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IMPACT OF 900 MHZ ELECTROMAGNETIC FIELDS ON LOCOMOTOR PERFORMANCE AND COLLECTIVE INTELLIGENCE IN *LASIUS NIGER*

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Abstract: The rapid expansion of wireless communication technologies has raised questions about the biological effects of radiofrequency electromagnetic fields on living organisms and ecosystems. This study investigated the effects of 900 MHz electromagnetic radiation on the locomotor activity and collective behaviour of the ant *Lasius niger*. Ant colonies were exposed to radiofrequency fields at a distance of 25 cm for acute (1 h) and chronic (48 h) periods. Behavioural changes were assessed using the open-field test and a collective path-selection test. The results showed a significant decrease in exploratory activity and locomotor speed in exposed ants compared to controls. Chronic exposure also disrupted collective organisation, causing disorientation and a delay in locating the food source. Exposed ants often failed to return to their nest, suggesting impaired orientation and pheromone-mediated communication. These results indicate that prolonged exposure to 900 MHz radiofrequency fields can impair neural and social functioning in *Lasius niger* and highlight the ecological risks associated with electromagnetic pollution.

Keywords: *Lasius niger*, electromagnetic fields, locomotor behavior, collective intelligence, nervous system.

INTRODUCTION

The widespread installations of mobile telecommunications equipment have a profound impact on the electromagnetic environment of most of the world's populated ecosystems. GSM technology operating in the 900 MHz and 1,800 MHz frequency bands is one of the most persistent sources of non-ionizing radiofrequency electromagnetic field (RF-EMF) exposure in both urban and rural settings (Cucurachi *et al*., 2013; Balmori, 2015). The advent of 4G, 5G, and millimeter-wave systems has triggered growing concerns over the biological effects of chronic RF-EMF exposure in several areas, from clinical neuroscience to environmental toxicology (Saili *et al*., 2015; Liu *et al*., 2024; Khorseva and Grigoriev, 2025). We now know that these biological impacts are not confined to thermogenic thresholds but also involve non-thermal interactions with neuronal membranes, signaling cascades, and gene expression programs (Sienkiewicz *et al*., 2005; Levitt *et al*., 2021).

Specifically, rodent hippocampal spatial memory is a targeted effect of RF-EMF exposure. Oxidative stress in specific areas of rat brains exposed to 900 MHz has been documented by Narayanan *et al*. (2014). Neurodegeneration and BBB permeability occurred after 2 hours of exposure to GSM-900 MHz EMFs, according to Salford *et al*. (2003). Specifically, dose-dependent c-Fos activity was seen in the prefrontal and cingulate cortices of rats when exposed to RF-EMFs at an SAR of 1 W/kg in the study by Bontempi *et al*. (2024). Locomotor behaviors (Shiryaeva *et al*., 2020; Mortazavi *et al*., 2020; Shepherd *et al*., 2021) and anxiety disorders (Burman *et al*., 2018; Kim *et al*., 2020; Zhao *et al*., 2023; Nikitina *et al*., 2024) are among the behavioral alterations caused by RF-EMFs in rodents. Similar findings have been reported in mice (Kim *et al*., 2018; Spandole-Dinu *et al*., 2023; Kim *et al*., 2024) and nonhuman primates (Aliyari *et al*., 2021), while neurotransmitter reviews by Kim *et al*. (2018) and Lai (1992, 2018) identify disruption of cholinergic, GABAergic, and dopaminergic pathways as the principal neurochemical substrate. Effects extend to aquatic vertebrates (Foroozandeh and Derakhshan-Barjoei, 2018), and Wyszkowska *et al*. (2016) have shown that ELF-EMFs alter behaviour, physiology and the expression of stress proteins in locusts, demonstrating that neurobiological responses to EMFs are common to arthropod lineages that are evolutionarily distant.

In humans, data from EEG studies confirm that RF EMFs from mobile phones systematically modulate brain oscillations at rest, particularly in the alpha and theta bands (Wallace *et al*., 2022, 2023; Van der Meer *et al*., 2023; Prins *et al*., 2025). Another study found harmful effects of brain RF-EMF exposure on visual memory in adolescents (Roser *et al*., 2018), and Khorseva and Grigoriev (2025) conclude that the cognitive and psycho-emotional parameters of the nervous system are among the most sensitive factors to be taken into account in regulation

Notwithstanding this convergent cross-taxa data, research explicitly focusing on social ant species is limited. Levitt *et al*. (2021) identified social insects as priority organisms whose chemical communication at the colony level makes them particularly vulnerable to environmental degradation caused by electromagnetic waves. *Lasius niger* (Linnaeus, 1758) provides essential ecosystem services, such as soil aeration, seed dispersal and the regulation of arthropod prey populations (Hölldobler and Wilson, 1990; Folgarait, 1998), and its colonial organisation depends critically on recruitment via pheromone trails, which require intact antennal chemosensation and neural integration (Czaczkes *et al*., 2015). Cammaerts *et al*. (2012) first

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showed that GSM-900 MHz exposure affects memory and pheromone sensitivity in ant colonies, which led to this quantitative study.

We investigated the dose-dependent effects of acute (1 h) and chronic (48 h) GSM-900 MHz exposure on individual locomotor activity, assessed via the Open Field paradigm (Hall and Ballachey, 1932), and collective foraging intelligence, evaluated with a binary bridge algorithm assay. We hypothesized that RF-EMF would produce progressive behavioral impairment consistent with the neurochemical dose-response relationships documented across mammalian and invertebrate models.

MATERIALS AND METHODS

Study Species and Colony Collection

Workers of *Lasius niger* were collected from a pristine natural site in the Skikda region of northeastern Algeria (36°54'N, 6°56'E), specifically selected for the absence of nearby telecommunications relay antennas to ensure naïve baseline electromagnetic exposure. Asexual worker ants (body length 3 mm) were used exclusively. Eighteen individuals were collected and maintained in standardized laboratory nests (glass test tubes, 10 cm length), in which 1/3 of the tube volume was filled with water retained by compacted cotton wool, with ants occupying the remaining two thirds sealed with loosely packed cotton to ensure adequate ventilation. All colonies were maintained at 23 ± 1°C and 60 ± 5% relative humidity under a 12:12 h photoperiod with ad libitum access to 10% sucrose solution.

Experimental Groups and RF-EMF Exposure

The eighteen worker ants were randomly allocated to three experimental groups of six individuals (Table 1): (i) unexposed control (sham), (ii) acutely exposed (GSM/1 h), and (iii) chronically exposed (GSM/48 h). A commercial mobile phone that transmitted at 900 MHz was the source of the RF-EMF. According to Atasoy *et al*. (2013), the apparatus was placed at a consistent distance of 25 cm from the lab nest housing the test animals as biologically relevant near-field exposure geometry. Incident power flux density at the exposure site was measured at 23 mW/cm². Sham controls were maintained under identical conditions with the handset powered off. No significant thermal variation between groups was detected throughout the exposure period.

Table 1.

Experimental group composition and exposure conditions

Group	n	Treatment	Exposure duration
Control (sham)	6	None	/
Acute exposure	6	GSM-900 MHz	1 h
Chronic exposure	6	GSM-900 MHz	48 h

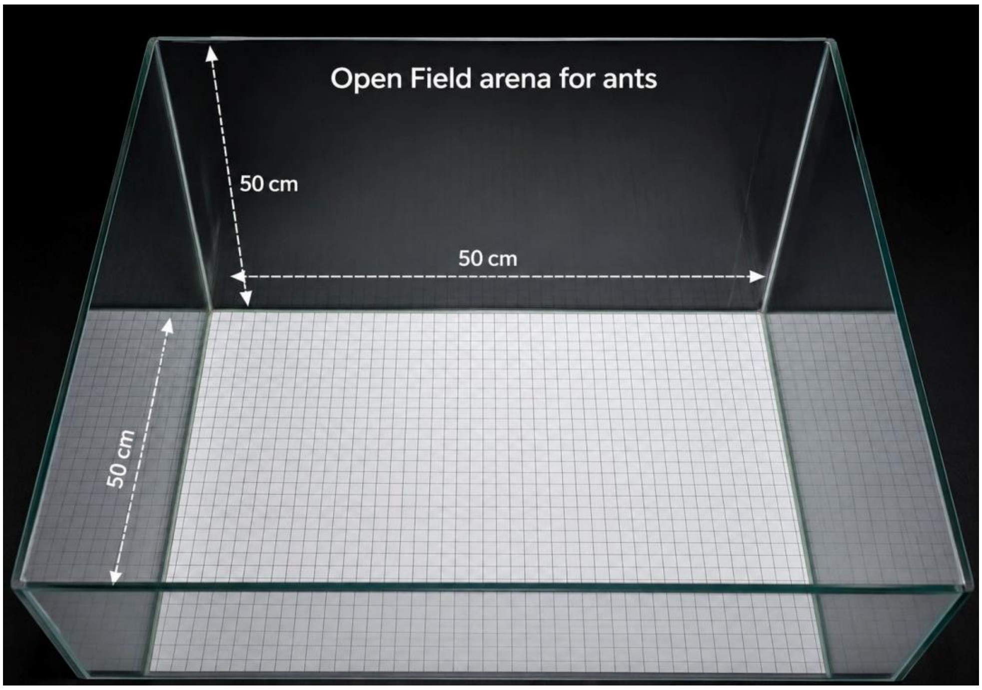

Fig. 1. The Open Field testing system.

Open Field Locomotor Activity Test

The Open Field paradigm was used to measure locomotor activity (Hall and Ballachey, 1932). The device was a 50 x 50 x 50 cm cubic terrarium whose inside surfaces were lined with black paper to reduce visual stress and guarantee consistent luminosity contrast (Fig. 1). An overhead digital video camera was used to film the activities of individual ants in the arena's center area for two minutes. The following three dependent variables were measured: (i) total mobility duration (s; defined as any body displacement observed), (ii) total resting duration (s; defined as total absence of locomotion for ≥ 1 s), and (iii) number of quadrants traversed (the arena floor was divided into 25 equal quadrant squares, each crossing counted once per entry). The total displacement distance was used to calculate the locomotor velocity ($cm•s^{-1}$). Locomotor velocity ($cm·s^{-1}$) was calculated from the total displacement distance divided by observation time ($V = d/t$).

Collective Foraging Intelligence: Binary Bridge Algorithm Assay

Collective foraging efficiency was evaluated using a binary bridge assay adapted from Gay Théraulaz (2009). A laboratory nest was connected to a sucrose food source (10% solution) via a bifurcated bridge presenting two unequal path lengths: a short branch (15 cm) and a long branch (approximately 25 cm). The two branches converged at both the nest end and the food end (Fig. 2). The time for the colony to collectively select and concentrate recruitment along the shorter branch was recorded. Trial outcome was classified as: (i) short-path selection within 2 min (successful optimization), (ii) partial or random trail establishment, or (iii) complete failure to recruit (no trail formed; ants failed to return to nest). Observations were conducted over a 4-min period per trial.

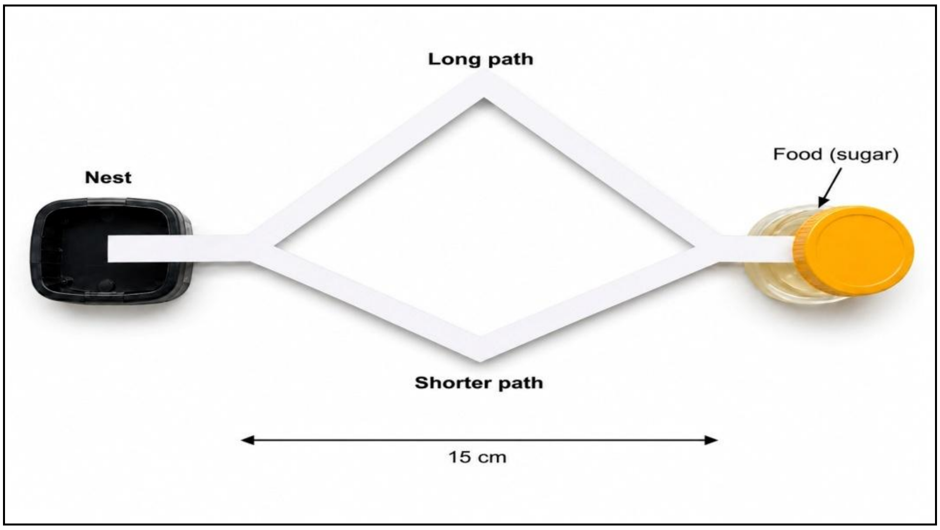

Fig. 2. Binary Bridge Algorithm Assay.

Statistical Analyses

All data are expressed as mean ± standard error of the mean (SEM). Between-group differences were analyzed using Student's t-test and one-way analysis of variance (ANOVA) followed by post-hoc comparison where appropriate. The threshold for statistical significance was set at $\alpha = 0.05$. Significance levels are indicated as: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. All analyses were conducted in R. Principal Component Analysis (PCA) was also employed to identify underlying patterns and correlations among operational parameters and their influence on ants behavior.

RESULTS

Open Field Locomotor Activity

Quadrant Traversal

Exposure to GSM waves appears to reduce the exploratory activity of *Lasius niger* ants, with this effect becoming statistically significant after 48 h of exposure (Fig. 3). The observed decline in exploratory behavior may indicate a disruption of normal foraging dynamics and spatial activity, potentially resulting from stress-related behavioral alterations induced by prolonged electromagnetic field exposure.

Mobility and Resting Duration

The effect of 48 h on the exposure was shown by the significant difference in mobility time between the experimental and control groups, implying that the exposure to the GSM wave significantly changes the behavior of *Lasius niger* with respect to exploring (Fig. 4). The effect can be attributed to the disruption of motor behavior control due to stress-induced hyperactivity.

A progressive decrease in resting time was observed with increasing exposure duration, becoming statistically significant after 48 h of GSM wave exposure (Fig. 5) . This reduction in resting behavior suggests that prolonged electromagnetic field exposure disrupts normal behavioral homeostasis in *Lasius niger*, potentially leading to sustained agitation and altered recovery dynamics.

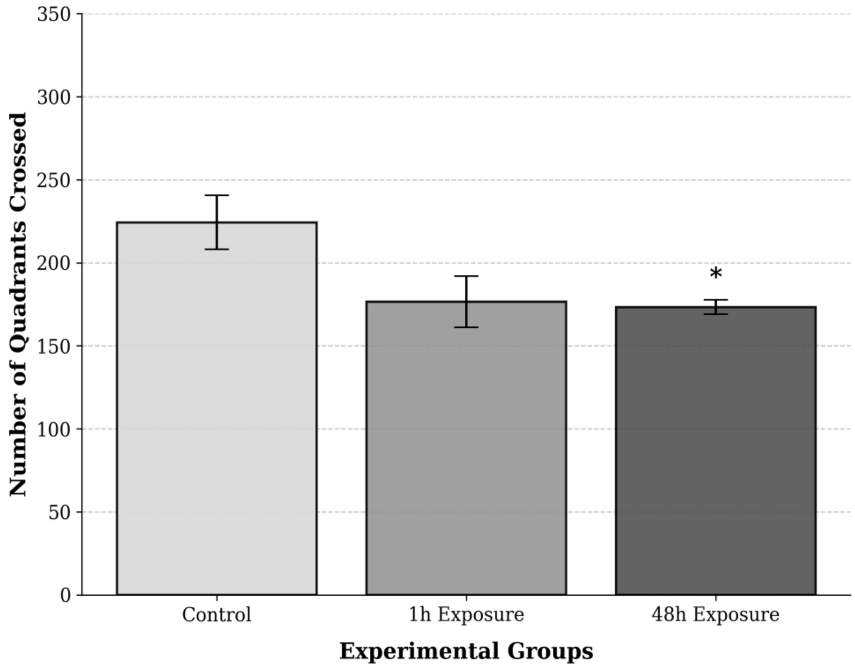

Fig. 3. Effects of exposure to a GSM signals (900 MHz; 1 h and 48 h) on the number of quadrants crossed by *Lasius niger*. Values are expressed as mean ± SEM of six determinations for control ants and six determinations for exposed ants (EX).

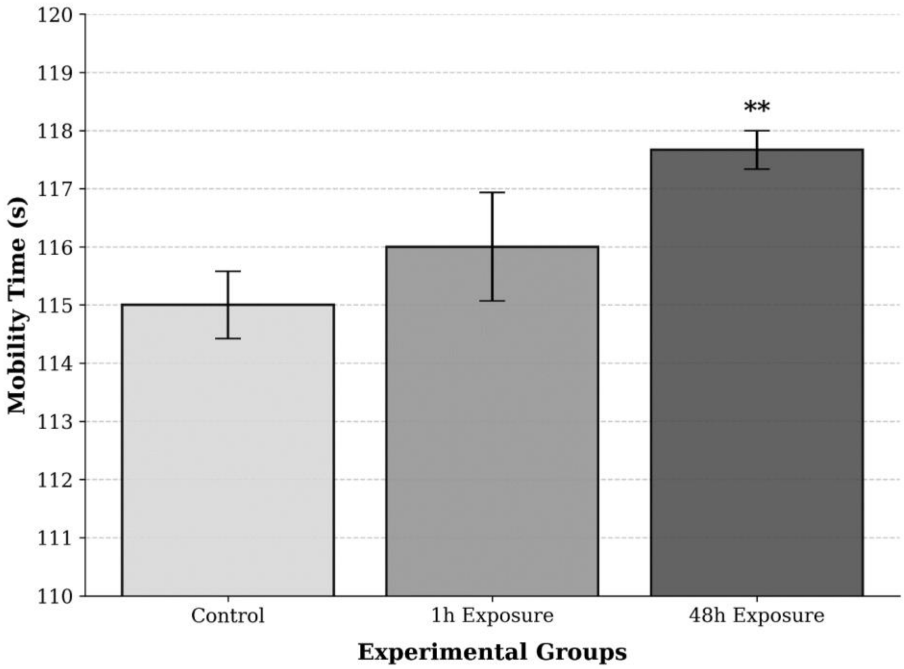

Fig. 4. Effects of exposure to a GSM signal (900 MHz; 1 h and 48 h) on the total mobility time of *Lasius niger* ants in the open-field apparatus. Values are expressed as mean ± SEM of six determinations for control ants (T) and six determinations for exposed ants (EX). Statistical significance was determined relative to the control group ($p < 0.05$).

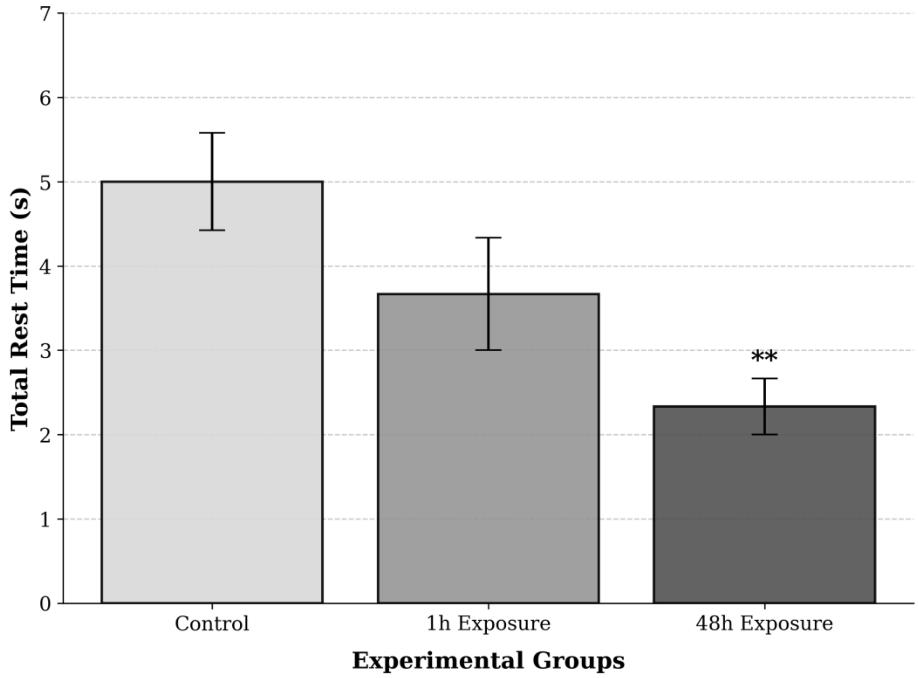

Fig. 5. Effects of exposure to a GSM signals (900 MHz; 1 h and 48 h) on the total resting time of *Lasius niger* ants. Values are expressed as mean ± SEM of six determinations for control ants (T) and six determinations for exposed ants (EX). Statistical significance was assessed relative to the control group.

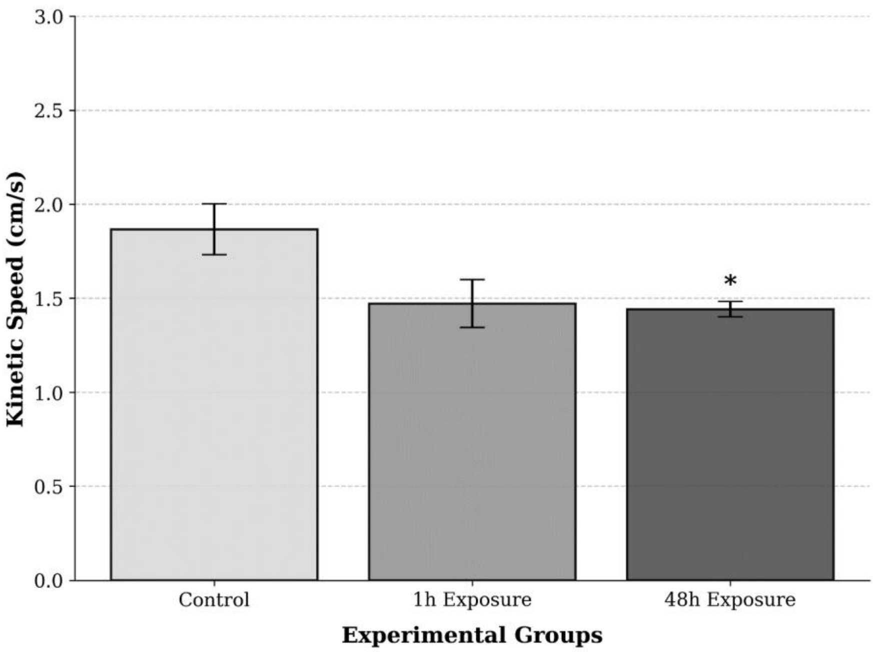

Fig. 6. Effects of exposure to a GSM signal (900 MHz; 1 h and 48 h) on the locomotor velocity of *Lasius niger* ants (control (T) vs exposed (EX)). Values are expressed as mean ± SEM of six determinations for each experimental group.

Locomotor Velocity

Prolonged exposure (48 h) to GSM waves appears to significantly reduce the locomotor velocity of *Lasius niger* ants. This decrease in movement speed suggests an impairment of motor efficiency following chronic electromagnetic field exposure, potentially reflecting physiological stress or altered neuromuscular functioning.

Collective Foraging Intelligence

In the binary bridge algorithm assay, control ants and acutely exposed ants (1 h) demonstrated consistent collective path optimization: both groups converged on the shorter branch within 2 min of access to the bifurcated bridge, with pheromone trail deposition visually confirming reinforced recruitment along the shorter route (Fig. 7a, Fig. 7b).

In marked contrast, chronically exposed ants (48 h) failed to establish coherent trail recruitment. Foragers distributed themselves across both path lengths in a random pattern without preferential reinforcement of the shorter branch. Trail convergence was not achieved within the 4-min observation window (Fig. 7c). Furthermore, a proportion of chronically exposed workers failed to return to the nest following food discovery, a behavior not observed in control or acutely exposed animals. The mean time to first food discovery was substantially prolonged in the 48 h group compared to both the control and 1 h groups.

These results indicate a qualitative threshold effect: acute exposure of 1 h did not detectably impair collective foraging optimization, whereas chronic exposure of 48 h produced complete disruption of pheromone trail-based collective decision-making.

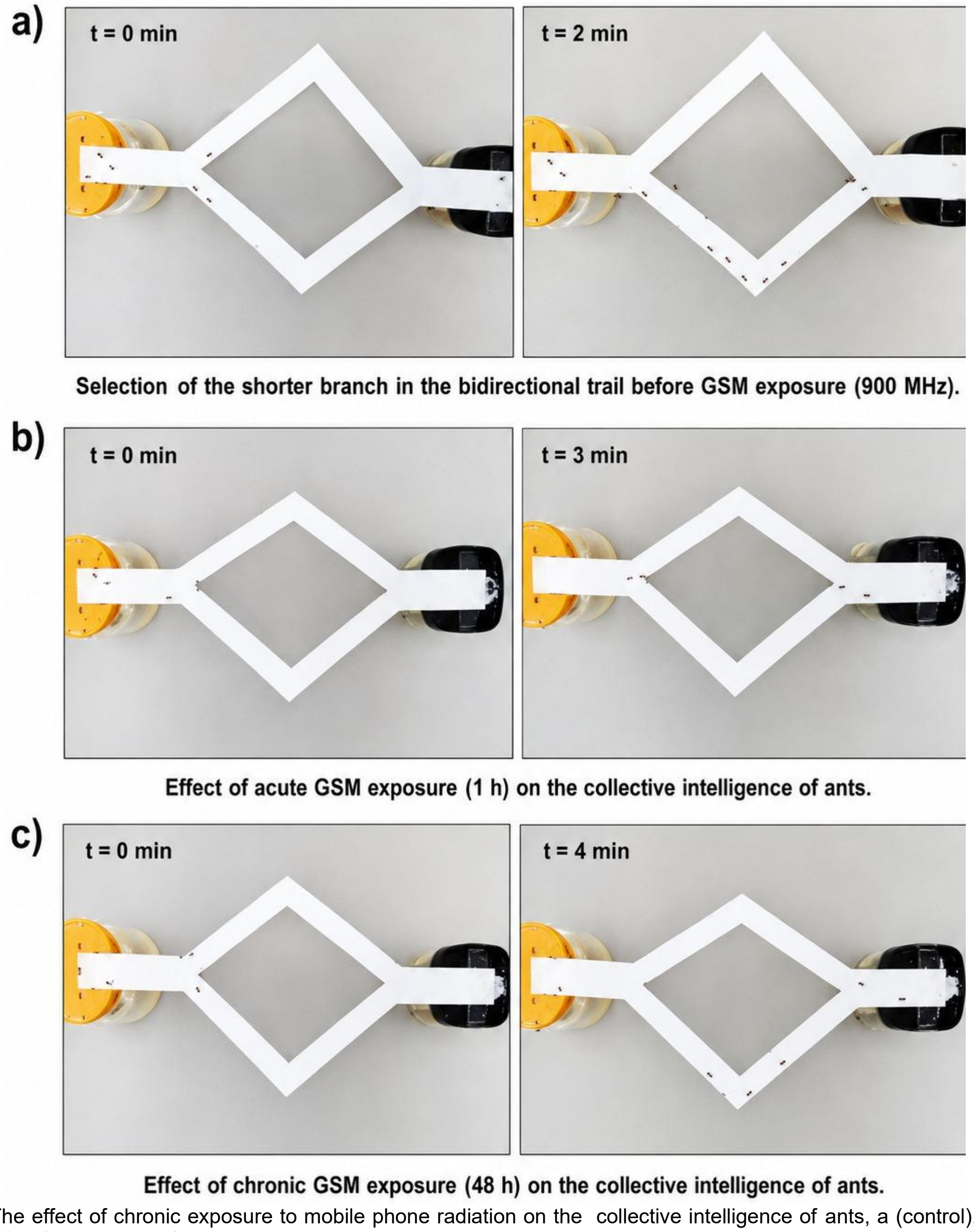

Fig. 7. The effect of chronic exposure to mobile phone radiation on the collective intelligence of ants, a (control), b (1h exposure), c (48h exposure).

PCA biplot

From the PCA biplot (Fig. 8), there appeared a discrimination of the three experimental groups on the main factorial axes, illustrating the process of progressive behavioral change that occurred following exposure to GSM waves in *Lasius niger* ants. The group subjected to no exposure to GSM waves (the control group) appeared in the top-right corner and was highly related to high locomotor velocity, increased distance (number of quadrants crossed), and resting time, which showed a consistent and energy-efficient state of behavior. On the other hand, the EX 1h group appeared in an intermediary place in the biplot, indicating a stage at which behavioral changes were already starting. This separation became highly evident for the EX 48h group, as the latter clearly appeared in the opposite side of the biplot concerning the control group.

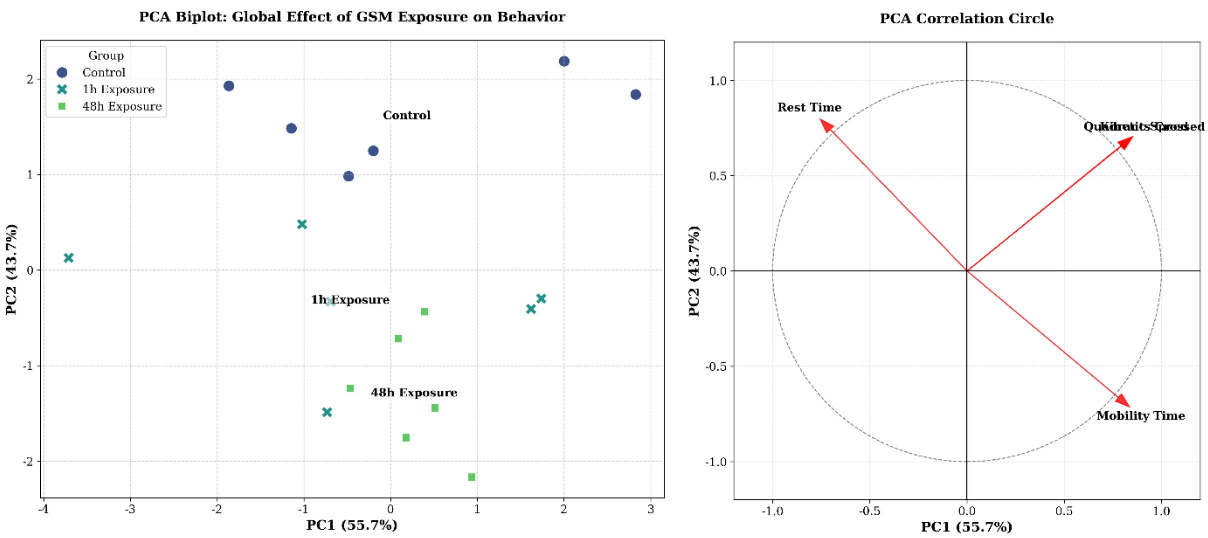

Fig. 8. PCA biplot analysis.

The correlation circle gave additional insight regarding the associations between the different behaviors examined. It was possible to notice a positive association between locomotor velocity and number of quadrants crossed, since faster subjects had higher spatial exploration capacity. On the other hand, mobility was negatively correlated with resting behavior, which showed how GSM waves reduced resting time while increasing activity. However, considering that while the movement duration increases, the velocity decreases, one can conclude that the observed phenomenon is inefficient hyperactivity and not improved performance of the locomotor system.

In conclusion, PCA has clearly shown that GSM exposure has caused a dramatic change in the behavioral profile of *Lasius niger*, which becomes more pronounced with time. After 48 hours, the exposed ants showed an abnormal behavioral profile consisting of increased activity but decreased efficiency and less rest. Such a behavioral pattern is typical for the organism undergoing stress or anxious state. Thus, the clear deviation of EX 48h sample from the control condition shows that long-term GSM exposure could greatly interfere with normal exploration and locomotion.

DISCUSSION

The present study demonstrates that GSM-900 MHz RF-EMF exposure produces significant, dose-dependent disruption of individual locomotion and collective foraging intelligence in *Lasius niger*, consistent with a broad cross-taxa evidence base documenting RF-EMF-induced neural alterations in rodents, primates, other invertebrates, and humans.

The reduction in quadrant-crossing speed and locomotor speed observed in the exposed ants corresponds to the suppression of locomotion reported in many species. Alterations in open-field behavior have documented in mice exposed to 1,950 MHz RF-EMF (Kim *et al*., 2020), in rats exposed to 900 MHz (Mortazavi *et al*., 2020; Shiryaeva *et al*., 2020), and in rodents exposed to mobile phone radiation (Sultangaliyeva *et al*., 2020). In invertebrates, Wyszkowska *et al*. (2016) demonstrated that ELF EMFs inhibited motor activity in locusts, and Nakada *et al*. (2023) described altered locomotor coordination in small laboratory animals exposed to magnetic fields. The contradictory pattern of sustained motor activity combined with reduced spatial coverage observed in our exposed ants mirrors the uncoordinated and non-directional locomotion of anxious rodents in open-field tests (Cosquer *et al*., 2005; Burman *et al*., 2018), RF-EMF can disrupt these processes through non-thermal induction of heat-shock proteins (De Pomerai *et al*., 2000), disruption of plasma membrane ion channel gating (Panagopoulos *et al*., 2015), and down-regulation of BDNF, which maintains synaptic plasticity in olfactory circuits (Zhao *et al*., 2023; Kim *et al*., 2024). The homing failure observed in chronically exposed workers further implicates hippocampal-equivalent spatial memory processes extensively documented as RF-EMF-sensitive in mammals (Salford *et al*., 2003; Narayanan *et al*., 2014; Bontempi *et al*., 2024) and primates (Aliyari *et al*., 2021) and already identified as a sensitive endpoint in early ELF-EMF reviews (Anderson, 1993; Levitt *et al*., 2021). The convergence of disorientation and stress protein responses between our 48 h ant group and ELF-EMF-exposed desert locusts (Wyszkowska *et al*., 2016) suggests that these behavioral targets represent ancient, conserved neural functions across arthropod lineages.

The reduction in the speed of traversing the quadrants and the difference between the results observed at 1 hour and 48 hours are theoretically instructive: locomotor speed was impaired following acute exposure, but the collective optimization of the route path remained intact, suggesting that individual motor performance and pheromone-mediated collective intelligence exhibit different sensitivities to RF EMFs. This probably reflects the redundancy of synergetic systems, which compensate for small individual deficits until a threshold is reached. Similar non-linear dose-response relationships have been described in human EEG research (Prins *et al*., 2025) and in rodents exposed to 5G (Nikitina *et al*., 2024), and Hirabayashi *et al*. (2025) also observed intensity-dependent effects of magnetic field exposure on emotional responses in living organisms.

This discrepancy is theoretically enlightening: locomotor velocity was affected post-acutely; yet collective trail optimization remained unaffected, indicating a differential sensitivity to RF-EMF between individual motor performance and pheromone-driven collective intelligence. This difference can be explained by the redundancy in stigmergy-based biological information processing networks, which compensate for minor deficiencies of individuals until a certain threshold is achieved. Similar phenomena have been reported in the context of human brain response studies (Prins *et al*., 2025) and experiments in vivo on rodents exposed to 5G radiofrequencies (Nikitina *et al*., 2024), where effects depended on RF-EMF intensity as well. Intensity-dependent effects on behavioral emotional reactions under the influence of a magnetic field were reported by Hirabayashi *et al*. (2025).

In a wider context, ants dwelling in peri-urban environments are chronically subjected to near-field RF-EMF similar to the ones tested in the present experiment. Thus, reduced efficiency of collective foraging activity would result in lower caloric income and decreased fitness. This in turn would affect bioturbation, seed dispersal and regulation of ecosystems as predicted by Levitt *et al*. (2021). Such adverse effects cannot be managed by regulations based only on human thermogenic parameters (Belyaev *et al*., 2016; Pall, 2016; Khorseva and Grigoriev, 2025).

The limitations associated with this study include relatively few subjects per group (n=6), no formal SAR dosimetry performed for the bodies of ant individuals, and lack of molecular analysis of trail pheromones. Future research could address these gaps by measuring biochemistry of the trail pheromone blend, performing electrophysiological recordings in the antennal lobe neurons, and determining dose-response relationships within an ecologically relevant range of GSM power densities.

CONCLUSION

The current study presents experimental evidence for GSM-900 MHz RF-EMFs negatively affecting locomotion and foraging intelligence in *Lasius niger* ants. A significant impairment in locomotion velocity and spatial exploration was observed following an acute one-hour RF-EMF exposure. In contrast, a chronic 48 hours RF-EMF exposure also inhibited optimal organization of pheromone trails in collective foraging tasks. The current data provide support for the assumption about a non-thermal effect interfering with chemoreception and/or pheromone production. Overall, this research confirms *L. niger* as a sensitive bioindicator for RF-EMF pollution and highlights the importance of using behavioral invertebrate endpoints in EMF environmental risk assessments. Future research perspectives involve the identification of the pheromone trail composition under RF-EMF exposure, the dynamics of information exchange in exposed ant colonies, as well as effects of RF-EMF on the reproductive success of colonies.

AUTHORS CONTRIBUTIONS

Conceptualization & methodology: S.L and B.D; data collection A.A; data validation B.Y and A.S; data processing B.F and B.Z; writing—original draft preparation, B.Y; writing—review and editing, M.F.Z.

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CONFLICT OF INTEREST

The authors have not any competing financial, professional, or personal interests from other parties. The authors declare no conflict of interest.

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