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ORIGINAL ARTICLE

Ants can be used as bio-indicators to reveal biological effects of electromagnetic waves from some wireless apparatus

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Abstract

Society is confronted with an increasing number of applications making use of wireless communication. We also notice an increasing awareness about potentially harmful effects of the related electromagnetic fields on living organisms. At present, it is not realistic to expect that wireless communication will decrease or disappear within the near future. That is why we currently are investigating the mechanisms behind these effects and the effectiveness of possible solutions. In order to be efficient and effective, we designed and validated a fast and easy test on ants – these insects being used as a biological model – for revealing the effect of wireless equipments like mobile phones, smartphones, digital enhanced cordless telephone (DECT) phones, WiFi routers and so on. This test includes quantification of ants' locomotion under natural conditions, then in the vicinity of such wireless equipments. Observations, numerical results and statistical results allow detecting any effect of a radiating source on these living organisms.

Keywords

Ants, electromagnetic waves, mobile phones, personal computer, WiFi apparatus

History

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Introduction

Currently, we see massive scientific support for the hypothesis that wireless communication may cause adverse effects on the well-being of living organisms (Adang et al., 2006; Belyaev and Grigoriev, 2007; Benlaidi and El Kharroussi, 2011; Bourthoumieu et al., 2010; Cammaerts et al., 2011; Cucurachi et al., 2013; Everaert and Bauwens, 2007; Haggerty, 2010; Joubert et al., 2006; Khurana et al., 2009; Nicholls and Racey, 2009; Orendaeova et al., 2009; Pakhomov and Murphy, 2000; Panagopoulos, 2012; Panagopoulos et al., 2004; Stever et al., 2005; Vignera et al., 2012; Wang et al., 2009). However, society claims to no longer be able to live without using such equipments, which functions by transmitting non-natural (''man-made'') electromagnetic waves. The solution for the future may be to include protective devices in any wireless apparatus. Such devices must be proven, by fast and simple tests, to really fulfill the claims made by their suppliers. Consequently, the first goal of our work was to set up a protocol, which allows immediate detection and measurement of any potential effects of electromagnetic fields. A second future step will be to assess the effectiveness of a protective system. In this first investigation, we examined under what conditions wireless equipments do have an adverse effect on living organisms as observed in our present animal model.

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For this work, our basic questions were as follows:

- Do smartphones and digital enhanced cordless telephone (DECT) phones cause harmful effects on living creatures?
- Do mobile phones cause such effects only when activated, or already in standby, in off-position or without their battery?
- Do WiFi stations cause harmful effects?
- Are wired computers free from harmful effects and under what conditions?

Some insects are very sensitive to changes in their environment. *Drosophila melanogaster*, for instance, could be used to very elegantly show, up to a quantitative level, the effect of mobile telephony radiation (Panagopoulos et al., 2010). Hymenoptera (such as bees and ants) are actually extremely sensitive. Bees (Favre, 2011; Sharma and Kumar, 2010; Harst et al., 2006; Kimmel et al., 2007; Warnke, 2009) and ants (Cammaerts et al., 2012a, 2013) have been demonstrated to suffer from electromagnetic waves in their environment. Ants can easily be maintained in a laboratory all over the year and can be tested at any moment in time. They are excellent biological sensors for detecting harmful waves from sources of electromagnetic radiation. Under normal, undisturbed conditions, they remain with a usual behavior; when exposed to devices generating an electromagnetic field, even of low intensity, they rapidly present a disturbed behavior. Consequently, using ants as a model, we set up a quick and easy ethological test, which allows revealing the existence of some adverse electromagnetic field. Thanks to this test, potential harmful effects of wireless phones, such phones in different modes, WiFi equipment and a state-of-the-art computer were investigated.

Material and methods

Wireless equipment

Experiments were performed under natural conditions, using commercially available equipment.

A standard, commercially available, mobile phone was used successively without battery, in switched-off mode, in switched-on mode (standby) and in active mode (during conversation). We also assessed the possible influence of the battery itself. Each time, we made the observation twice, e.g. on two nests, so on 2×10 ants (see below). Later on, we performed the four experiments again using a mobile phone, once more twice, on two nests, the observer being this time blind to the experimental situation, e.g. another person prepared the phone and set it under the ants' tray in the absence of the observer. The used mobile phone (Nokia 3120) emits in the 900 MHz range. As detailed in Cammaerts et al. (2011, 2012a), the specific energy absorption rate (SAR value) very near the mobile phone (where the ants were located) is of no use, essentially because an ant body differs from a human one. The phone used has a battery of 3.7 Volt able to deliver electricity at 700 mAh. The electromagnetic field around the used global system for mobile communication (GSM) amounts 3.7 Volt $\times$ 700 mAh, that is about 2.6 W(h). The mobile phone increases its output power when located further away from the communication antennae. In this case (approx. 100 meters from a communication antenna, which is not very far), the power intensity near the used GSM can be estimated as equaling about 2 watts.

A standard, commercially available smartphone was also used, as well as a common DECT phone, i.e. a digitally enhanced cordless telephone, each one twice, on two nests (so on 2×10 ants). These two phones generate around them, at 10 cm–20 cm of distance, an electromagnetic field of rather high and variable intensity (800, 1000 or more than 2000 $\mu W/m^2$).

A WiFi station (Wi-Fi NETGEAR, ref DGN1000, frequency: 2.4 Ghz) was tested as well. The antenna was located at a distance of 30 cm from the ants.

In another experiment, the ants were observed in the presence of a common notebook computer (ACER Aspire 2920). The ants were located in front of the computer, at a distance of 20 cm and 5 cm beneath, i.e. where a user's body is usually located.

We measured the intensity of the electromagnetic fields generated by the employed wireless equipments using a HF 35 C radiation intensity meter for frequencies from 800 MHz to 23 GHz; Gigahertz solutions GmbH, Am Galgenberg 12, D-90579, Langenzenn, Germany).

Biological material

The experiments were conducted with eight large colonies of *Myrmica sabuleti* Meinert 1861 and two large colonies of *Myrmica ruginodis* Nylander 1846 collected in the Aise valley (Ardenne, Belgium). Each of these colonies contained a queen, brood and about 500 workers. They were maintained in the laboratory in artificial nests made of one to three glass tubes, half-filled with water and a cotton-plug separating the ants from the water. The glass tubes were deposited in trays ($33 \times 22 \times 2.5$ cm or $43 \times 28 \times 7$ cm), which served as foraging areas. The sides of the trays were covered with talc powder to avoid ants escaping. Food (see following alinea) was provided *ad libitum*, and ants were tested in these trays (Figure 1A).

The room temperature was maintained at 20 °C $\pm$ 2 °C. Humidity was about 80% and remained constant over the course of an experiment. The lighting had a constant intensity of 330 lux while caring for the ants (e.g. providing food and renewing nesting tubes) as well as during our experiments. Food consisted of sugared water permanently offered in a small glass tube plugged with cotton and of chopped *Tenebrio molitor* larvae served twice a week on a glass-slide (Figure 1A).

Set up of a biological test

Electromagnetic waves appear to have effects on the ants' conditioning, on their responses to their pheromones and on their food collection (Cammaerts et al., 2012a, 2013). Briefly, under radiation, it appeared that ants can no longer be conditioned, and conditioned ants very quickly lose their learning. Furthermore, during exposure, ants respond to their trail pheromone, their alarm signal and their area marking pheromone at to a too low (so inefficient) level, and they no longer collect food. Such observations are very instructive for understanding the effects of electromagnetic waves on living organisms, but collecting them is really time-consuming (one week, a few days and one hour, respectively). For detecting effects of electromagnetic waves and assessing the effectiveness of protective systems, we need a much shorter and constantly reproducible test in order to have the results immediately. We looked at the ants' locomotion while they were moving, without and with radiation, and observed a significant difference between the ants' movement under these different conditions. In this way, we used this ants' reaction for setting up an adequate biological test, which is fast, simple, reproducible and yields quantitative results.

As a first step, we made each set of experiments on two or four ant nests under normal conditions, without any wireless equipment nearby. Herewith, we obtained the numerical results for the control situation. As a second step, we did the same experiments, with the same ants, but this time located in the vicinity of an electromagnetic source. Herewith, we obtained the numerical results corresponding to the radiating condition.

To assess the results of our experiment on each nest, under given conditions, we recorded the trajectories of 10 ants, randomly chosen, using a water-proof marker pen, on a glass slide horizontally set 12 cm above the foraging area (Figure 1E). The trajectories were then copied with a water-proof marker pen, onto transparent polyvinyl sheets, which stuck to the computer screen due to their own static electricity. The trajectories could then be analyzed using newly elaborated software (Cammaerts, 2012b). In this investigation, we only quantified the ants' linear and angular speed. The linear speed (V) of the animal is the length of its trajectory divided by the time spent moving along

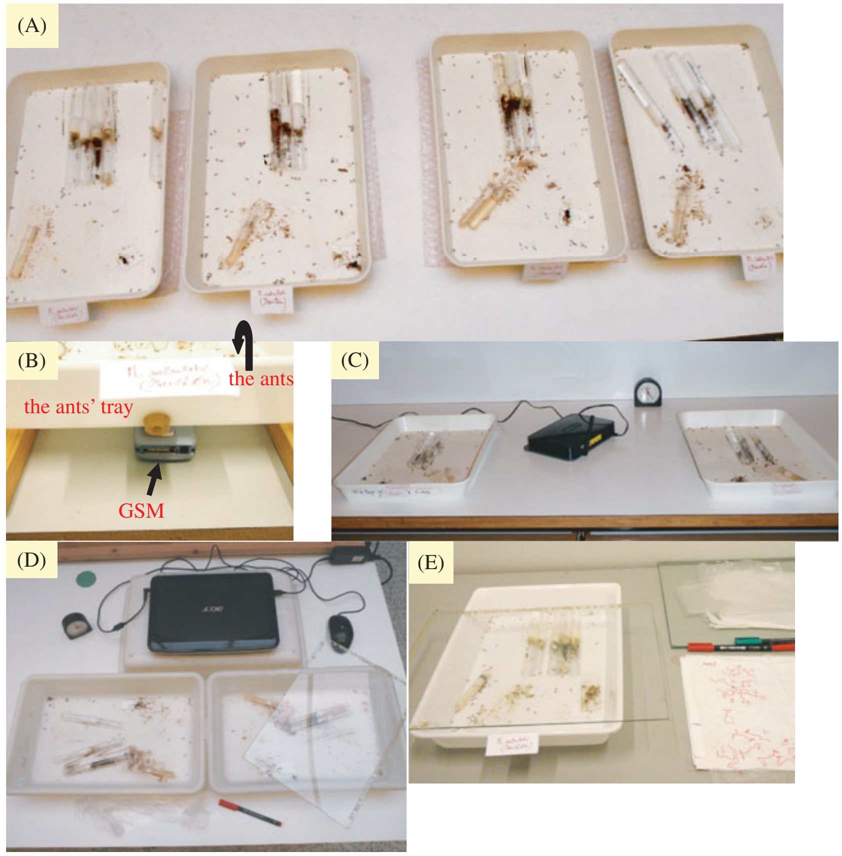

Figure 1. A few views of experimental designs. (A) Four of the eight used colonies of *Myrmica sabuleti*. Each colony lived in 3 to 4 glass tubes set in a tray. (B) Setting of a GSM under an ants' tray. (C) Experiment with a WiFi apparatus, on two colonies of *M. sabuleti*. (D) Experiment with a PC, on two colonies of *M. ruginodis*. (E) Recording of ants' trajectories.

this trajectory. In this study, it was measured in mm/s, and time was evaluated by listening to a metronome beating each second. The angular speed (S) (i.e. the sinuosity) of the animal's trajectory is the sum of the angles, measured at each successive point of the trajectory, made by the segment ''point i – point i – 1'' and the segment ''point i – point i + 1'', divided by the length of the trajectory. In this study, this variable was measured in angular deg./cm. Thanks to the newly elaborated software, the quantification of these two variables for one trajectory takes a few seconds.

In this study, the linear speed and the angular speed of 10 ants for each nest, and so of 20 or 40 ants for each experiment, could thus be rather rapidly obtained. Then, the distributions of these values were characterized by their median value and their quartiles because these distributions were not normal (Gaussian) (Table 1). The distribution of the values obtained while ants were in the vicinity of electromagnetic equipment was compared to the corresponding one obtained during a control experiment. We applied the non-parametric χ^2 test (Siegel and Castellan, 1989) and an alpha (α) level of probability of 0.05.

Results

Effect of several kinds of wireless phones (Table 1A)

These wireless phones were each time located under the ants' tray so that the ants could not be perturbed by the visual and potential olfactory perception of the phone (Figure 1B).

A battery, taken out of a common mobile phone and placed under an ants' tray, did not affect the ants' locomotion. The insects' linear and angular speeds were statistically identical to those presented under natural conditions. In the same way, a mobile phone, not provided with its battery, did not change the ants' movement. The values of linear and angular speed then obtained were statistically similar to the control ones.

On the contrary, a mobile phone provided with its battery but yet maintained in the off-mode already affected the ants' movement. The insects' angular speed statistically increased (median = 295 ang. deg./cm vs 163 ang. deg./cm; $p < 0.001$). This slight effect was checked by performing the experiment once again, the observer being this time blind to the experimental situation (see below). When the mobile phone was used in standby-mode, the effect on the ants' angular speed was more pronounced (median = 318 ang. deg./cm vs 163 ang. deg./cm; $p < 0.001$). As soon as (e.g. two to three seconds after that) the GSM was activated (i.e. in receiving or sending condition), it's effect on the ants' movement and behavior was again stronger. This time, not only the ants' angular speed increased (median = 340 ang. deg./cm vs 163 ang. deg./cm; $p<0.001$) but also the ants' linear speed statistically decreased (median = 6.7 mm/s vs 8.2 mm/s; $p < 0.01$).

Later on, we performed these experiments again, the observer being blind to the experimental situation (Table 1). In the absence of the observer, another person randomly set the GSM phone without battery, off, on or activated under the ants' tray. The then obtained results confirmed the previous ones. When the GSM was activated (Table 1A1), the ants linear speed statistically decreased, and these insects' angular speed statistically increased. Above a GSM without battery (Table 1A2), the ants walked at a normal speed with a low sinuosity. When the GSM was provided with its battery but was off (Table 1A3), the ants' locomotion changed, the sinuosity of their trajectories being larger. Above a GSM in

Table 1. Ants' locomotion near mobile phones, WiFi and PC. The table gives the linear speed (mm/s, column 3) and the angular speed (sinuosity, angular degrees/cm and column 4) of ants (number observed; in how many colonies, column 2) under natural condition (control) or near a piece of equipment (column 1). Results of non-parametric χ^2 tests between the distributions of values obtained under two different experimental conditions are given in the text, ''Results'' section.

Experiments (species)	Number of ants and colonies	Linear speed	Angular speed
A control (*M. sabuleti*)	20 ants 2 colonies	8.2 (7.7–9.6)	163 (156–178)
Battery out of the phone	10 ants 1 colony	8.3 (7.5–9.0)	151 (135–194)
Battery alone, a second time	10 ants 1 colony	8.5 (7.4–8.9)	165 (137–188)
GSM without battery	20 ants 2 colonies	7.9 (7.4–8.3)	157 (127–191)
GSM + battery, off	20 ants 2 colonies	8.1 (7.7–8.9)	295 (273–366)***
GSM phone in standby	20 ants 2 colonies	8.1 (6.4–8.7)	318 (287–334)***
GSM phone activated	20 ants 2 colonies	6.7 (5.2–7.5)**	340 (300–372)***
Being blind (control)	20 ants 2 colonies	10.2 (9.3–11.3)	134 (118–162)
1. GSM phone activated	20 ants 2 colonies	7.1 (6.3–7.6)***	271 (242–287)***
2. GSM without battery	20 ants 2 colonies	10.6 (9.4–11.0)	114 (94–159)
3. GSM + battery, off	20 ants 2 colonies	10.2 (8.9–11.4)	182 (143–192)***
4. GSM phone in standby	20 ants 2 colonies	9.1 (8.3–10.8)	179 (166–222)***
Another control	20 ants 2 colonies	8.3 (7.5–9.5)	101 (86–129)
Smart phone on	20 ants 2 colonies	6.9 (6.0–7.4)*	228 (194–253)***
DECT phone on	20 ants 2 colonies	6.9 (4.5–8.3)**	319 (246–347)***
B control (*M. sabuleti*)	20 ants 2 colonies	11.9 (10.0–14.1)	135 (94–152)
WiFi, during 5 min	20 ants 2 colonies	7.7 (6.8–8.7)***	235 (219–245)***
WiFi, during 30 min	20 ants 2 colonies	7.9 (6.8–9.2)***	266 (231–297)***
C control, PC off (*M. ruginodis*)	20 ants 2 colonies	11.2 (10.3–13.0)	125 (115–143)
PC on WiFi function activated	20 ants 2 colonies	11.4 (9.9–12.5)	192 (168–217)***
Control, PC off	20 ants 2 colonies	15.9 (14.6–17.6)	120 (103–135)
PC on, WiFi deactivated	20 ants 2 colonies	15.1 (12.9–17.0)	113 (93–120)

standby mode (Table 1A4), the ants' sinuosity statistically increased while their linear speed somewhat decreased.

The electromagnetic field near a GSM phone in off or in standby mode has a very low intensity, which cannot be assessed with our radiation intensity meter. A low intensity (of about 5 $\mu W/m^2$) could be measured near an activated GSM phone.

The effects of a modern phone (a smartphone) and of a DECT phone were studied using ants not yet exposed to radiation (''fresh'' ants). These two electromagnetic sources (placed under the ants' tray) clearly affected the ants with a very short delay (1–3 s). The smartphone statistically decreased the insects' linear speed (6.9 mm/s vs 8.3 mm/s; $p < 0.05$) and increased their angular speed (228 ang. deg./cm vs 101 ang. deg./cm; $p < 0.001$). The ants moved with difficulty (Figure 2A). A DECT phone had similar but yet stronger effects. The ants' linear speed drastically decreased (6.9 mm/s vs 8.3 mm/s; $p < 0.01$) while their angular speed reached a very high value (319 ang. deg./cm vs 101 ang. deg./cm; $p < 0.001$). The ants were exposed to each of these two sources only for three minutes, but needed two to four hours for exhibiting their usual behavior again. During the exposure, the ants presented locomotion ataxia, having difficulties in moving their legs, being nearly paralyzed (Figure 2A); they could no longer forage as usual, move toward their nest or go to their food site.

Examples of ants' trajectories during control experiments, experiments using a smartphone and experiments using a DECT phone are shown in Figure 2(C–E), respectively.

Finally, we made a complementary observation on a *M. sabuleti* colony in good health. We located a common mobile phone in standby mode under the ants nest (e.g. the nesting tubes, so not just under their foraging area but further away) and immediately observed that the ants left their nest taking their brood (eggs, larvae and nymphs) with them. It looked spectacular (Figure 2B). They relocated their nest far from the place under which the mobile phone was located. After the experimentation, when the mobile phone has been removed, the ants returned to their initial nest, transporting back their brood into the nest. This relocation lasted about one hour.

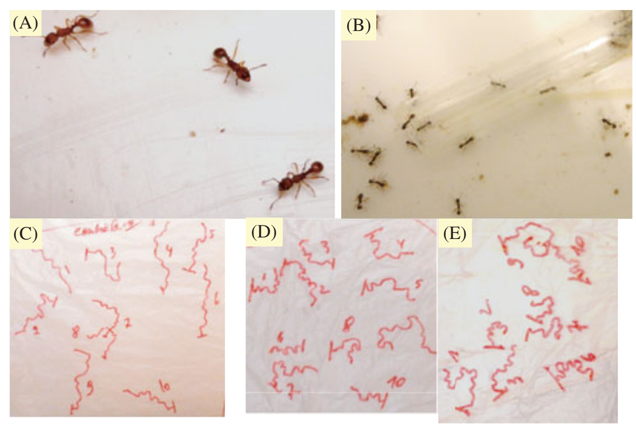

Figure 2. Ants' reactions. (A) Ants perceived the presence of a GSM under their tray and began to move with difficulty. (B) Ants went out of their nest, taking their larvae, as soon as a GSM was set under their nest tube. (C–) Recorded ants' trajectories: (C) under normal condition, (D) while a smartphone was lying under the ants' tray and (E) while a DECT phone was lying under the ants' tray.

Effect of WiFi equipment

When activated, the WiFi router we used generated, all around it, an electromagnetic field with an average intensity ranging about 600–800 μW/m². We located the WiFi router between two colonies of *M. sabuleti*, at 30 cm from each as shown in Figure 1(C). First, we made a control experiment, with the WiFi apparatus being switched off (Table 1B). Then, we switched on the WiFi router and made two tests under this condition, i.e. the ants were exposed during 30 min and quantification was made after 5 min as well as after 30 min (Table 1B).

After a few seconds of exposure, the ants clearly presented signs of bad health and, consequently, a disturbed behavior. This could be noticed by the ants' locomotion: their linear speed statistically decreased ($p < 0.001$) while their angular speed (=their sinuosity) largely and statistically increased ($p < 0.001$) (Table 1B). Based on our observations, the impact of the activated WiFi station on the ants was more severe after a time period of 30 min than after a time period of 5 min, and the ants' angular speed (sinuosity) was larger, though not statistically larger (266 ang. deg./cm vs 235 ang. deg./cm; Table 1B). After having been exposed during 30 min, the ants had to recover during six to eight hours before foraging as usual again. Unfortunately, several ants never recovered and were found dead a few days later.

Effect of a personal computer

Using the same radiation intensity meter, we observed that the personal computer (ACER Aspire 2920) generated, in front of it, at about 20–30 cm distance, a little beneath, i.e. approximately where the body of a human conventionally looking to the screen is located, an electromagnetic field the intensity of which largely varied. This intensity reached, every few seconds, peak values ranging from 600 to 800 μW/m². During the duration of the exposure (5 min), the electromagnetic field had an intensity of about 300–500 μW/m². We located two colonies of *M. ruginodis* just at that place, as shown in Figure 1(D), to detect the possible effect of a computer. Using such an experimental design, we made four experiments: first, we performed a control, e.g. the computer being present but not activated (switched off); then we made a test, the computer being switched on; later one, after the ants had recovered, we made a second control experiment, with the PC being present but switched off again; and finally we made a second test experiment, the computer being switched on but its WiFi function being inactivated (Table 1C).

The ants appeared to be disturbed as soon as the computer was switched on and began to suffer a few seconds later. They behaved like classical ill animals. Once more, this effect could be revealed by a statistically significant increase of the ants' angular speed (192 ang. deg./cm vs 125 ang. deg./cm; $p < 0.001$); however, no effect was seen on the linear speed (Table 1C).

Modern computers automatically function with their WiFi function activated. This function is required for using Internet, a wireless printer or scanner or a WiFi system. We deactivated that function on our computer and observed again the ants, located, as previously, in front of the PC, first with the PC not activated and second with the PC activated. In front of the not activated PC (control situation), the ants appeared to be in good condition. Their linear speed was high and their angular speed was low. In front of an activated PC, its WiFi function having been switched off (de-activated) as soon as the PC was switched on, the ants appeared not to be disturbed and not to suffer anymore. The values of linear speed and angular speed were statistically not different from the control ones (Table 1C). Radiofrequency intensity measurements confirmed this ethological observation: when the WiFi function of the computer was inactivated, the intensity of the electromagnetic field generated in front of the PC no longer reached high values and equaled 5–8 μW/m² which were the values of the ambient electromagnetic field.

Discussion

(1) The fact that electromagnetic waves generate an impact on living organisms has already been largely documented (several references are cited in the ''Introduction'' section, in the first alinea). A large amount of websites actually deal with this problem, 13 are given in the references section. These results confirm that wireless technology harmfully impacts living organisms and shows that ants react very quickly to the existence of electromagnetic waves in their environment.

A large number of ants can easily be maintained during years in laboratories. This makes these insects appropriate ''biological models'' for performing studies about the existence and the impact of electromagnetic fields, as well as for assessing the effectiveness of protective systems. Our ants appear to be excellent bio-indicators for immediately revealing the effects of electromagnetic fields.

(2) It appeared that ants' linear and angular speeds of movement are immediately altered by the presence of electromagnetic waves. Assessment of these two ants' locomotion characteristics constitutes a quick, easy and efficient means for revealing the existence of electromagnetic fields and for evaluating their effect on living organisms. Such an immediate assessment is made possible thanks to the use of updated software, which is available for everyone on the website of the journal ''Belgian Journal of Zoology'' (Cammaerts et al., 2012b).

(3) All radiating sources tested in this study on the ants demonstrated clear and statistically significant effects. It was already known that a mobile phone in standby mode affects living organisms (e.g. see Cammaerts et al., 2011; Favre, 2011; Panagopoulos et al., 2004; Sharma and Kumar, 2010). In this study, we showed that a common mobile phone has an effect while in standby mode and even in off-condition. Of course, when activated, the effect of a mobile phone is stronger. Without its battery, such a phone has no longer an effect. Our ants demonstrated that a modern smartphone and even more so a DECT phone do affect living organisms. Furthermore, the electromagnetic waves generated by a WiFi router impact our ants and such an effect increases during the course of the exposure time. Persons working in rooms provided with wireless equipment should note this result. A modern personal computer also generates electromagnetic waves. This is due to the PC

WiFi function, which is automatically activated. Based on these results, we advice users to deactivate the WiFi function of their PC as long as they do not use it. This can also be deduced from the study related in http://bigbrouser.blog.lemonde.fr/2011/12/01/micro-onde-le-wi-fi-tueur-de-spermatozoïdes/.

(4) The electromagnetic technology invades every human work task, equipment, hobby and also for very young persons. Efficient protections should be inserted inside the different wireless equipments present at home, at work, in public establishments and so on (e.g. WiFi, DECT phone, GPS, keys, baby phones, etc.). Another step could be to decrease the number and the power density of communication antennae and to invent ''built in'' protection for them. Such measures would be beneficial for all living organisms, including trees, plants, fruits, vegetables, insects (such as bees and bumblebees), birds, bats, and other types of animals, which are necessary for human survival.

(5) Finally, one very elegant feature of using ants as experimental animals is – as for other animal species, plants and bacteria – that they do not lend themselves to psychological explanatory models, such as mass media-driven psychoses (Witthöft and Rubin, 2013). If they react to artificial electromagnetic fields, it is not because they have listened to radio broadcasts, watched the TV news or read columns in tabloids. No, then they do react to the actual adverse environmental exposure.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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