Effects of mobile phone radiation on heart rate: a radiation-detector controlled pilot study

ABSTRACT

Objectives: To investigate to what degree radiofrequency electromagnetic radiation, induced by a mobile phone placed on the chest, impacts cardiac rhythm.
Design: n=1, single blinded pilot study
Setting: Academic hospital, Maastricht, the Netherlands
Participants: One healthy female 24 years old participant.
Interventions: The participant underwent four experimental sessions, spread over four days. A session consisted of four consecutive 15 minute conditions, three with a sham phone and one with a dialling mobile phone. The participant was blind for the condition. During each condition, per-millisecond electrocardiac activity (lead V4) and radiofrequency radiation was recorded jointly.
Primary outcome measures: Heart rate. The association with radiation was analysed at two levels, (i) at macrolevel, based on averaged condition effects, and (ii) at microlevel, focusing on radiation peak-related effects within the exposure condition.
Results: The macrolevel analysis clearly indicated that heart rate was lowered during the radiation exposure condition. The heart rate during the preceding and subsequent sham phone condition was respectively 1.014 beats/minute ($p < 0.001$) and 1.009 beats/minute ($p < 0.001$) higher compared to the radiation exposure condition. In order to conduct radiation-detector controlled microlevel analyses, 142 critical segments were identified, in which a radiation-free period was followed by a radiation peak. The heart rate during the radiation-free period showed a mean increase, whereas the radiation peak period was associated with a mean decrease in heart rate (time*period interaction: p=0.001). Thus, the macrolevel finding was confirmed at microlevel.
Conclusions: Mobile phone radiation may impact heart rate, suggesting urgent further study to assess physiological safety parameters.

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INTRODUCTION

The number of mobile phones and the amount of mobile phone usage has expanded massively in the last decennium. In 2011 there were 5.9 billion mobile phone subscriptions, whilst about 16.7 billion text messages were sent each day in 2010(InternationalCommunicationUnion, 2011). In addition to the basic phone function, many other functions have been developed, transforming mobile phones into multimedia devices. For young people, mobile phones have become an integrated part of everyday behavioural interactions. A less conspicuous statistic, showing a parallel increase, is the level of exposure to radiofrequency electromagnetic fields (RF-EMF), necessary for mobile phone connections, particularly in densely populated countries. The electromagnetic field is classified according to wavelengths. It contains the following varieties of radiation: ionizing radiation, ultraviolet, visible light, infrared, radiofrequency (10 kHz-300 GHz, mobile phones are within this range) and extremely low frequencies. For ionizing radiation, the photon energy is large enough to knock out electrons from atoms and molecules. It is acknowledged that ionizing radiation leads to cellular damage in biological tissue. Lower frequencies of the electromagnetic spectrum are called 'non-ionizing radiation'. There is debate to what degree non-ionizing radiation may also induce biological changes. It has been demonstrated that electromagnetic fields from 100 kHz and higher cause a thermal, heating effect(Adair & Black, 2003). Apart from thermal effects, mobile phone use may also induce non-thermal effects. Non-thermal effects refer to the possible direct and indirect effects of absorbed energy inside biological tissue. However, how these may be mediated at cellular level remains unclear(Gaestel, 2010).

For thermal effects, the rate at which energy is absorbed per unit of biological tissue is known as the 'specific absorption rate' (SAR), expressed in watts per kilogram (W/kg). The International Commission on Non-Ionizing Radiation Protection has recommended a SAR-limit of 0.08 W/kg average for the entire body and a SAR-limit of 2W/kg average for the head. For electromagnetic radiation up to 10 GHz, the localized SAR averaging mass is any 10 grams of contiguous tissue, averaged over a 6 minute period(ICNIRP, 1998). These values are maintained by several countries, but substantial differences exist between countries in public recommendations in relation to mobile phone use.

As opposed to RF-EMF producing devices such as televisions and microwaves, the radiation caused by a mobile phone may be more invasive, as direct body contact with a mobile phone is the norm and the radiation the device emits is practically inescapable. In recent years, intense use of mobile phones has raised concerns about possible adverse health effects. The number of studies on this topic is increasing rapidly, with a primary focus on pathological effects, such as hypothesized carcinogenesis and infertility. However, despite the large body of work, results remain largely inconclusive due to contradictory findings. A possible explanation is that mobile phone radiation may not produce harmful health effects in the short term. However, possible adverse health effects, particularly in the long-term, cannot be entirely discarded. In addition, the field is rife with possible conflicting interests(Huss, Egger, Hug, Huwiler-Müntener, & Röösli, 2006).

Within the broad spectrum of mobile phone radiation research, effects on electrophysiological functioning have also been examined. Although a large number of studies exist on the effects on electroencephalography, relatively few studies have been performed to investigate the possible cardiovascular effects of RF-EMF. Given that the heart is a vital organ, the functions of which are subserved by electrically excitable tissue, more research is required to unequivocally assess its susceptibility to RF-EMF, particularly given the fact that phones often are carried in proximity to the heart. The hypothesis that RF-EMF has systemic effects on the autonomic nervous system has been voiced frequently(Ahamed, Karthick, & Joseph, 2008; Andrzejak et al., 2008; Bortkiewicz, Zmyślony, Gadzicka, & Szymczak, 2006; Kwon, Choi, Kim, Yoo, & Kim, 2012; Parazzini et al., 2007), however the majority of studies investigating RF-EMF effects on heart rate (HR) showed non-significant results(Andrzejak, et al., 2008; Atlasz et al., 2006; Barutcu et al., 2011; Braune, Riedel, Schulte-Monting, & J., 2002; Huber et al., 2003; Kwon, et al., 2012; Nam et al., 2009; Oftedal, Straume, Johnsson, & Stovner, 2007; Parazzini, et al., 2007; Tahvanainen et al., 2004; Tamer, Gunduz, & Ozyildirim, 2009; Wilen, Johansson, Kalezic, Lyskov, & Sandstrom, 2006). Nevertheless, an animal study as well as experiments on human subjects show a strong tendency towards lowering of the HR under RF-EMF exposure(Augner, Gnambs, Winker, & Barth, 2012; Colak et al., 2012; Hietanen, Hamalainen, & Husman, 2002).

An important source of variability between studies concerns the use of different exposure methods. Whereas some studies use a continuously radiating module or a computer-controlled cellular phone(Atlasz, et al., 2006; Hietanen, et al., 2002; Kwon, et al., 2012; Nam, et al., 2009; Oftedal, et al., 2007; Parazzini, et al., 2007; Tahvanainen, et al., 2004; Wilen, et al., 2006), other studies use a regular mobile phone. Although a module may be preferred to exactly control the radiation exposure, it may not represent an accurate simulation of reality. To our knowledge, no studies have investigated a direct relationship between a radiation peak and the immediate subsequent change in cardiac function. In addition, effect analyses are regularly based on averaged radiation (condition) effects, whereas it may be argued that a more fundamental and important question is to what degree radiation peaks (caused by a mobile phone) impact on subsequent electrocardiac activity. A further issue is that consecutive heart rate values are strongly interdependent. In the analysis, this interdependency should be taken into account.

A pilot study was set up to test the hypothesis whether radiation, induced by a mobile phone, causes a decrease in heart rate. In addition to the standard 'macrolevel' analysis (based on averaged condition effects), analyses were also carried out at 'microlevel' (i.e. radiation peak-related effects), taking into account interdependency among observations. This study was also intended to trial a new procedure for a larger programme of research.

MATERIALS AND METHODS

Participant

The participant was a 24-year old healthy female, non-smoking, with a BMI of 21.7. The ECG was regular and there was no history of cardiac or nervous system disorders.

The participant had used a mobile phone in the previous 9 years and had been using a smart-phone over the last 10 months, with approximately 1 hour of mobile phone usage per day.

On experimental days, no caffeine-containing beverages were used 3 hours before the start of the session. No alcohol was used during the 12 previous hours. At least 8 hours of sleep were ensured and care was taken that the participant's private mobile phone was switched off the night before each experimental session.

Experimental procedures

The pilot study consisted of four sessions, each session taking place on a separate day. At each session, an ECG was administered using three electrodes: the first, lead V4, was placed in the fifth intercostal space at the mid-clavicular line, the second electrode was placed on the manubrium as a reference and the third ground-electrode was placed in the abdominal region on the right hand side. The electrodes were connected to a BrainAmp ExG amplifier (Brain Products). Both ECG- and radiation data were sampled with 1000Hz using Brain Vision Recorder software. As per the schedule shown in table 1, the participant was exposed to four consecutive conditions during each session: three with a sham phone, and one with a dialling mobile phone. In order to ensure blinding, the order of the conditions was variable and unknown to the participant, with two days during which the 'dialling' condition was second, and two days during which the 'dialling' condition was third. The experimenter changed the telephone every 15 minutes as per the schedule in table 1. At the end of each 15 minute condition, the experimenter entered the experimenting room to change the telephone according to the schedule in table 1. In the case of two consecutive sham phone conditions, the same procedure was followed.

The telephone characteristics were as follows:

- A 'smartphone' was used. During exposure conditions, the phone was dialled from a fixed line in another room. No sound was exchanged (mute settings), in order to ensure that the participant could not identify the dialling condition.
- The frequency band was a combination of GPRS (general packet radio service, including the Global System for Mobile communication GSM) and UMTS (Universal Mobile Telecommunications System) - the default setting the phone. These bands operate in the following frequencies: GSM: 800-900 MHz and 1.8-1.9 GHz and UMTS: 1.9-2.2 GHz.
- The SAR level was 0.353W/kg(www.sardatabase.com, 2011-2013).
- The sham phone was a non-functioning replica, of the same weight and the same characteristics as the smartphone.

As described in the introduction, a real mobile phone was used as inductor of RF-EMF. The timing of radiation-peaks was detected with a radiation detector (type: HF59B, Gigahertz Solutions), connected to an omnidirectional antenna. This detector was connected from the DC output with an auxiliary plug to the ExG-amplifier. The detector was placed in the upright position, 30 cm above the table (at which the participant was sitting) and 20 cm left from the participant. The phone was placed adjacent to the left side of the sternum, bordering the sternoclavicular joint at the caudal side, thus ensuring that there was no contact between the phone and the V4 lead. Previous testing experiments showed that there was no direct disturbing interference of the mobile phone impacting on either the V4 electrode or the amplifier (tested with a shielded and non-shielded electrode). The backside of the phone was placed on the skin. The phone was fixed using an elastic band. In order to maintain the participant's alertness and to guarantee a relatively stable mood, she read affectively neutral sections of a book during the experiment. All experimental sessions were carried out in the afternoon.

	15 minutes	**15 minutes**	**15 minutes**	**15 minutes**
Day 1 and 4	Pre-exposure	Exposure	Post-exposure	Not used
Day 2 and 3	Not used	Pre-exposure	Exposure	Post-exposure

Table 1 Experimental design. The sequence was randomly defined by the experimenter to ensure blinding of the participant. In conditions labelled as 'not used', an identical sham telephone was placed in the same way as in the pre- and post-exposure conditions.

ECG analysis

ECG data were analysed offline with the software program Brain Vision Analyser 2.0. Data were filtered using a high cut-off filter of 40 Hz and a low cut-off filter of 0.5 Hz. R-peaks were detected by the program and manually checked. The SPSS dataset was constructed in such a way that each record contained one heartbeat (amplitude measured in microvolts and time measured in milliseconds), including the following related variables: (i) heart rate, estimated as the difference in milliseconds with the previous heartbeat and (ii) radiation intensity, calculated as the sum of radiation values over the previous thousand milliseconds.

Statistical analysis

Analyses were split into macro- and microlevel analyses, in which 'macro' refers to averaged condition effects (comparing pre-exposure (PRE), exposure (EXP) and post-exposure (POST)), and 'micro' refers to radiation peak-related electrophysiological effects.

Macrolevel analysis

A linear regression was used to compare the averaged condition effects. The dependent variable was the $\log_{10}$-transformed heart rate (log-HR). This transformation was performed because of a positively skewed distribution. The categorical condition variable (PRE, EXP and POST) was recoded into two dummy variables which were used as predictor variables. As mentioned in the introduction, consecutive heart rate values are strongly interdependent. A time series analysis was performed to adjust for autocorrelation and to check whether the macrolevel effect of the linear regression would remain significant. Thus, a time series model, using an ARIMA structure with 10 lags of autocorrelation, with the two condition predictor variables, was carried out.

Microlevel analyses

Case-control radiation peak finding within EXP: For this analysis, radiation information was used. A mobile telephone does not produce and receive radiation continuously. In this analysis, radiation peaks within EXP were detected. In order to achieve this goal, a dichotomous radiation-peak-variable was computed. Within the exposure condition the radiation level of all records were recoded into a '0' or a '1'. A value of '0' represented a relatively low radiation level, a value of '1' a radiation peak. The cut-off point for '0' was a value lower than the mean radiation level (of all records) plus half a standard deviation. Higher radiation levels were recoded into a '1'. Identification of case-control elements was based on the finding of '0011' patterns, in which '00' stands for two consecutive 'non-radiated' records, immediately followed by two '11' peak-radiated records (see fig. 1). This pattern was found 142 times over the four exposure sessions.

For the statistical analysis, a within-subject ANOVA model for repeated measures was used. There were two within-subject factors, as depicted in fig. 1: (i) 'case-control', contrasting the '00' non-radiated records with the '11' peak-radiated records and (ii) 'time-effect': testing the time effect within the '00' and '11' (i.e. the effect from the first 0 to the second 0 and the first 1 to the second 1, respectively). The dependent variable was log-HR. The critical interaction to be tested was 'case-control*time-effect'.

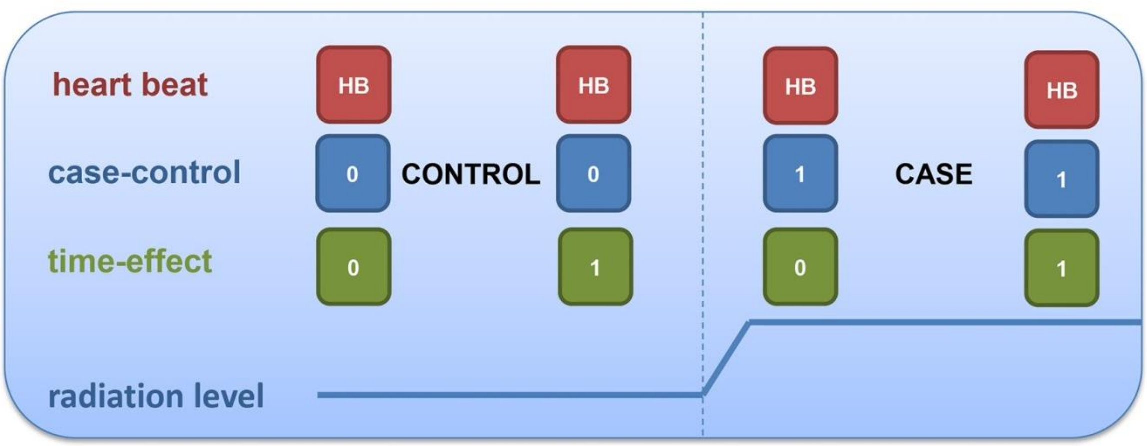

Figure 1. **'0011' pattern.** Horizontally, time passes by per heartbeat; the blue line represents an emerging radiation peak after a relatively low radiation level. The interaction of interest is the 'case-control*time-effect' (blue 00 11* green 01 01).

Control finding within PRE: In order to obtain control heartbeats for the '0011' patterns in EXP '0000', patterns were identified only in PRE (given that POST may be biased by EXP). The goal was to compare the ‘0011’ patterns from EXP with the radiation free ‘0000’ pattern, derived from PRE. A ‘0000’ pattern represents a radiation level lower than the median radiation value in four consecutive records in the PRE condition. In order to balance the amount of controls with the cases (defined as ‘0011’ found in EXP), a random sample of 142 ‘0000’ patterns were used for the analysis. A comparable within-subject ANOVA model was used, but with the inclusion of a between-subjects-factor (‘condition’), contrasting EXP with PRE. The critical interaction to be tested was the ‘case-control*time-effect*condition’.

RESULTS

Validity of radiation

During the four sessions, level of radiation in the experimenting room was collected with the aid of the radiation detector. Figure 2 shows an overview of the level of radiation during the four experimental sessions. Radiation activity was relatively high during the EXP conditions. Low levels of radiation peaks in PRE and POST are likely associated with unknown background radiation processes including the elevator near the experimenting room and/or other mobile telephone users in the building.

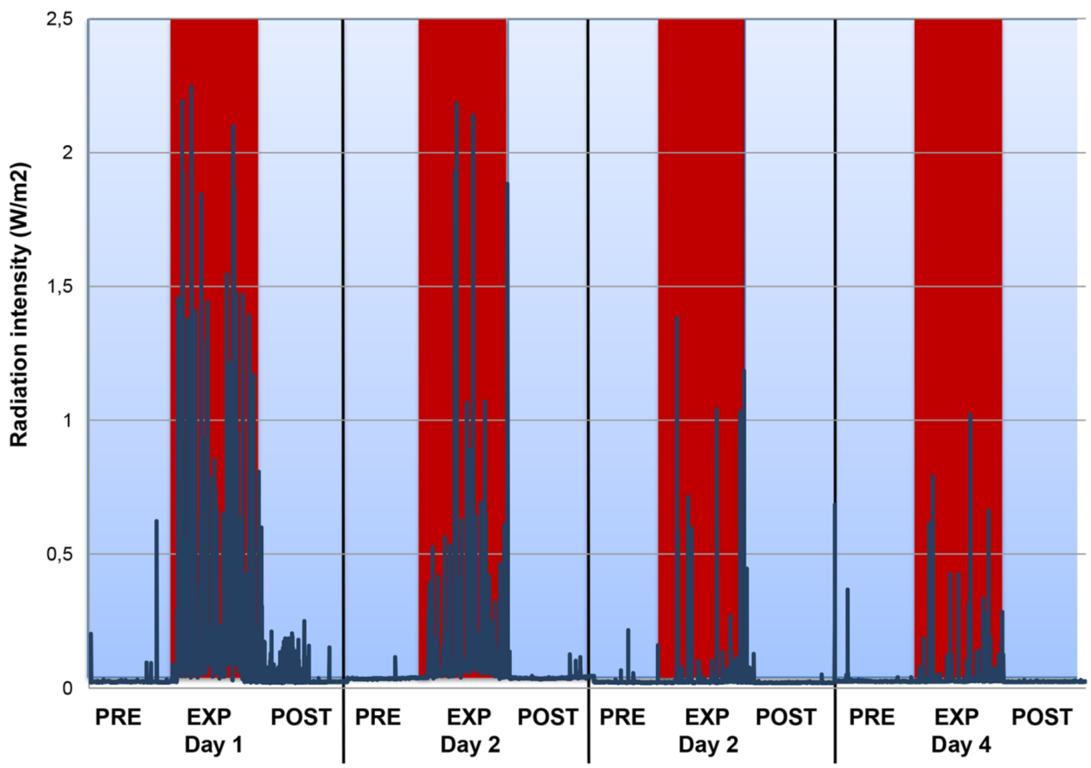

Figure 2. Overview of radiation levels over four days of testing.

Over the four sessions, the mean time distance between radiation peaks was 25.6 seconds (SD = 23.6 sec). The mean duration of a radiation peak was 2.5 seconds (SD = 3.1).

Macrolevel analysis

Compared to EXP, the mean HR in PRE was 1.014 beats per minute higher (95% CI 1.009-1.019). POST displayed an almost identical inversed effect: a higher mean HR of 1.009 beats per minute (95% CI 1.007-1.014), compared to EXP. The regression model with the two dummy variables was significant ($F = 27.5$, $p < 0.001$; R Square = 0.004). The dummy variable contrasting PRE vs. EXP had a t-value of 7.1 ($p < 0.001$) and the dummy variable contrasting POST vs. EXP had a t-value of 5.2 ($p < 0.001$). Figure 3 shows the mean estimated HR for each of the three conditions.

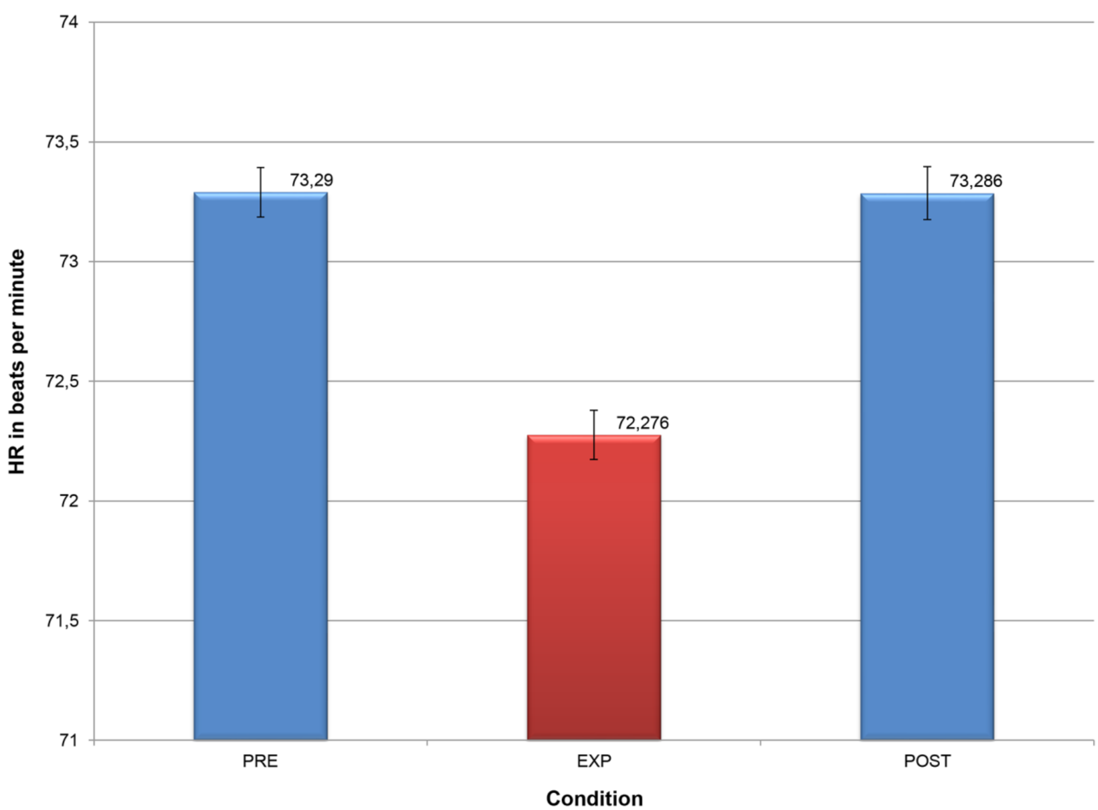

Figure 3. **Estimated heart rate values for the three conditions.**

A strong interdependency between heart beats was apparent; for example, the correlation with lag1 heart rate was > 0.9. Therefore, the regression assumption of independence of observations was not fulfilled. A time series model, using an ARIMA structure with 10 lags of autocorrelation and the two condition predictor variables was carried out. The results of this analysis indicated that the condition effects obtained by the linear regression analysis remained significant: the estimated HR in PRE was 1.0 beats per minute higher compared to EXP (t-value = 3.7; $p < 0.001$) and POST was 1.0 beats per minute higher than EXP (t-value = 4.7; $p < 0.001$).

The residuals of two models, as provided by the SPSS output, with and without the 10 lags of autocorrelation, are depicted in fig. 4. It is evident that the residuals deviate less from zero in the corrected model compared to the original model, thus demonstrating the surplus value of the autoregressive model.

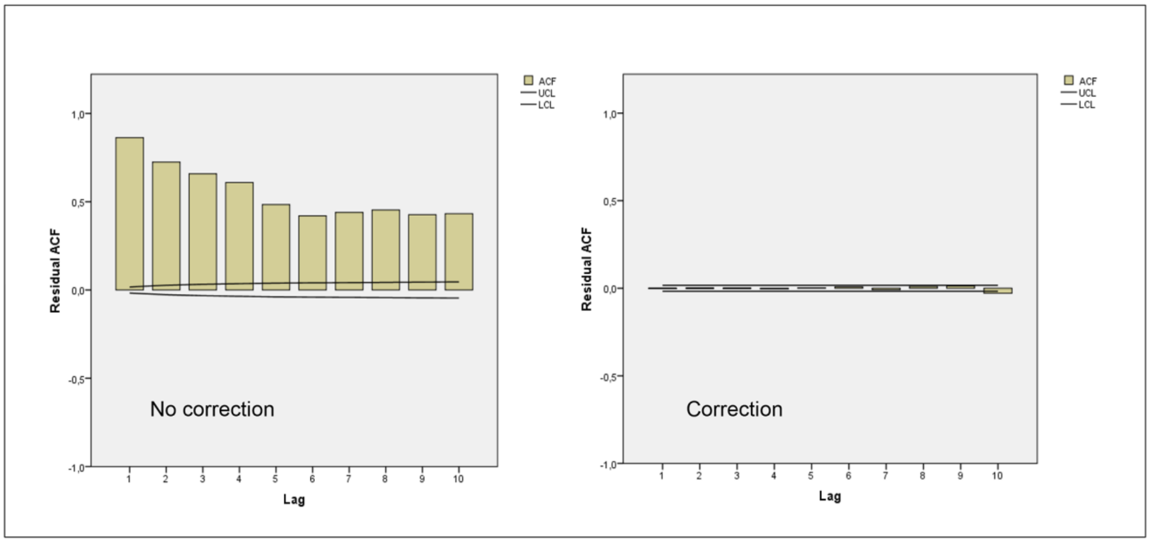

Figure 4. Residual plots without and with correction for autocorrelation. ACF: autocorrelation function, UCL: upper confidence limits, LCL: lower confidence limits for the values (95%).

Microlevel analyses

Case-control radiation peak finding within EXP: The mean values for the 0011 pattern are displayed in fig. 5, indicating that the no-radiation period ('00') showed an increase in heart rate, whereas the radiation period ('11') demonstrated a decrease. The hypothesized time-effect*case-control interaction (as explained earlier), differed significantly ($F_{(\text{Hotelling's Trace})} = 10.5$; $p = 0.001$), between case and control observations.

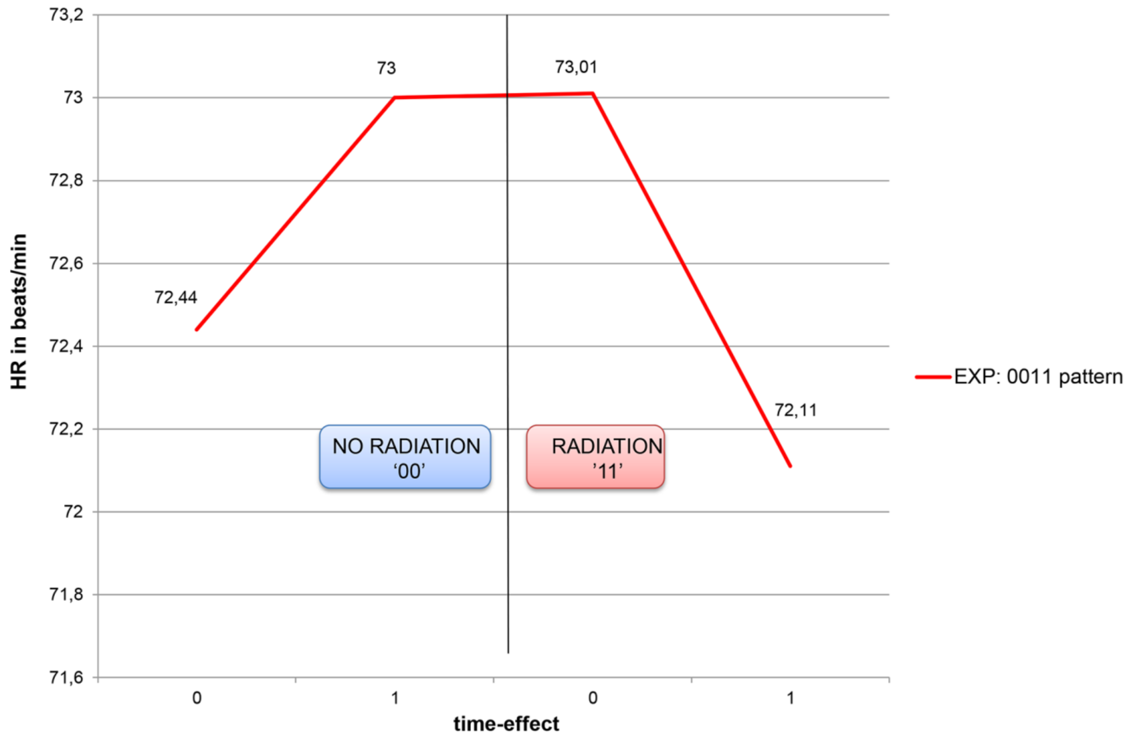

Figure 5. Microlevel analysis in EXP: mean heart rates in a 0011 pattern.

Control finding within PRE: Figure 6 displays the mean values for the 0011 pattern in EXP (red line), compared to the '0000' pattern in PRE (blue line). The time course of the four radiation-free moments in PRE was different from the '0011' pattern. The critical time-effect*case-control*condition interaction indicated significant differences between case and control observations ($F_{(\text{Hotelling's Trace})} = 8.5$; p = 0.004).

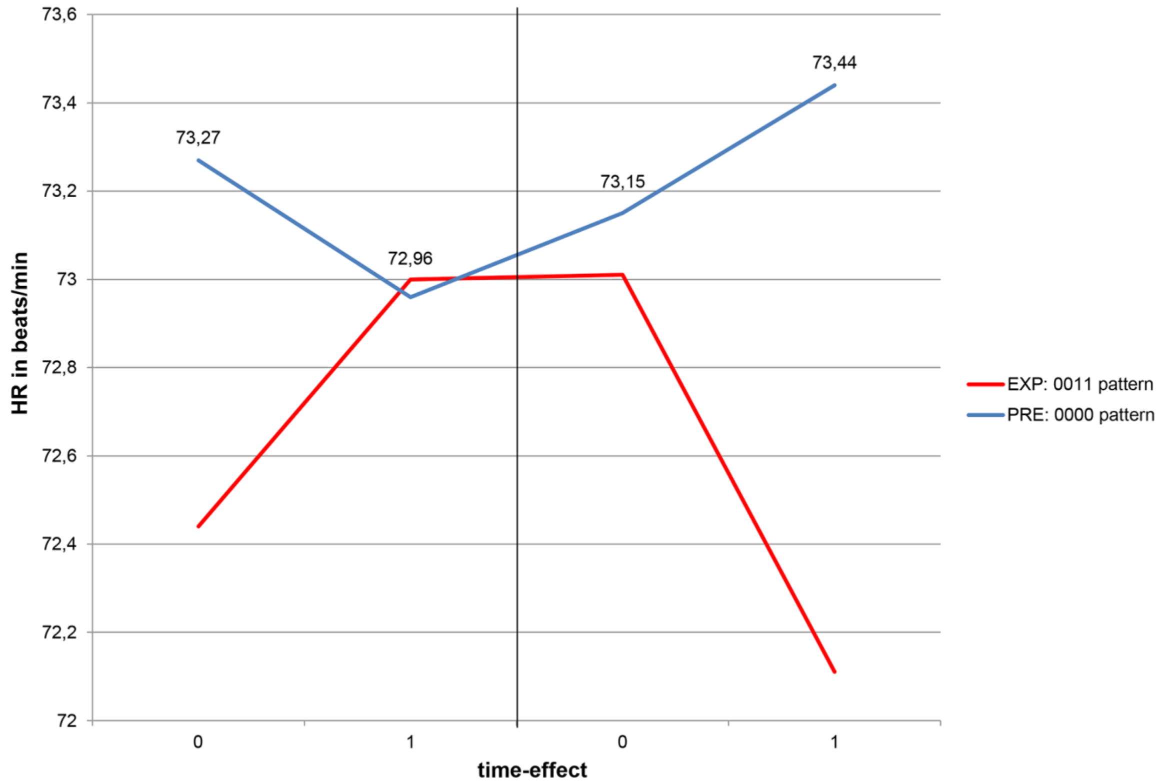

Figure 6. Microlevel analysis contrasting PRE and EXP. Mean heart rates in a 0011 vs. 0000 pattern.

DISCUSSION

In this pilot study a significant drop in heart rate, due to the placement of a dialling mobile phone on the chest, was found, thus confirming the hypothesis. Compared to the sham phone condition in the preceding 15 minutes, heart rate was lowered with approximately one beat per minute during the radiation condition. Heart rate returned to approximately the same level as before the radiation exposure in the subsequent sham phone condition. The results of the microlevel analyses were in line with the macrolevel finding that heart rate drops after the onset of a radiation peak. The macrolevel effect remained significant after correction for the autoregressive nature of the heart rate data.

A significantly lowered heart rate under RF-EMF exposure has also been reported in a study on rats(Colak, et al., 2012) and in a Finnish study on human subjects (using by a 900 MHz mobile phone)(Hietanen, et al., 2002). Although the authors of the latter study attributed the observed lowered heart rate to initial “mental strain and nervousness of the volunteers”, their observed decrease might in fact be due to mobile phone radiation. This alternative explanation would then be in accordance with the results of the present study. However, the effect of a decrease in heart rate in this n=1 study, due to mobile phone radiation, needs to be placed into perspective since the majority of studies(Andrzejak, et al., 2008; Atlasz, et al., 2006; Barutcu, et al., 2011; Braune, et al., 2002; Huber, et al., 2003; Kwon, et al., 2012; Nam, et al., 2009; Oftedal, et al., 2007; Parazzini, et al., 2007; Tahvanainen, et al., 2004; Tamer, et al., 2009; Wilen, et al., 2006) did not report large or significant effects. Nevertheless, in a recent meta-analysis on this topic, the direction of the effect, albeit statistically inconclusive, is towards lower heart rate in association with mobile phone radiation(Augner, et al., 2012).

In order to compare the results of the present study with those from others, it should be noted that the methodology of the present study differs in several aspects. First, in the current study, the mobile phone was placed on the chest instead of the ear. This placement in the proximity to the heart may have increased the effect size (and thus the significance level). Second, in contrast to all other studies, this study was based on the data of a single participant. Although each of the four experimental days contained one exposure and two sham conditions, there was no between-subject factor. Third, the RF-EMF exposure condition in this study was always directly preceded and followed by a sham condition, whereas in other studies the sham-condition was regularly performed on a separate day. Fourth, with respect to data analysis, the current study also focused on immediate radiation peak (microlevel) effects, which may represent a more sensitive way to detect radiation-related impact on heart rate.

A possible mechanism for the observed drop in heart rate has been proposed in the literature, suggesting that RF-EMF may activate the autonomic nerve system resulting in a slow diastolic depolarization(Ahamed, et al., 2008; Andrzejak, et al., 2008; Inc. & Cardiology, 1996; Kwon, et al., 2012; Parazzini, et al., 2007). The microlevel finding of an increase in heart rate directly preceded by radiation peaks (see fig. 5) could be explained as a 'compensatory' effect for the decrease in heart rate caused by earlier radiation peaks. Both the direct radiation peak effect as well as the compensating effect were absent (fig. 6 even suggests a trend in the opposite direction) in the PRE phase, thus providing more support for the notion of a genuine radiation peak effect in the EXP phase.

The observed heart rate effect needs to be interpreted in a clinical perspective. Although the effect is significant, the short reversible change of one beat per minute unlikely represents a large or clinically relevant change in healthy individuals in the short term. The goal of this pilot study was not to demonstrate risk, but to investigate whether there are electrocardiac changes at all. The results indicate that more research is required to examine long-term effects. It is also recommended to investigate the effects of mobile phone radiation in specific (vulnerable) subgroups, such as children(Feychting, 2011).

Limitations

Some critical limitations require consideration. First, the fact that the reported results are based on a n=1 sample restricts the generalisability of the findings. A replication study with a larger sample size is necessary. Significant findings may be due to a (relatively) high susceptibility to

RF-EMF of the participant(Bergqvist & Vogel, 1997; Hietanen, et al., 2002; Nam, et al., 2009; Oftedal, et al., 2007; Wilen, et al., 2006). Although the participant in the current study did not report RF-EMF sensitivity (headaches or other complaints) it cannot be ruled out that individual susceptibility played a role. Another critical issue is the fact that this study was single blinded. It is, however, unlikely that the non-blindness of the experimenter influenced the results. Third, as can be seen in fig. 2, radiation level decreased over the four days of testing. A post-hoc explanation may be that this effect was due to randomly different occupation of the telecom network over the four days. A final critical aspect pertains to the chosen setting of the frequency band GPRS/UMTS. This setting was chosen because it mimics real phone usage. As a consequence, however, the exact frequency in which radiation took place was unknown (although the exact timing of radiation was).

Future studies are required to further explore the interference of RF-EMF with human physiology. Within the field of electrophysiology, heart rate variability, EEG and respiratory rate would be interesting parameters to explore RF-EMF influence on the autonomic nervous system. Another aspect to elaborate further is the microlevel technique of analysis. In order to unravel microlevel peak-related radiation effects, a radiation detector is indispensable. Finally, because of its potentially global relevance, it is important to set up longitudinal studies to examine whether there are also long-term effects of RF-EMF.

REFERENCES

Adair, E. R., & Black, D. R. (2003). Thermoregulatory responses to RF energy absorption. [Review]. *Bioelectromagnetics, Suppl 6*, S17-38. doi: 10.1002/bem.10133

Ahamed, V. I., Karthick, N. G., & Joseph, P. K. (2008). Effect of mobile phone radiation on heart rate variability. *Computers in biology and medicine, 38*(6), 709-712. doi: 10.1016/j.compbiomed.2008.03.004

Andrzejak, R., Poreba, R., Poreba, M., Derkacz, A., Skalik, R., Gac, P., . . . Pilecki, W. (2008). The Influence of the Call with a Mobile Phone on Heart Rate Variability Parameters in Healthy Volunteers. [Field Report]. *Industrial Health, 46*, 409-417.

Atlasz, T., Kellenyi, L., Kovacs, P., Babai, N., Thuroczy, G., Hejjel, L., & Hernadi, I. (2006). The application of surface plethysmography for heart rate variability analysis after GSM radiofrequency exposure. [Research Support, Non-U.S. Gov't]. *Journal of biochemical and biophysical methods, 69*(1-2), 233-236. doi: 10.1016/j.jbbm.2006.03.017

Augner, C., Gnambs, T., Winker, R., & Barth, A. (2012). Acute effects of electromagnetic fields emitted by GSM mobile phones on subjective well-being and physiological reactions: a meta-analysis. [Meta-Analysis]. *The Science of the total environment, 424*, 11-15. doi: 10.1016/j.scitotenv.2012.02.034

Barutcu, I., Esen, A. M., Kaya, D., Turkmen, M., Karakaya, O., Saglam, M., . . . Kirma, C. (2011). Do mobile phones pose a potential risk to autonomic modulation of the heart? *Pacing and clinical electrophysiology : PACE, 34*(11), 1511-1514. doi: 10.1111/j.1540-8159.2011.03162.x

Bergqvist, U., & Vogel, E. (1997). Possible health implications of subjective symptoms and electromagnetic fields. A report prepared by a European group of experts for the European Commission DG V. (Vol. 19): Arbetslivsinstitutet, National Institute for Working Life.

Bortkiewicz, A., Zmyślony, M., Gadzicka, E., & Szymczak, W. (2006). Neurovegetative Disturbances in Workers Exposed to 50 Hz Electromagnetic Fields. *International Journal of Occupational Medicine and Environmental Health, 19*(1), 53-60. doi: 10.2478/v10001-006-0001-1

Braune, S., Riedel, A., Schulte-Monting, J., & J., R. (2002). Influence of a Radiofrequency Electromagnetic Field on Cardiovascular and Hormonal Parameters of the Autonomic Nervous System in Healthy Individuals. *Radiation Research, 158*(3), 352-356.

Colak, C., Parlakpinar, H., Ermis, N., Tagluk, M. E., Sarihan, E., Dilek, O. F., . . . Acet, A. (2012). Effects of electromagnetic radiation from 3G mobile phone on heart rate, blood pressure and ECG parameters in rats. [Research Support, Non-U.S. Gov't]. *Toxicology and industrial health, 28*(7), 629-638. doi: 10.1177/0748233711420468

Feychting, M. (2011). Mobile phones, radiofrequency fields, and health effects in children--epidemiological studies. [Review]. *Progress in biophysics and molecular biology, 107*(3), 343-348. doi: 10.1016/j.pbiomolbio.2011.09.016

Gaestel, M. (2010). Biological monitoring of non-thermal effects of mobile phone radiation: recent approaches and challenges. [Research Support, Non-U.S. Gov't

Review]. *Biological reviews of the Cambridge Philosophical Society, 85*(3), 489-500. doi: 10.1111/j.1469-185X.2009.00112.x

Hietanen, M., Hamalainen, A. M., & Husman, T. (2002). Hypersensitivity symptoms associated with exposure to cellular telephones: no causal link. [Research Support, Non-U.S. Gov't]. *Bioelectromagnetics, 23*(4), 264-270.

Huber, R., Schuderer, J., Graf, T., Jutz, K., Borbely, A. A., Kuster, N., & Achermann, P. (2003). Radio frequency electromagnetic field exposure in humans: Estimation of SAR distribution in the brain, effects on sleep and heart rate. [Clinical Trial Comparative Study Controlled Clinical Trial Research Support, Non-U.S. Gov't Validation Studies]. *Bioelectromagnetics, 24*(4), 262-276. doi: 10.1002/bem.10103

Huss, A., Egger, M., Hug, K., Huwiler-Müntener, K., & Röösli, M. (2006). Source of Funding and Results of Studies of Health Effects of Mobile Phone Use: Systematic Review of Experimental Studies. *Environmental Health Perspectives, 115*(1), 1-4. doi: 10.1289/ehp.9149

ICNIRP. (1998). Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). *Health Physics, 74*(4), 494-522.

Inc., A., & Cardiology, E. S. o. (1996). Heart rate variability Standards of measurement, physiological interpretation, and clinical use. *European Heart Journal, 17*, 354-381.

InternationalCommunicationUnion. (2011). ICT facts and figures

Kwon, M. K., Choi, J. Y., Kim, S. K., Yoo, T. K., & Kim, D. W. (2012). Effects of radiation emitted by WCDMA mobile phones on electromagnetic hypersensitive subjects. *Environmental Health, 69*(11), 1-8.

Nam, K. C., Lee, J. H., Noh, H. W., Cha, E. J., Kim, N. H., & Kim, D. W. (2009). Hypersensitivity to RF fields emitted from CDMA cellular phones: a provocation study. [Research Support, Non-U.S. Gov't]. *Bioelectromagnetics, 30*(8), 641-650. doi: 10.1002/bem.20518

Oftedal, G., Straume, A., Johnsson, A., & Stovner, L. J. (2007). Mobile phone headache: a double blind, sham-controlled provocation study. [Randomized Controlled Trial

Research Support, Non-U.S. Gov't]. *Cephalalgia : an international journal of headache, 27*(5), 447-455. doi: 10.1111/j.1468-2982.2007.01336.x

Parazzini, M., Ravazzani, P., Tognola, G., Thuroczy, G., Molnar, F. B., Sacchettini, A., . . . Mainardi, L. T. (2007). Electromagnetic fields produced by GSM cellular phones and heart rate variability. *Bioelectromagnetics, 28*(2), 122-129. doi: 10.1002/bem.20275

Tahvanainen, K., Nino, J., Halonen, P., Kuusela, T., Laitinen, T., Lansimies, E., . . . Lindholm, H. (2004). Cellular phone use does not acutely affect blood pressure or heart rate of humans. [Clinical Trial Comparative Study Randomized Controlled Trial Research Support, Non-U.S. Gov't]. *Bioelectromagnetics, 25*(2), 73-83. doi: 10.1002/bem.10165

Tamer, A., Gunduz, H., & Ozyildirim, S. (2009). The cardiac effects of a mobile phone positioned closest to the heart. *Anadolu Kardiyol Derg, 9*, 380-384.

Wilen, J., Johansson, A., Kalezic, N., Lyskov, E., & Sandstrom, M. (2006). Psychophysiological tests and provocation of subjects with mobile phone related symptoms. [Randomized Controlled Trial

Research Support, Non-U.S. Gov't]. *Bioelectromagnetics, 27*(3), 204-214. doi: 10.1002/bem.20195

. www.sardatabase.com. (2011-2013)