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The Effect of GSM and TETRA Mobile Handset Signals on Blood Pressure, Catechol Levels and Heart Rate Variability

**Anthony T. Barker,[1]* Peter R. Jackson,[2] Helen Parry,[1]
Leslie A. Coulton,[3] Greg G. Cook,[4] and Steven M. Wood[1]**

[1]Department of Medical Physics and Clinical Engineering, Sheffield Teaching Hospitals NHS Foundation Trust, Royal Hallamshire Hospital, Sheffield, United Kingdom
[2]Academic Unit of Clinical Pharmacology, University of Sheffield, Sheffield, United Kingdom
[3]Academic Unit of Bone Biology, University of Sheffield, Sheffield, United Kingdom
[4]Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, United Kingdom

An acute rise in blood pressure has been reported in normal volunteers during exposure to signals from a mobile phone handset. To investigate this finding further we carried out a double blind study in 120 healthy volunteers (43 men, 77 women) in whom we measured mean arterial pressure (MAP) during each of six exposure sessions. At each session subjects were exposed to one of six different radio frequency signals simulating both GSM and TETRA handsets in different transmission modes. Blood catechols before and after exposure, heart rate variability during exposure, and post exposure 24 h ambulatory blood pressure were also studied. Despite having the power to detect changes in MAP of less than 1 mmHg none of our measurements showed any effect which we could attribute to radio frequency exposure. We found a single statistically significant decrease of 0.7 mmHg (95% CI 0.3–1.2 mmHg, $P = .04$) with exposure to GSM handsets in sham mode. This may be due to a slight increase in operating temperature of the handsets when in this mode. Hence our results have not confirmed the original findings of an acute rise in blood pressure due to exposure to mobile phone handset signals. In light of this negative finding from a large study, coupled with two smaller GSM studies which have also proved negative, we are of the view that further studies of acute changes in blood pressure due to GSM and TETRA handsets are not required. Bioelectromagnetics 28:433–438, 2007.

Key words: mobile phone; electromagnetic radiation; cardiovascular; double blind; health effects

INTRODUCTION

Effects of signals from a mobile phone handset on the blood pressure of normal volunteers were first reported by Braune et al. [1998] and showed increases of 5–10 mmHg. In 1999 the UK government set up the 'Independent Expert Group on Mobile Phones' (IEGMP) following concerns about a variety of possible health effects from mobile phones and the base stations with which they communicate. Its report [IEGMP, 2000] contained recommendations for future research including the need for a larger, better controlled study to investigate further the findings of Braune et al. [1998]. Subsequently, two small studies have not been able to confirm the original findings [Braune et al., 2002; Tahvanainen et al., 2004]. The UK Mobile Telecommunications and Health Research (MTHR) Programme [MTHR, 2002] was set up in response to the IEGMP report and funded the study reported here as part of an initial programme of 20 projects.

The primary aim of this study was to investigate whether the radio frequency signals from GSM handsets cause acute changes in the blood pressure of normal volunteers. Exposure to Terrestrial Trunked

The authors declare that they have no conflict of interest in undertaking this Study.

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*Correspondence to: Anthony T. Barker, Department of Medical Physics and Clinical Engineering, Sheffield Teaching Hospitals NHS Trust, Royal Hallamshire Hospital, Sheffield S10 2JF, United Kingdom. E-mail: a.t.barker@sheffield.ac.uk

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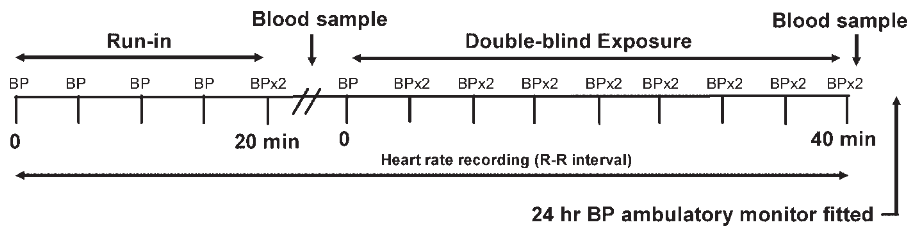

Fig. 1. Timing of procedures within each visit.

Radio (TETRA) handsets was also included in the study design because of health concerns about this form of radio frequency signal, particularly from users in the police service [TetraHealth; TetraWatch].

Secondary aims were to study heart rate variability and blood catechol concentrations as markers of sympathetic nervous system activity, and to measure ambulatory blood pressure for 24 h after exposure to determine the duration of any pressure changes observed.

METHODS

Participants

We recruited 125 normal volunteers between January 2002 and May 2005. Inclusion criteria were: age 18–65 and being able to complete the seven visits required. Exclusion criteria were kept to a minimum to ensure as representative a population sample as possible but included: known hypertension (baseline systolic pressure >200 mmHg or diastolic >120 mmHg), use of anti-hypertensive medications, pregnancy, atrial fibrillation or the need to wear spectacles whilst watching television. The cut-off blood pressures of 200/120 mmHg were to ensure that subjects with severe hypertension were not included in the study. In the event less than 1% of systolic pressure readings exceeded 140 mmHg and no diastolic readings exceeded 100 mmHg during the exposures. Spectacle wearers were excluded because of the potential effect of metal in the frame of glasses on the distribution of radio frequency fields around the handset [Anderson and Joyner, 1995]. The study was approved by the South Sheffield Research Ethics committee and all subjects gave informed written consent.

Procedures

Participants were recruited by advertisement within the Royal Hallamshire Hospital and the University of Sheffield, and by word of mouth. At an initial screening visit full information was provided and informed consent requested. Blood pressure was measured in standard fashion using the Omron 705 CP semi-automated device, following American Society of Hypertension guidelines. After the screening visit participants attended on 6 further occasions each separated by at least 7 days. These later visits all had an identical structure, with standardised blood pressure measurements. Subjects remained seated throughout and refrained from eating, drinking or smoking for 1 h prior to and during the visit. Following the fitting of the MTHR handset (see Interventions for details) in a standard position against the left side of the head, a 20 min run-in period allowed parameters to stabilise. The handset was then switched on for a 40 min exposure period. Throughout the run-in and exposure periods all subjects watched the same series of natural history programmes on a television screen approximately 3 m from them. Figure 1 shows the timing of the blood pressure and other measurements made during each visit. A total of 23 blood pressure measurements were made at each visit.

Venous blood was sampled from the dominant arm using individual punctures, both at the end of run-in and at the end of the 40 min exposure period. EGTA/glutathione preservative was added, the mixture immediately spun, and the separated plasma frozen at −80 °C for subsequent analysis for catechols. Heart rate data were recorded in the form of R-R intervals using a Polar S810 system, which telemetered the data via an infra-red link to disk throughout the visit. Immediately following the final blood pressure reading of the exposure phase the Omron 711 cuff was replaced on the same arm by the cuff for a Spacelabs 90217 ambulatory blood pressure monitor which was programmed to take readings at 20 min intervals from 07.00 until 23.00 and at 30 min intervals from 23.00 until 07.00. Participants returned their monitors the following day and the data was downloaded for analysis.

On study days, and whilst the ambulatory monitor was in place, participants were asked to avoid lengthy mobile telephone conversations. At each visit, they were also asked to estimate a number of parameters relating to their mobile phone usage that day, the preceding day and since their previous visit. At the end of each exposure session subjects were asked whether or not they thought their handset was transmitting, and why.

Interventions

The interventions (radio frequency exposures and sham exposures) were delivered by the MTHR standard exposure system. This system was developed specifically for the MTHR volunteer studies and, briefly, consists of mobile phone-type handsets which are capable of transmitting a wide variety of radio frequency signals based on the setting of two coded switches on the handset. For technical reasons different handsets were used to generate the TETRA and GSM signals. The handsets were calibrated to give a peak SAR (specific absorption rate) of 70% of the ICNIRP general public exposure limits of 2 W/kg averaged over 10 g to head and trunk when placed in a standard position against the head (ICNIRP and EC Directive 2004/40 both specify occupational exposure limits five times higher than this at 10 W/kg). Further technical information on the handsets can be found elsewhere [MTHR, 2005].

There were six interventions, each delivered at a separate visit. Three different outputs of a standard MTHR GSM handset, namely GSM Modulated (GSM Mod), GSM Carrier Wave (GSM CW), GSM Sham (GSM Sham—defined as GSM CW delivered to an internal load rather than the antenna) and the equivalent modes for a TETRA handset were used. The order of the interventions was determined by a balanced Latin square design and subjects were randomly allocated to a sequence within the squares. All interventions were administered double blind.

Electromagnetic Interference With Monitors

Both the Omron monitor and Polar chest band were tested for susceptibility to interference from the handsets prior to the commencement of the study. For both devices interference (usually in the form of an artefactual increase in the displayed heart rate) was caused at a greater range when the handsets were transmitting in modulated rather than CW or sham mode. No effects were observed in any mode when the handset antennae were more than 8 and 5 cm respectively from the devices. During the study the actual separation was 2 m and 30 cm, respectively. However, as an additional safeguard, the Omron was placed within an aluminium sheet Faraday screen in which windows were cut for the display and controls. The Polar chest band electronics were screened by wrapping in lead foil which was insulated from the body with pvc tape. These measures decreased the maximum distance at which interference could be detected to 5 and 1 cm, respectively. No problems with interference were noted at any stage throughout the study.

TABLE 1. Demographics of Study Population

Age (years)	Male	Female
18–28	30	46
29–38	10	14
39–48	2	7
>49	1	10

Statistical Analyses

The study was planned to enable detection of differences in mean arterial pressure (MAP) $\geq$2 mmHg with 90% power but, due to the number of dropouts and variance in blood pressure being smaller than expected, the study was able to detect differences $<$1 mmHg with similar power. Statistical analyses were performed using SPSS for Windows 10. The model employed for all endpoints was ANCOVA with baseline values as covariates, subjects as random-effect factors and exposure as a fixed-effect factor. The reported estimated marginal means are the average of values in that category when adjusted for all other parameters in the statistical model. Between exposure comparisons were only performed when $P < .05$ for an overall exposure effect.

RESULTS

Full data sets were obtained from 120 healthy volunteers, five subjects dropped out due to practical difficulties in taking blood samples or time commitments. None of the data from these subjects has been used in the final analysis. Table 1 shows the age and sex distribution of the volunteers.

For both the Omron and Spacelabs monitors MAP was calculated from the recorded systolic and diastolic measurements using the standard definition of MAP = diastolic + (systolic−diastolic)/3.

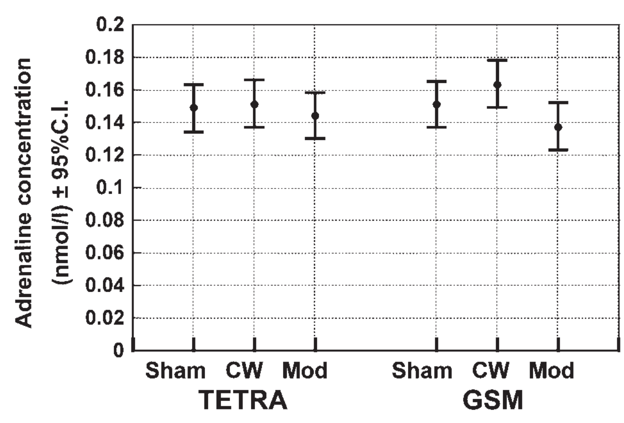

Fig. 2. Estimated post-exposure marginal means for adrenaline.

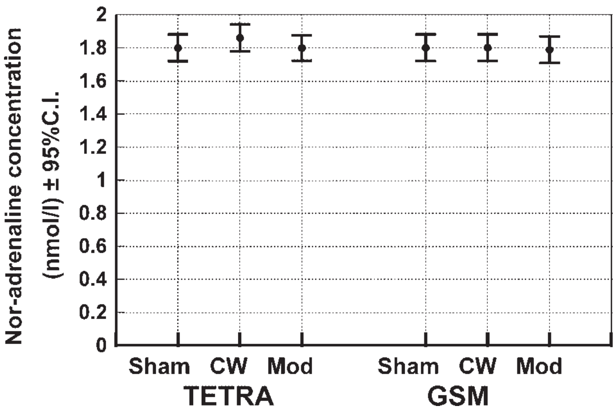

Fig. 3. Estimated post-exposure marginal means for nor-adrenaline.

Blood Catechols

Catechol concentrations were analysed using ANCOVA, with run in sample values as the covariate. Figures 2 and 3 show the estimated marginal mean concentrations of adrenaline and nor-adrenaline versus exposure. There were no significant differences between the groups ($P = .22$ for adrenaline and $P = .84$ for nor-adrenaline).

Heart Rate Variability

Heart rate variability (HRV) was calculated using purpose developed software written in Matlab and based on the Lomb algorithm [Laguna et al., 1998]. Correct functioning of the software was confirmed by analysing synthesised data for which the solution was known. The normalised power spectral density (nPSD) was integrated over the standard low frequency (0.04–0.15 Hz) and high frequency (0.15–0.4 Hz) bands and the ratio of these integrals calculated [European Society of Cardiology, 1996]. ANCOVA was used to analyse the first 20 min of the exposure period, the second 20 min and the total 40 min of the exposure period, using the corresponding 20 min run-in period data as the covariate. Figures 4–6 show, as examples, the estimated marginal means calculated over the full 40 min of exposure. None of the nine measures showed any statistical association with exposure type ($P = .22–.64$).

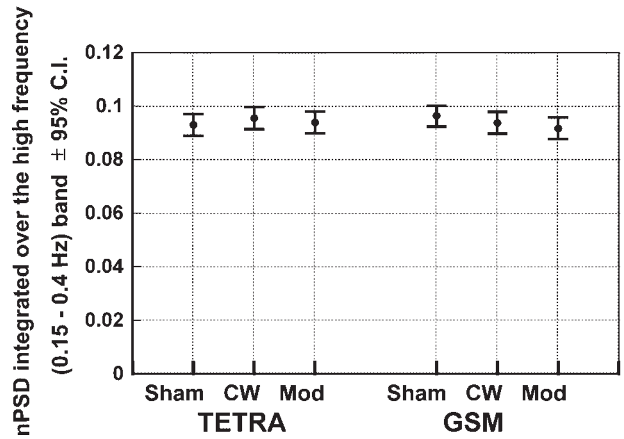

Fig. 5. Estimated marginal means for the 40 min exposure period of the heart rate variability normalised power spectral density (nPSD) integrated over the high frequency band.

Mean Arterial Pressure Over the Exposure Period (the Primary Metric of the Study)

Average MAP over the 40 min exposure period differed between the treatment groups ($P = .04$) as shown by repeated measures ANCOVA using the average MAP over the run-in period as the covariate. One of the six interventions, GSM Sham, appears different from the others. This has a mean value of MAP 0.7 mmHg lower (95% confidence limits

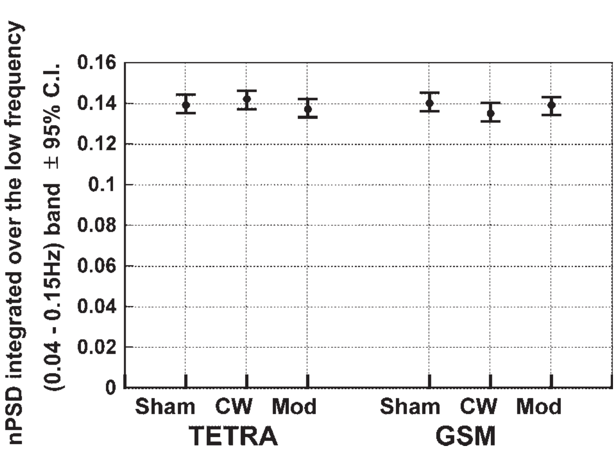

Fig. 4. Estimated marginal means for the 40 min exposure period of the heart rate variability normalised power spectral density (nPSD) integrated over the low frequency band.

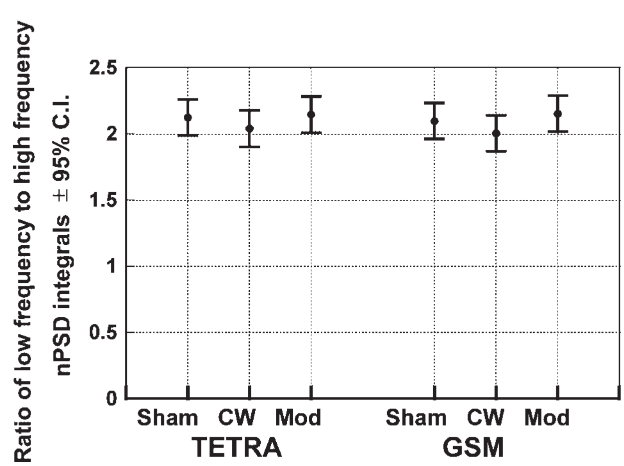

Fig. 6. Estimated marginal means for the 40 min exposure period of the ratio of band integrated low frequency to high frequency heart rate variability normalised power spectral density (nPSD).

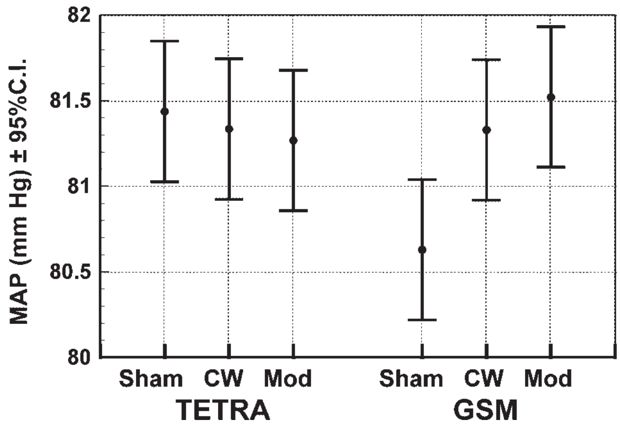

Fig. 7. Estimated marginal means of MAP over the 40 min exposure period.

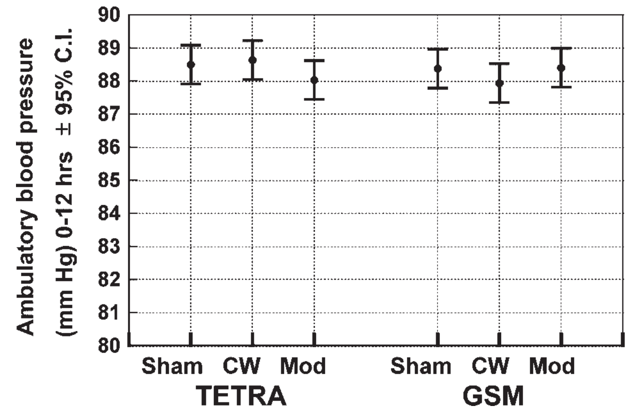

Fig. 9. Estimated marginal means of MAP over the first 12 h of post-exposure ambulatory recording.

0.3–1.2 mmHg) than that of the other five exposures, which are all tightly grouped within a range ± 0.13 mmHg. Figure 7 shows the estimated marginal means of MAP over the 40 min exposure period versus intervention group. Figure 8 shows the estimated marginal means of MAP at 5 min intervals throughout the exposure period (error bars not shown to aid clarity).

Twenty-Four Hours Ambulatory Blood Pressure Recordings

To allow for missing and delayed readings, the data for each subject has been linearly interpolated to 10 min epochs from the commencement of the recordings. This has then been analysed using repeated measures ANCOVA in three blocks, the first 12 h of the recording, the second 12 h and the full 24 h, using run-in MAP as the covariate. No statistical association with exposure type was seen ($P = .12–.53$). The estimated marginal means of MAP over the first 12 h (Fig. 9) and at ten min intervals during the first 2 h (Fig. 10) are shown as examples. Error bars have not been included in these figures to aid clarity.

DISCUSSION

Despite having the power to detect changes of MAP of less than 1 mmHg, this study has demonstrated no effect of GSM and TETRA signals on blood pressure and related physiological parameters. Our analysis has identified a single statistically significant finding, which suggests that GSM handsets in Sham mode decrease MAP by ∼0.7 mmHg. It seems unlikely that this represents an effect of the radio frequency signals since the hypothesis that the other 5 MAPs were, in fact, actively raised by their exposures is not consistent with one of them being a TETRA handset in Sham mode (Fig. 7). At present we have no well-founded explanation for this finding, but are of the view that it is likely to represent a real effect rather than a chance occurrence. This is supported by the GSM Sham data

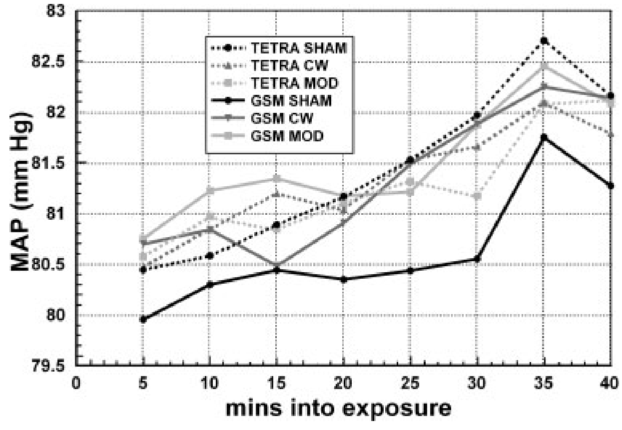

Fig. 8. Estimated marginal means of MAP at 5 min intervals during the course of the exposure.

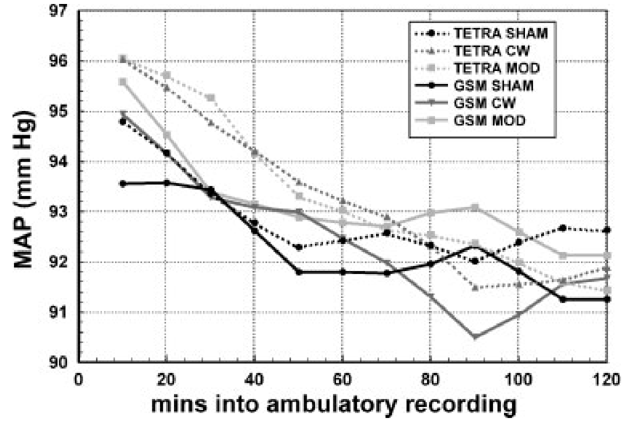

Fig. 10. Estimated marginal means of MAP at 10 min intervals during the first 2 h of post-exposure ambulatory recording.

being below that of all the other interventions throughout the exposure period (Fig. 8) and for the first 20 min of the ambulatory MAP data (Fig. 10) (though not statistically significantly so). MAP rose during exposure (Fig. 8) as has previously been observed with prolonged sitting, and fell in the hours after leaving the research centre (Fig. 10) but there were no trends for differences between exposed and sham to vary with time.

We have carried out comprehensive checks on our data to look for methodological errors, including the randomisation procedure, the mapping of exposure type onto our blinding code, and ambient temperature measurements made during the course of the exposure sessions, but these have revealed no anomalies. Based on the replies to our standard question set, subjects were not able in general to distinguish between the different exposure modes. Our data provides no evidence that the GSM Sham mode could be consistently identified, either correctly or incorrectly.

In an attempt to throw light on this unexpected (but small) finding of an apparent effect of GSM Sham exposure on MAP we have made measurements of the average power consumption of our handsets as a surrogate for temperature. These show that the handsets, when in GSM Sham mode, dissipate internally about 0.6 W more power (out of a total of $\sim$3 W) than in any of the other modes.

This would suggest that they are slightly warmer in operation, but it is unknown whether this putative small increase in handset temperature would have a systemic effect on MAP. We have not made an attempt to quantify this temperature rise, but crudely estimate it to be about 1 °C based on our previous measurements of skin temperature rise due to handsets applied to the side of the face in the standard exposure position.

The findings presented here have been unable to demonstrate an effect of GSM and TETRA signals on blood pressure and related cardiovascular parameters in a large double-blind study. When coupled with the results of other, smaller, studies of GSM signals [Braune et al., 2002; Tahvanainen et al., 2004] this leads us to suggest that further investigation of acute effects of GSM and TETRA radio frequency signals from mobile handsets on blood pressure in normal subjects, at levels to which the general public are exposed, is not required.

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REFERENCES

Anderson V, Joyner KH. 1995. Specific absorption rate levels measured in a phantom head exposed to radio frequency transmissions from analog hand-held mobile phones. Bioelectromagnetics 16(1):60–69.

Braune S, Riedel A, Schulte-Monting J, Raczek J. 2002. Influence of a radiofrequency electromagnetic field on cardiovascular and hormonal parameters of the autonomic nervous system in healthy individuals. Radiat Res 158(3):352–356.

Braune S, Wrocklage C, Raczek J, Gailus T, Lucking CH. 1998. Resting blood pressure increase during exposure to a radiofrequency electromagnetic field. Lancet 351(9119):1857–1858.

European Society of Cardiology. 1996. Heart rate variability: Standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation 93(5):1043–1065.

IEGMP. 2000. Report of the Independent Expert Group on Mobile Phones. Health Protection Agency, Radiation Protection Division, Didcot, Oxon OX11 0RQ, U.K http://www.iegmp.org.uk/report/text.htm.

Laguna P, Moody GB, Mark RG. 1998. Power spectral density of unevenly sampled data by least-square analysis: Performance and application to heart rate signals. IEEE Trans Biomed Eng 45(6):698–715.

MTHR. 2002. Mobile Telecommunications and Health Research Programme http://www.mthr.org.uk/research_projects/research.htm.

MTHR. 2005. Standard exposure system http://www.mcluk.org/MTHR_exposure_systems/.

Tahvanainen K, Nino J, Halonen P, Kuusela T, Laitinen T, Lansimies E, Hartikainen J, Hietanen M, Lindholm H. 2004. Cellular phone use does not acutely affect blood pressure or heart rate of humans. Bioelectromagnetics 25(2):73–83.

TetraHealth. TETRA Health Effects, Home Office http://police.homeoffice.gov.uk/operational-policing/technology-equipment/tetra-terrestrial-radio/tetra3.html.

TetraWatch. TETRA WATCH http://www.tetrawatch.net/main/index.php.