavioral modifiers in the form of changing conditions or insect interference, as all individuals were evaluated under the same conditions. Independent variables such as age were excluded. At the same time, it was not assessed whether the insect's body had any deformations or damage, and all individuals were treated equally.

The average duration of the behavior (how much time the bees in the group spent performing a given behavior) and the average number of occurrences of a given behavior (how many times during the observation the individuals in the group showed the selected behavior) were analyzed.

2.5. Statistical Analysis

Statistical analysis was carried out using the “R” program with the “R-Studio” (R Core Team, 2021, R-3.4.4 for Windows, CRAN, Vienna, Austria) overlay. During the analysis, a library (readxl) package was used, which helps in downloading data from Excel. The library (tidyverse) package, through which access was gained to the tidyr package (makes it easier to organize data) and dplyr (helps in data management).

The Shapiro–Wilk test was used to analyze the normality of the data distribution. The statistical significance of data between groups was determined using the non-parametric Kruskal–Wallis test with Holm's correction for multiple comparisons (*agricolae* package). In all tests, a significance level of 5% was set.

2.6. Ethical Note

Our research does not require approval from an ethics committee.

3. Results

Most groups except the control-1D, 12V/m3h1D, 12V/m3h7D, 28V/m3h7D, 61V/m15'7D, and 61V/m3h7D exhibited all five behaviors.

3.1. Total Number of Observed Behaviors

Analyzing the total number of occurrences of the indicated behavior of “walking” in 1D bees, there were no significant differences between the control and test groups (Figure 3). In 7D bees, it was possible to notice a statistically significant difference between the Control-7D group and 12V/m15'7D ($p\text{-value} < 6.96 \times 10^{-7}$). The difference between the two was almost 50%. Comparing the test groups of 1D bees to 7D bees, the opposite pattern was observed. In 1D bees, the number of repetitions of the “walking” behavior increased with increased exposure time to the RF-EMF, while for seven days after exposure (7D) the number of repetitions of this behavior decreased with increased exposure time to the RF-EMF.

In the case of the behavior of “individual contact”, no significant changes were observed between the test groups and the control group in both the “1D” bees and the bees seven days after exposure (7D). However, it is worth noting that between the 61V/m3h1D test group and the same group seven days after exposure (61V/m3h7D), there was an almost fourfold increase in the repetition of the behavior that was “individual contact” ($p\text{-value} = 0.0032$). This difference is statistically significant. A similar situation was also

noted when comparing the 28V/m15'1D group with 28V/m15'7D. Seven days after exposure, the observation of the behavior of “individual contact” was almost three times greater, and this difference was also statistically significant (p -value = 0.0015).

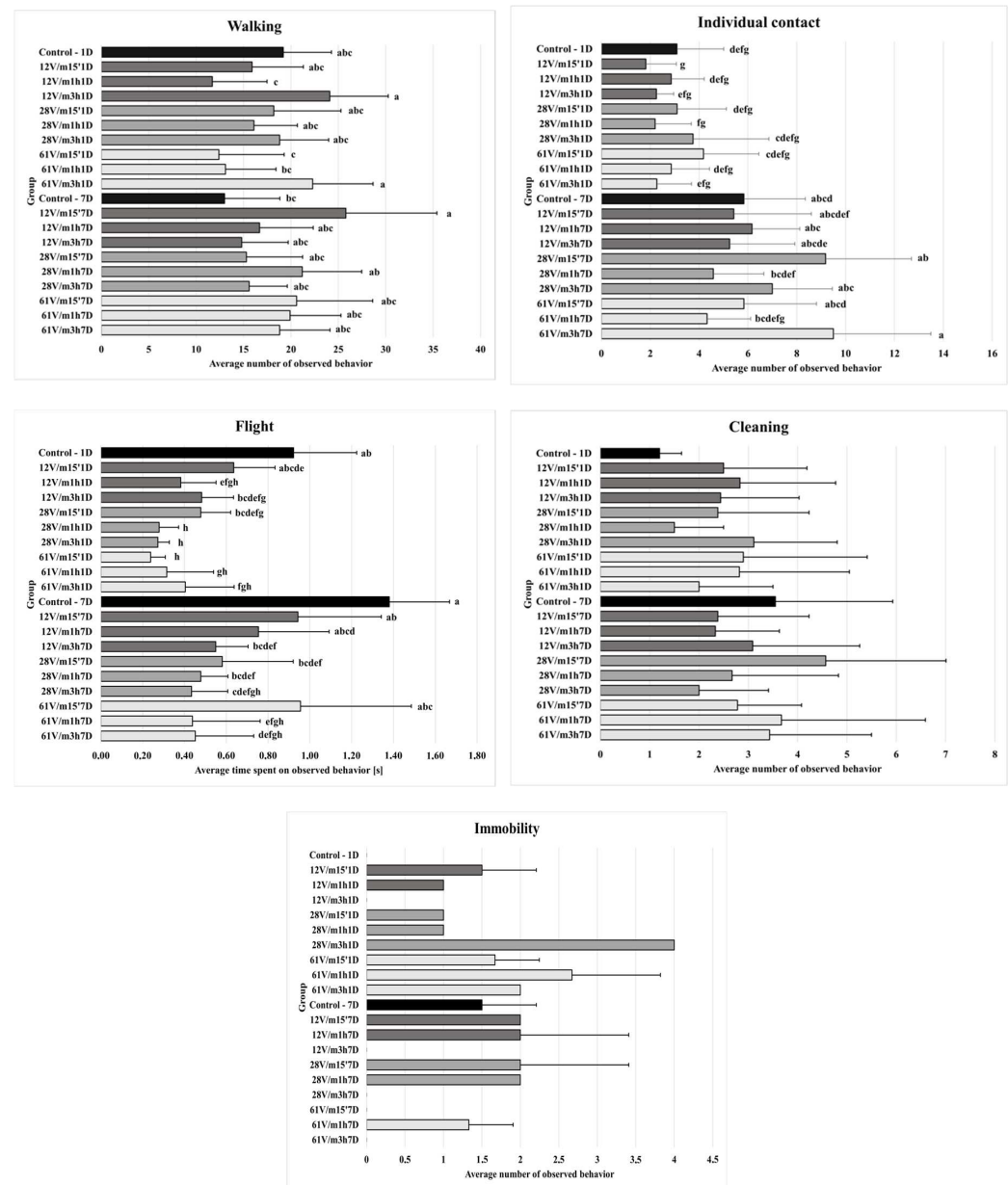


Figure 3. Average number of observed behaviors. 1D—Bees on the day of exposure; 7D—bees seven days after exposure. Different letters indicate statistical differences between one-day and seven-day bees. Bars present mean value; error bars show standard deviation.

The number of repeated behaviors which were “flight” did not show statistically significant differences when comparing the 1D test groups with the control group-1D. However, it was observed that 1D bees exposed to the intensity of 12 V/m and 61 V/m were more likely to exhibit the “flight” behavior as exposure time increased (p -value = 0.0001). In bees seven days after exposure (7D), we observed a threefold increase in the number of repeated “flight” behaviors in the 12V/m15'7D group compared to the control-7D group and a twofold decrease with increased exposure time (p -value = 0.0005).

Behaviors such as “immobility” and “cleaning” showed no statistically significant differences.

3.2. Average Time Spent on a Given Behavior

Analyzing the average time spent on a given behavior such as “walking”, no difference was observed between the group of bees tested at 1D and the control group-1D (Figure 4). On the other hand, it can be seen that the bees in the 12V/m3h1D group spent, on average, twice as much time “walking” as the bees in the 12V/m1h1D group. In the case of 7D, only bees in the 12V/m15'7D group devoted about 32% less time to “walking” than bees in the control-7D group ($p\text{-value} < 4.26 \times 10^{-3}$).

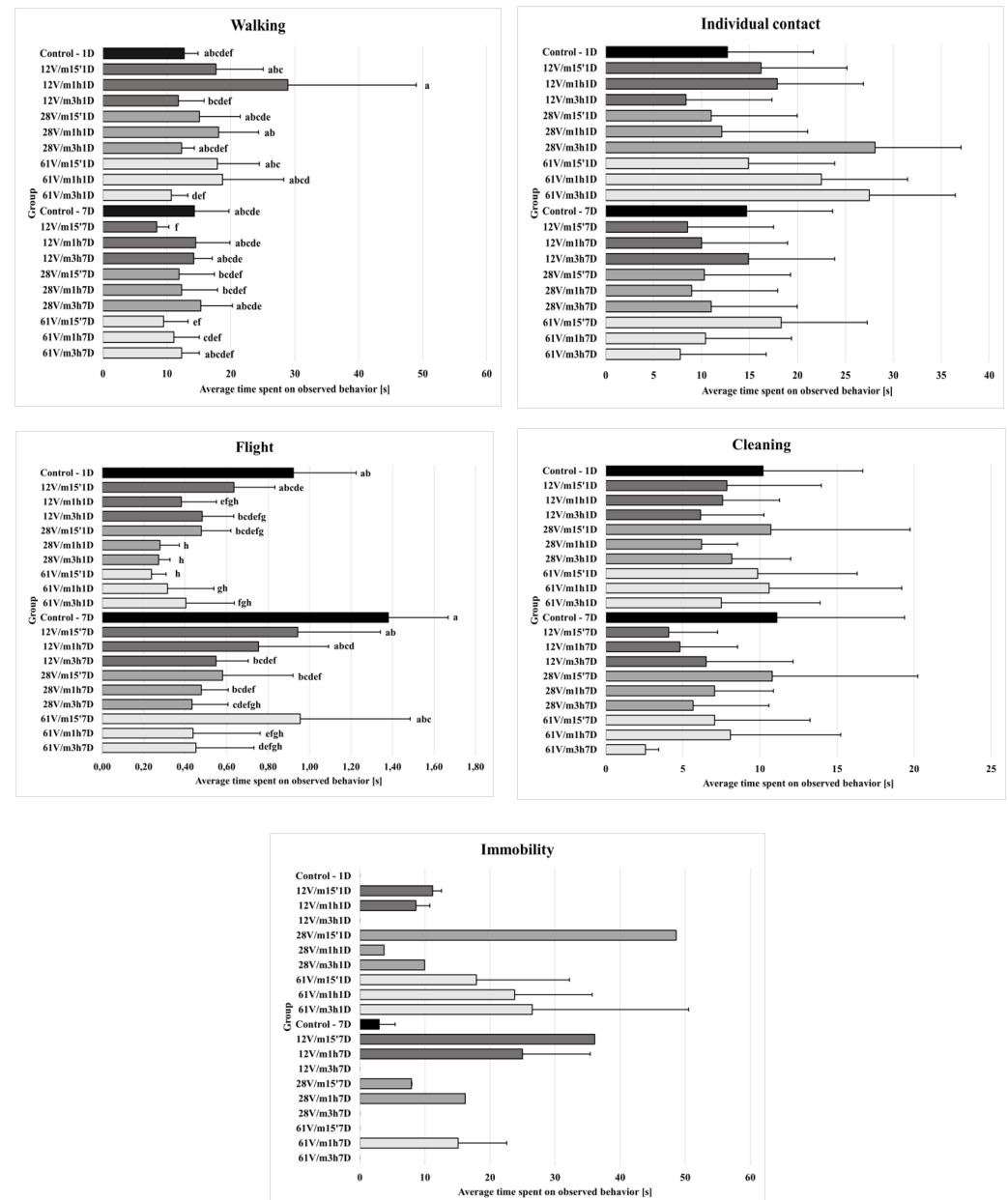


Figure 4. Average time spent on observed behavior. 1D—Bees on the day of exposure; 7D—bees seven days after exposure. Different letters indicate statistical differences between one-day and seven-day bees. Bars present mean value; error bars show standard deviation.

In the case of the “flight” behavior, it can be noted that bees in the test groups devoted less time to the behavior than those in the control group for both bees tested immediately after exposure (1D) and seven days after exposure (7D). It can also be seen that the average “flight” time was shorter with increased intensity and exposure time. Bees tested immediately after exposure from the 61V/m15'1D group spent an average of 74% less time on

“flight” than bees from the control-1D group. For bees tested seven days after exposure (7D), the 28V/m3h7D group spent an average of 68% less time on “flight” than bees in the control 7D group. Also noticeable was the large difference between the 61V/m15’1D and 61V/m15’7D test groups. Seven days after exposure, the bees devoted four times more time (75%) to “flight” than the bees tested immediately after exposure (p -value $< 1.32 \times 10^{-4}$).

Behaviors such as “individual contact”, “cleaning,” and “immobility” showed no statistically significant differences.

4. Discussion

Many studies using low- or extremely low-frequency electromagnetic fields have reported that they observed no significant effects on honey bee behavior [9,18–21] but few include radiofrequency electromagnetic fields. In this study, bees were exposed to radiofrequency electromagnetic fields (900 MHz) to assess the effect of this factor on their behavior.

Our research has shown that the radio field (900 MHz) slightly affects the behavior of bees compared to the control group. On the other hand, it notes statistically significant differences between the test groups exposed to the radio field immediately after exposure and seven days after exposure. This implies that behavioral changes occur only sometime after exposure to the RF field. Sharma and Kumar (2010) [22], studying the effects of electromagnetic fields produced by cell phones (with a frequency of 900 MHz and an intensity of 56.8 V/m) on honey bee behavior, noted that colony strength began to decline and the queen began to lay fewer eggs. At the end of the experiment, the colony had no honey or pollen reserves as a result of changes in the behavior of the foragers. The experiment was conducted twice a week from February to April. However, the research that was conducted by Mall and Kumar (2014) does not confirm that radio fields (from cell phones or near a cell tower) affect brood rearing, honey production, or foraging behavior in the honey bee [23].

The CCD phenomenon (colony collapse disorder), as previously described [24], may be due to the effect of the RF field (900 MHz) in disrupting orientation in the field [6,8–10]. The limitation of the direct link between RF-EM and CCD is the fact that the changes mainly concern flying bees, and in the case of CCD, the disappearance of young bees is also important. However, the factor RF-EM is not indifferent to the behavior of worker bees, as shown in these studies. Our study showed that RF fields reduce bee flight activity, providing additional evidence that an RF-EMF may cause the weakening of bee colonies by reducing their food supply and contributing to the intensification of the CCD phenomenon. According to Sharma and Kumar (2010) [22], this can result in lower stores of honey and pollen in honey bee colonies [22]. A study by Taye et al. (2017) [25] showed that the RF field emitted by a cell phone mast had the greatest effect on the bee colony closest to the mast (at a distance of 100 m). Bees from this colony showed reduced flight activity, like in our study, and fewer returns to the hive.

Insects can sense weak electromagnetic fields, thanks to mechanoreceptors. Honey bees use the Johnston’s organ located in the antennae to do this [26]. Greggers et al. (2013) described that the honey bee’s antennae oscillate when stimulated by an electric field, which can stimulate the sensory nerve system [26]. Studies conducted on ants show that 900 MHz electromagnetic fields (emitted by cell phone masts) can have serious effects on nerve cells, interfering with visual memory and smell and can even lead to complete memory loss [27,28]. Insects (including honey bees) possess gamma-aminobutyric acid (GABA), which is an inhibitory neurotransmitter [29]. GABA in the honey bee brain is found, among others, in the antennal lobes, optic lobes, mushroom bodies, central complex, and subesophageal ganglion [30,31]. It affects brain structures responsible for motor behavior,

breathing, and flight [32,33]. Additionally, studies conducted on rats and mice exposed to a radio field with a frequency of 900–2100 MHz on the central nervous system have shown that the radio field affects brain development. Studies report that neurodegeneration occurs in the brain after exposure to an RF-EMF [34–37].

The “cleaning” behavior refers to self-grooming and care between bees (allo-grooming). Self-care in relation to honey bees involves cleansing their own body of the presence of pathogens and parasites, and social grooming involves mutual cleansing of the bodies of cohabiting individuals [38]. As mentioned, the radio field can affect the honey bee’s nervous system and thus change its behavior. Our research showed no significant differences between the control and study groups in terms of “cleaning” behavior. In the study by Migdał et al. 2021 [18] it was observed that bees showed lower cleaning behavior than the control group when exposed to a 50 Hz electromagnetic field. In our study, the effect of a 900 MHz radio frequency field was assessed, indicating that this field has no effect on cleaning behavior in honey bee workers.

In Lupi’s study (2021) [39], the influence of the electromagnetic field was also examined, not as a direct cause of the threat to the honey bee, but as one of the factors, so the bees were tested in multi-stress conditions. In the assessment of the impact of the electromagnetic field with simultaneous exposure to pesticides, compared to the groups not exposed to an EF, the worst general health condition was shown, including the survival of the colony, the appearance of pathologies, and behavioral anomalies, such as improper storage of honey and excessive deposition of drone brood. This confirms the negative impact of the field on the bees’ organism.

5. Summary

A study of the effects of a radio frequency field (900 MHz) on honey bees under laboratory conditions showed that the field slightly affected their behavior compared to the control group. Significant differences in selected behaviors appeared only seven days after the time of disposition. These studies have certain limitations because they are conducted in laboratory conditions and on bees of a specific age. However, it is necessary to build a solid foundation for further research and analysis of the impact of the electromagnetic field of radio frequencies on the body and behavior of the honey bee.

Research on this issue should be continued and deepened. Further phases of research should also include investigating the effects of an RF-EMF on the expression of genes responsible for honey bee behavior.

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