ehp Environmental Health PERSPECTIVES
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**doi:10.1289/ehp.8934 (available at http://dx.doi.org/)**
**Online 6 June 2006**

The National Institute of Environmental Health Sciences
National Institutes of Health
U.S. Department of Health and Human Services

# UMTS Base Station-Like Exposure, Well Being and Cognitive Performance

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**Acknowledgments**

The study was supported by the Swiss Research Foundation on Mobile Communication grant A2004-0. All authors declare no conflict of interest. We thank Nora Burgermeister and Eveline Honegger for her help with the experiment, Denis Spät for support with exposure equipment, Dr. Brad Anholt for help with power analysis, Dr. Roland Dürr, Peter Sepan and Karl Wüthrich for technical support, and Dr. Alexander Borbély for comments on the manuscript. We acknowledge the support of Dr. Gregor Dürrenberger in fund rising and the scientific expert panel (Drs. Peter Zwamborn, Heinz-Gregor Wieser, Christian Schindler and Alexander Grob) in the design of the study.

**Article descriptor:** Risk assessment or Population health

**Running title:** UMTS exposure, well being and cognitive performance

**Keywords:** base station, cognitive function, electromagnetic hypersensitivity, human exposure, mobile phones, RF EMF

**Abbreviations**

BMI: Body mass index

BQW: Bern questionnaire on well being

CRT: Two-choice reaction time task

E-field: Electric field

EHS: Electromagnetic hypersensitivity

FDTD: Finite-difference time-domain

GSM: Global System for Mobile Communication; second generation of mobile networks

N-back: N-back task

QCD: Short questionnaire on current disposition

QOF: Self designed questionnaire on other well-being related factors

RF EMF: Radio frequency electromagnetic fields (3 kHz to 300 GHz)

SAR: Specific absorption rate

SRT: Simple reaction time task

TNO: Netherlands Organization for Applied Scientific Research

TNO-Q: TNO questionnaire; modified Bulpitt & Fletcher questionnaire on "quality of life"

UMTS: Universal Mobile Telecommunication System; third generation of mobile networks

VSAT: Visual selective attention task

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## Abstract

### Background

Radio-frequency electromagnetic fields (RF EMF) of mobile communication systems are widespread in the living environment, yet their effects on humans are uncertain despite a growing body of literature.

### Objectives

We investigated the influence of a Universal Mobile Telecommunication System (UMTS) base station-like signal on well being and cognitive performance in subjects with and without self-reported sensitivity to RF EMF.

### Methods

We performed a controlled exposure experiment (45 min at an electric field strength of 0, 1 or 10 V/m, incident with a polarization of 45º from the left back side of the subject, weekly intervals) in a randomized, double-blind crossover design. 117 healthy subjects (33 self-reported sensitive, 84 non-sensitive subjects) participated in the study. We assessed well being, perceived field strength and cognitive performance with questionnaires and cognitive tasks and conducted statistical analyses using linear mixed models. Organ and brain tissue specific dosimetry including uncertainty and variation analysis was performed.

### Results

In both groups, well being and perceived field strength were not associated with actual exposure levels. We observed no consistent condition-induced changes in cognitive performance except for two marginal effects. At 10 V/m, we observed a slight effect on speed in one of six tasks in the sensitive subjects and an effect on accuracy in another task in non-

sensitive subjects. Both effects disappeared after multiple endpoint adjustment.

**Conclusions**

In contrast to a recent Dutch study, we could not confirm a short-term effect of UMTS base station-like exposure on well being. The reported effects on brain functioning were marginal and may have occurred by chance. Peak spatial absorption in brain tissue was considerably smaller than during usage of a mobile phone. No conclusions can be drawn regarding short term-effects of cell phone exposure or the effects of long-term base station-like exposure on human health.

## Introduction

In 2003, a Dutch study on the effects of controlled exposure to mobile communication system radio-frequency electromagnetic fields (RF EMF) at base station intensities on human well being and cognitive function was published (Zwamborn et al. 2003), hereafter called TNO study (TNO Netherlands Organization for Applied Scientific Research, Physics and Electronics Laboratory). Effects of two systems were explored, the second generation Global System for Mobile Communication (GSM) widely used around the world and its successor the Universal Mobile Telecommunications System (UMTS), the third generation of mobile networks. Two groups of subjects were investigated, consisting of individuals with and without self-reported health complaints attributed to daily life exposures to RF EMF. Whereas exposure to GSM-like EMF had no effect at the time-averaged incident electric field (E-field) strength of 0.7 V/m, UMTS-like exposure at an E-field strength of 1 V/m reduced well being in both groups. No consistent effects on cognitive performance were found. The 3 dB difference of the averaged incident fields was unlikely to have contributed to the different outcome of GSM and UMTS exposure on well being. The results were hypothesized to be due to the different modulation schemes.

The TNO-study was the first study to investigate a base station-like exposure and to indicate a reduction in well being. With respect to the stronger but much more localized exposure by mobile phone handsets there is an abundant, yet controversial body of research regarding potential non-thermal effects on humans. Data on well being are inconclusive (Rubin et al. 2006; for a review see Seitz et al. 2005), yet various studies identified subtle effects regarding changes in brain activity or influences on cognitive function such as reaction times, working memory and attention (e.g. Curcio et al. 2005; Freude et al. 2000; Huber et al. 2002; Huber et al. 2005; Hyland 2000; Koivisto et al. 2000b; Krause et al. 2000a). Some of the reported changes (e.g., acceleration of response times in certain cognitive tasks, altered oscillatory activity in the EEG as a function of time and task) were however inconsistent and could not be replicated (Haarala et al. 2003; Krause et al. 2004; Preece et al. 2005).

An ongoing debate in RF EMF research and the general public is concerned with self-reported electromagnetic hypersensitivity (EHS) relating to persons attributing subjective complaints of impaired well being (e.g., headache, nausea, sleep disturbances) to EMF exposure comprising radio frequency, as well as extremely low-frequency fields of domestic power supplies (e.g., National Institute of Environmental Health Sciences 1998; Röösli et al. 2004). So far, no causal link was found between exposure to mobile phones and EHS symptoms (for a review see Rubin et al. 2005) and objective criteria for EHS specification could not be established.

The persisting uncertainty associated with potential adverse health effects of the new UMTS technology, together with its rapidly ongoing implementation has lead to widespread public concern in many countries. We designed the present experiment as a follow-up study to clarify the reliability of the TNO study that was largely debated in the scientific community. Meanwhile, additional follow up studies were initiated in Denmark, the U.K. and Japan (personal communications). We used validated measuring instruments and an improved setup yielding better uniformity of exposure, as well as an additional E-field strength (10 V/m) to establish a dose-response relationship. Based on the results reported by Zwamborn et al. (2003), we hypothesized that exposure to UMTS-like radiation would attenuate subjective well being in both sensitive and non-sensitive subjects, possibly in a dose-dependent manner, but would not affect cognitive performance.

## Methods

### Study Participants

We investigated the effects of UMTS-like EMF in subjects with self-reported sensitivity to RF EMF (N=37) and a reference group without complaints (N=91). Due to non-compliance of three subjects and eight dropouts, the final study group included N=33 sensitive (14 males, 19 females) and N=84 non-sensitive subjects (41 males, 43 females). Both groups were recruited from the general public by advertisement in a local newspaper, by flyers and from databases of two previous studies with sensitive participants willing to participate in future research projects. Due to a lack of an operational tool for measuring sensitivity to EMF (WHO, 2005), criteria for recruitment were based on self-reported sensitivity to RF EMF, i.e., purported sensing of RF EMF or afflictions related to RF EMF as emitted by mobile or cordless phones and antennas.

Subjects were contacted by telephone and pre-selected by a standardized interview. Exclusion criteria comprised pacemakers, hearing aids, artificial cochleas, regular consumption of narcotics or psychoactive drugs in the previous six months, smoking, polymorbidity with respect to chronic diseases, pregnancy, a medical history of head injuries and or neurologic/ psychiatric diseases, sleep disturbances, an average consumption of alcohol >10 drinks/ week, and of caffeinated beverages amounting to >450 mg caffeine/ day (e.g., approximately 3 cups of coffee). We also excluded shift workers and persons undertaking long-haul flights (>3 h time zone difference) within the last month prior to the experiment.

On their first appointment, all subjects filled in a questionnaire to verify the exclusion and matching criteria (age (in decades), gender, and residential area). The entire reference group was frequency matched to the sensitive group and a subgroup was 1:1 matched, also including body mass index (BMI). Subjects were aged between 20 and 60 years (mean age 37.7±10.9 y (±SD)), right-handed (Oldfield 1971) and of normal body weight (BMI 19-30 kg/m2). They gave their written informed consent and were reimbursed for participating. The ethical committee of the Canton Zürich approved of the study protocol.

**Study Design**

We performed the study at the Institute of Pharmacology and Toxicology, University of Zürich, between February 1 and May 20, 2005. It consisted of three experimental sessions at one-week intervals (±1 day) that were preceded by a training session 7±1 days ahead and that were always scheduled at the same time of day (approximately ±2 h). Subjects were evenly distributed across experimental period, weekdays and time of day. We asked them to abstain from any medication 24 h prior to each session and also requested not to use a mobile or cordless phone for 12 h preceding the sessions.

Exposure was computer controlled providing double blind conditions, which we applied in a randomized crossover design. Before and after exposure, subjects filled in the questionnaires in an office room and were then escorted to the exposure chambers. Exposure took place in two identical and specially adapted, but separate rooms with constant temperature and light conditions. We randomly assigned pairs of subjects to one of six possible sequences of the three exposure conditions (0 (sham), 1, 10 V/m), but shifted the subjects in each pair by 20 min to minimize contact between them. Each exposure session lasted 45 min, during which subjects performed two series of cognitive tasks (session 1 and 2), starting at the beginning and after 22 min of exposure, respectively. Between sessions, subjects remained in front of the computer and were allowed to read magazines.

**Exposure and Dosimetry**

Each experimental room included an exposure area installed as a one side open chamber shielded with RF radiation absorbers (Figure 1). We placed the antenna (Huber&Suhner type

SPA 2000/80/8/0/V) in 1.5 m height and 2 m distance from the subjects, targeting the left side of the body from behind, with a field incidence angle of 25° with respect to the ear-ear vertical plane (see Figures 1 and 2). To produce the same polarization as in the TNO study, we tilted the antenna and thus the E-field 45° from vertical. The antenna possessed a –3 dB beam width of approximately 75° in horizontal and vertical directions, resulting in a uniform E-field distribution similar to the far field of a base station. We verified field uniformity before and after the experimental phase by scanning the exposure area with a field probe. The UMTS signal format was identical to the one used by Zwamborn et al. (2003), consisting of four control and synchronization channels (Primary Synchronization Channel at -8.3 dB below total RF power, Secondary Synchronization Channel, at -8.3 dB, Primary Common Control Physical Channel, at -5.3 dB, Common Pilot Channel, at -3.3 dB) with a center frequency of 2140 MHz and chip rate of 3.84 Mchips/s. The signal, generated by a commercial generator (Agilent E4433B Options 200, 201, UN8, UN9), corresponded to a UMTS base station frequency division duplex mode downlink configuration with no active voice calls. Exposure was continuously monitored and regulated (3-axis E-field probe). Each chamber was equipped with a wooden table and chair, a flat panel monitor with keyboard, a plastic response box for the cognitive tasks and the UMTS antenna with a field probe (Figure 1). We kept the web cam that recorded the subjects from top left (1 frame/s) and the computer hardware outside the exposure chamber. The sum of all magnetic fields (frequency range 30 Hz to 400 kHz) was below 0.2 μT. We measured background RF radiation levels (80 MHz to 4 GHz) before and after the experiment and they remained below 1 mV/m over the whole exposure area.

We conducted numerical dosimetry according to Kuster and Schönborn (2000) using the finite-difference time-domain (FDTD) simulation platform Semcad X (SPEAG, Switzerland) and three whole-body anatomical phantoms (two male, one female). We treated reflections from furniture as uncertainty, reducing the computational space to 2.6 x 1 x 1.8 $m^3$ (l x w x h). We modeled the floor as concrete ($\varepsilon = 7.5$, $\sigma = 0.12$ S/m), whereas the walls and ceiling were modeled as perfectly absorbing boundaries. The numerical discretization of the chamber was 5 x 5 x 5 $mm^3$, of the human model 2 x 2 x 2 $mm^3$, and of parts of the antenna 1 x 0.5 x 1 $mm^3$, resulting in approximately 335 million voxels.

The sources contributing to the absolute uncertainty of the average dosimetry were: 1) antenna modeling: 0.1 dB (experimentally verified); 2) deviation of incident field exposure with respect to the target field including transfer calibration, sensor linearity, feedback control and reflections from furniture: 0.7 dB; and 3) average anatomy, dielectric parameters and discretizations. The variation as function of weight, gender and position was assessed separately by 1) scaling the three phantoms in the range of our subjects (47-110 kg; head tissues were based on non-scaled phantoms), and 2) by rotating the phantoms ±25° around their axis. Due to good uniformity of the field, we could neglect the effect of movement.

**Questionnaires**

The short Questionnaire on Current Disposition (QCD) (Müller and Basler 1993) measures subjective well being within short test-retest intervals using six bipolar items (tense – calm; apprehensive – unperturbed; worried – unconcerned; anxious – relaxed; skeptical – trusting; uneasy – comfortable) and was applied before and after each experimental condition.

We used the modified Quality-of-life Questionnaire (Zwamborn et al. 2003), hence referred to as TNO-Q, as a reference questionnaire for comparison with the TNO study. The validated, original questionnaire had been developed to estimate "quality of life" during trials of an antihypertensive drug treatment (Bulpitt and Fletcher 1990) and was modified by Zwamborn et al. (2003) by using a selection of 23 items separated in five subscales (anxiety, somatic symptoms, inadequacy, depression and hostility).

We applied a self-designed Questionnaire to include Other Factors (QOF) potentially related to well being (sleep duration, quality of previous night, suffering from a cold, amount of alcohol and caffeine consumed and medication taken on the day of the experimental session, (pre-) menstrual complaints and stressful events). Moreover, subjects had to rate the perceived field strength of the same day's exposure condition on a visual analogue scale. We applied the TNO-Q and the QOF after each experimental condition. Completion of all questionnaires took 5-15 min.

One week prior to the training and one week after the last session, we applied a paper version of the Bern Questionnaire on Well-being (BQW) (Grob 1995). It measures well being over a few weeks (39 items separated into two main scales (satisfaction, ill health)) and was used to assess whether participation per se had an influence on well being, irrespective of exposure.

**Cognitive Tasks**

We investigated the effects of UMTS-like radiation on brain functioning with the Simple Reaction Time Task (SRT) and 2-Choice Reaction Time Task (CRT) (Koivisto et al. 2000b; Preece et al. 1999; Preece et al. 1998), the N-back Task (N-back) (Koivisto et al. 2000a) and the Visual Selective Attention Task (VSAT) adapted from Zwamborn et al. (2003) and applied the tasks in fixed order (SRT, CRT, 1-, 2-, 3-back, VSAT). We implemented the tasks by using software from e-Prime (Psychology Software Tools Inc., USA). We instructed subjects to respond as quickly and accurately as possible by using their right index (targets) and middle finger (non-targets). Completion of one series took 15-20 min.

In the SRT, a "0" appeared on screen until the subjects pressed the corresponding "0" button on the response box. In the CRT, either "JA" (yes) or "NEIN" (no) was shown and subjects had to press the "J" (targets) and "N" button (non-targets).

In the N-back task, single consonants were randomly presented. Subjects had to compare each current letter with any letter presented 1-, 2- or 3-trials back and press “J” for same letters and “N” for different letters.

In the VSAT, a random combination of four letters and/ or crosses in a square was presented. The targets were “U” and “F” appearing on the diagonal from upper left to lower right. When one or both appeared, subjects had to press “J” and “N” when no target was presented.

**Statistical Analysis**

We used linear mixed models for statistical analyses (questionnaires: STATA 9.0 (StataCorp, USA); cognitive tasks: SAS 8.2 (SAS Institute Inc., USA)). With respect to reaction times, we excluded individual outliers over all sessions according to a robust rejection-estimation procedure (4* median deviation) (Hampel 1985). We transformed reaction times (1/ reaction time), which are referred to as speed [1/s; correct responses only] and checked residuals for normal distribution.

We performed stratified analyses for the sensitive and non-sensitive group by using a random intercept model presuming an identical intraclass correlation for all subjects. The base model included the factor *Condition* (sham, 1, 10 V/m) and *Week* (1, 2, 3) to account for possible order effects. The model for cognitive data also contained the factor *Session* (S1, S2) and corresponding interaction effects. We modeled *Condition* as a continuous variable to test for a dose response relationship and assessed differences between groups with an overall model including the factor *Sensitivity* and a *Sensitivity*Condition* interaction. We evaluated the robustness of results by adjusting the model for potential confounding factors (see Table 1 and 2).

We used the percentage of correct answers in the CRT, 1-, 2-, 3-back and VSAT as a measure of accuracy. Except for the 3-back, residuals were not normally distributed and differences were assessed using non-parametric Wilcoxon-Signed-Rank tests. We performed comparisons of 1 V/m vs. sham and 10 V/m vs. sham for S1, S2, and the difference between the two sessions. The resulting p-values were adjusted for multiple testing (six tests) according to Bonferroni-Holm (Holm 1979).

In order to generally control for multiple testing, a multiple endpoint adjustment was performed for the cognitive outcomes using the method proposed by Tukey and colleagues (Tukey et al. 1985).

We analyzed the ability to perceive EMF by calculating Spearman rank correlations between perceived field intensity and true exposure status for each subject. We tested the number of positive and negative correlations using Sign test and used the same procedure to evaluate the association between perceived field intensity and well being (QCD, TNO-Q).

## Results

### Questionnaires

Well being as measured by the QCD and the TNO-Q was not affected by exposure (Table 1). With respect to the six items in the QCD and the five subscales of the TNO-Q, we found no significant exposure-response associations in any of the two groups. Irrespective of the actual condition, sensitive subjects generally reported more health problems, particularly in the TNO-Q. Neither group showed a relationship between perceived field intensity and true exposure status (Table 1). Sensitive subjects indicated higher field strengths in all conditions ($p<0.001$), even though score values were not associated with exposure levels. 17 out of 31 sensitive subjects had a positive correlation between perceived and real field intensity, 13 a negative correlation (non-sensitive group: 22 and 27 out of 57 subjects, respectively), which can be expected by chance (Table 3). Irrespective of exposure condition, perceived field intensity was positively correlated with impaired well being in 68% of sensitive ($QCD_{diff}$: $p=0.043$) and 64% of non-sensitive subjects ($p=0.001$). Similar results were found with respect to the $QCD_{post}$ and the TNO-Q (data not shown).

In the BQW, comparison of scores one week prior to and after study participation showed no significant changes for satisfaction and ill health in the sensitive group. In the non-sensitive group, the score for ill health was lower after the experiment ($p=0.004$), but satisfaction remained unchanged.

### Cognitive Tasks

In the course of the entire study, subjects got faster in all tasks ($p<0.02$) except the SRT. In both groups and irrespective of condition, speed decreased significantly from S1 to S2 in both the SRT and CRT, but increased in the 1-, 2-, 3-back and VSAT ($p<0.0001$). In the following, only effects including *Condition* or a *Condition*Session* interaction are described.

In both groups, we observed no condition-induced effects on speed in the SRT, 1-, 2-, 3-back and VSAT. In the CRT, speed decreased in the sensitive group from S1 to S2 in the sham and 1 V/m condition (~20 ms), but not in the 10 V/m condition (*Condition*Session*: p=0.007, Table 2). In contrast, we observed a decrease in speed between sessions irrespective of exposure condition in the non-sensitive group (p=0.254, Table 2). A mixed model ANOVA including the factor *Sensitivity* (sensitive, non-sensitive) corroborated the observed differences between groups with respect to exposure (*Condition*Sensitivity*: p=0.005). Accuracy was not affected by exposure in a dose response manner in any of the cognitive tasks, except for the 1-back task in the non-sensitive group, where it decreased from 98.2% (sham) to 97.3% (10 V/m; p=0.046) in session 1.

Adjusting the models for potential confounding factors (see Table 1 and 2) or performing the analyses with only the 1:1 matched subjects did not alter the results. After multiple endpoint adjustment (alpha=0.05; number of tests=44, overall correlation among cognitive outcomes=0.39), however, all reported p-values exceeded the significance level of p=0.0051 (Tukey et al. 1985).

**Dosimetry**

Penetration depth was low and highest specific absorption rate (SAR) values occurred predominantly at the illuminated side close to the skin (Table 4, Figure 2). Whole-body average absorption was 6.2 ±1.8 and 620 ±180 µW/kg for 1 V/m and 10 V/m, respectively, with an absolute uncertainty of 41% (Table 4). Peak spatial SAR (averaged over 10 g) was 45 ±13 and 4500±1300 µW/kg for brain tissue. At 10 V/m, all values were at least 100x below recommended safety limits (International Commission on Non-Ionizing Radiation Protection 1998). Compared to usage of a mobile phone at the ear or to exposure levels used in other studies, the peak spatial SAR of the brain was more than 100x lower at 10 V/m in our study. SAR values for head tissues and left/ right differences are provided in Table 5.

The SAR values are strongly dependent on the incidence angle and the polarization of the field which were fixed in our study. Variation of incidence angle and polarization at the same field strength will lead to considerable changes of the SAR values in different parts of the body.

## Discussion

In contrast to our hypothesis, well being as assessed by the QCD and TNO-Q questionnaires was not affected by UMTS radiation, neither at the 1 V/m nor at the 10 V/m condition. Even though sensitive subjects generally reported more health problems, we found no difference overall between the two groups with respect to the applied field conditions. Similarly, cognitive performance was not affected, except for two separate and marginal effects in the 10 V/m condition. In the CRT, we could not observe a slight decrease in speed across sessions in sensitive subjects and in the 1-back task, accuracy was reduced in non-sensitive subjects compared to the sham condition.

Cognitive tasks with moderate to high workload have frequently been used as a tool to assess RF EMF effects on brain physiology by measuring simple motor responses requiring selective attention and higher cognitive functions such as working memory (e.g. Krause et al. 2000b). Except for the VSAT, which was taken from the TNO battery of cognitive tasks for follow-up reasons, we chose the SRT, CRT and N-back on the basis of recently published work attempting to assess EMF-induced changes with respect to brain physiology (Koivisto et al. 2000a; Koivisto et al. 2000b; Preece et al. 1999). However, the described effects showed no consistent picture and could not be replicated (Haarala et al. 2003; Preece et al. 2005).

In general, exposure in these studies was poorly defined and the inconsistencies in cognitive outcome may be due to differences in the design, blinding, study population and sample size, thus preventing a comparison of the results. Alternatively, cognitive tasks used so far may not be sensitive enough to reliably measure potential RF EMF effects on brain functioning, leading to a masking of existing effects or resulting in significant effects of tests that stochastically respond to RF EMF. Moreover, statistical analysis of several tests increases the risk of false positive findings.

In the present study, speed was affected in the sensitive group in one of six cognitive tasks and accuracy in the non-sensitive group in one of five tasks. Although we cannot exclude an actual *Condition*Session* interaction in the CRT in sensitive subjects and, similarly, a *Condition* effect in the 1-back task in non-sensitive subjects, the findings seem to be coincidental because they did not reach significance after multiple endpoint adjustment.

Both the sensitive and the non-sensitive group were unable to identify the applied fields better than expected by chance. Because we investigated only three conditions per subject, the likelihood of correct field rating by chance was relatively high. The observed distribution of 39 individuals with a positive correlation between the applied and estimated exposure condition and 40 individuals with a negative correlation was likely to be expected by chance. Nevertheless, we cannot exclude that among these subjects a minority was actually able to perceive the applied exposure. The identification of such individuals has failed in several provocation studies so far (reviewed in Rubin et al. 2005) and would require a multiple testing approach in order to reduce the likelihood of a correct rating by chance. Perceived field strength correlated with an impairment of current well being in both groups irrespective of exposure condition. Also, sensitive subjects rated perceived field strengths higher than non-sensitive subjects, yet ratings in both groups were not better than expected by chance and not associated with exposure levels. This indicates that sensitive subjects overestimate their ability to better perceive RF EMF than the general public (Leitgeb and Schröttner 2003).

Our results differ with respect to both well being and cognitive performance from the results reported by Zwamborn et al. (2003). The TNO-Q is an adapted and not validated version of the original questionnaire (Bulpitt and Fletcher 1990) and was not designed for short retest intervals. Our findings were corroborated by the results of the QCD, a standardized questionnaire that more reliably measures changes in well being over short test-retest intervals (Müller and Basler 1993). Contrary to the TNO study, we found no significant effect on speed in the VSAT. It was however the only task applied in both studies; all other cognitive tasks were distinct. Zwamborn et al. (2003) found other effects with respect to cognitive tasks and exposure conditions (GSM and UMTS) and we also report an effect on speed in one out of six tasks and an effect on accuracy in one out of five tasks used. No clear picture therefore emerges across the two studies showing reproducible effects of exposure condition or cognitive task.

A number of other factors may contribute more generally to the discrepancies between the TNO study and our study. Sample sizes differ substantially (sensitive subjects: 24 versus 33; non-sensitive subjects: 24 versus 84). Our reference group was frequency matched to the sensitive group and a subgroup was 1:1 matched with respect to gender, age, residential area and BMI. In the TNO study, all conditions in a particular subject were carried out on a single day, whereas we investigated the subjects at the same time of day in weekly intervals to rule out possible circadian and carry-over effects. We further controlled circadian influences by a uniform distribution of experimental sessions across the time of day. Carry-over effects may lead to an accumulation of RF EMF radiation over time, thus falsifying potential effects of discrete conditions. Furthermore, inclusion of an additional E-field strength of 10 V/m is likely to have contributed to a more reliable assessment of RF EMF effects.

Technical improvements necessitated the modification of the exposure setup used in the TNO study to achieve a more uniform and reproducible base station-like exposure. Whereas the signal (carrier frequency and modulation) and the angle of incidence were identical, the spatial incident field distribution was less uniform in the TNO study, where a narrow exposure beam of only 5° width was used resulting in a larger variation due to differences in height and position of the subjects. In addition, the whole-body exposure conditions applied in this study correspond better to a base-station exposure scenario. However, exposure of head tissues was equivalent in both studies, even though we had a smaller inter-subject variability.

Further insights regarding the discrepancies between the present and the Dutch study might be gained from other follow up studies underway in Denmark, the U.K. and Japan, which are also investigating the effect of UMTS base station-like radiation on well being and cognitive function (personal communications).

In summary, we found no causal relationship between RF EMF and a decrease in well being or adverse health effects under the given exposure conditions, but cannot exclude an effect of UMTS-like EMF on brain functioning. The described effects were weak and not consistent in the two groups. Regarding the implications for public health due to widespread exposure in the living environment, no conclusions about long-term effects of UMTS base station-like EMF can be drawn from the present study, as only a short-term exposure was applied.

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## Tables

Table 1: Results of applied questionnaires (mean scores ±SD; N=33 sensitive and N=84 non-sensitive subjects). Outcomes of the QCD (*Short questionnaire on current disposition*) comprise the difference between pre and post experimental scores ($QCD_{Diff}$) as well as post experimental scores ($QCD_{post}$). A difference score >0 corresponds to a degradation in current well being during the experiment. In the $QCD_{post}$ and the TNO-Q (*Quality-of-life questionnaire*) higher scores refer to a lower well being. We measured subjective field perception by means of a 100 mm visual analogue scale ranging from "*not at all"(0)* to *"very strong" (100 mm)*. We only report p-values of *Condition* (Cond) (for details see Methods).

| Outcome | Group | Sham | 1V/m | 10V/m | Cond[a] | Cond[b] |
|---|---|---|---|---|---|---|
| | | Mean ±SD | Mean ±SD | Mean ±SD | p-value | p-value |
| $QCD_{diff}$ | Sensitive | 0.30 ±0.83 | 0.24 ±0.99 | 0.24 ±0.95 | 0.88 | 0.95 |
| | Non-Sensitive | 0.05 ±0.73 | -0.04 ±0.59 | 0.02 ±0.55 | 0.93 | 0.95 |
| $QCD_{post}$ | Sensitive | 2.57 ±1.06 | 2.65 ±1.22 | 2.61 ±0.97 | 0.97 | 0.96 |
| | Non-Sensitive | 2.19 ±0.76 | 2.05 ±0.80 | 2.13 ±0.78 | 0.97 | 0.89 |
| TNO-Q | Sensitive | 10.53 ±9.51 | 9.61 ±8.96 | 9.79 ±8.38 | 0.84 | 0.65 |
| | Non-Sensitive | 5.23 ±5.09 | 4.45 ±4.92 | 4.96 ±5.08 | 0.78 | 0.92 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Field perception | Sensitive | 26.0 ±31.9 | 31.2 ±33.7 | 29.4 ±29.7 | 0.89 | 0.67 |
| | Non-Sensitive | 12.9 ±22.8 | 5.7 ±13.1 | 12.2 ±23.2 | 0.24 | 0.33 |

[a] Adjusted for order; [b] Adjusted for order, age, gender, BMI, caffeine intake, medication, (pre-) menstrual complaints, sleep quality and suffering from a cold

Table 2: Results of cognitive performance. Mean speed ±SD (1/Reaction time [1/s]; N=33 sensitive and N=84 non-sensitive subjects) in the two sessions (1st and 2nd half of exposure) in the SRT (*Simple reaction time task*), CRT (*Two choice reaction time task*), N-back task (*1-, 2-, 3-back*), and VSAT (*Visual selective attention time task*). We only report p-values of *Condition* (Cond) and of the interaction *Condition*Session* (for details see Methods). Statistical analysis is based on data of all subjects. Due to a missing session in some subjects, mean values are based on subjects who completed both sessions in each condition (N= at least 32 sensitive and at N= at least 77 non-sensitive subjects).

| Outcome | Group | Session | Sham | 1V/m | 10V/m | Cond[a,b] | Cond*Session[a,b] | Cond[b,c] | Cond*Session[b,c] |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mean ±SD | Mean ±SD | Mean ±SD | p-value | p-value | p-value | p-value |
| SRT | Sensitives | 1 | 3.86 ±0.52 | 3.78 ±0.44 | 3.84 ±0.48 | 0.09 | 0.27 | 0.07 | 0.27 |
| | | 2 | 3.73 ±0.56 | 3.65 ±0.43 | 3.78 ±0.47 | | | | |
| | Non-Sensitives | 1 | 3.85 ±0.37 | 3.85 ±0.38 | 3.84 ±0.43 | 0.59 | 0.51 | 0.37 | 0.50 |
| | | 2 | 3.70 ±0.44 | 3.70 ±0.49 | 3.68 ±0.41 | | | | |
| CRT | Sensitives | 1 | 2.37 ±0.28 | 2.33 ±0.25 | 2.33 ±0.28 | 0.03 | 0.01 | 0.02 | 0.01 |
| | | 2 | 2.25 ±0.30 | 2.20 ±0.27 | 2.31 ±0.22 | | | | |
| | Non-Sensitives | 1 | 2.27 ±0.26 | 2.27 ±0.27 | 2.24 ±0.25 | 0.13 | 0.25 | 0.08 | 0.24 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 2.22 ±0.27 | 2.21 ±0.27 | 2.21 ±0.25 | | | | |
| 1-Back | Sensitives | 1 | 2.15 ±0.56 | 2.12 ±0.55 | 2.13 ±0.55 | 0.90 | 0.67 | 0.93 | 0.67 |
| | | 2 | 2.27 ±0.57 | 2.29 ±0.54 | 2.29 ±0.49 | | | | |
| | Non-Sensitives | 1 | 2.12 ±0.44 | 2.12 ±0.48 | 2.10 ±0.42 | 0.57 | 0.97 | 0.46 | 0.98 |
| | | 2 | 2.25 ±0.44 | 2.28 ±0.48 | 2.24 ±0.43 | | | | |
| 2-Back | Sensitives | 1 | 1.59 ±0.46 | 1.53 ±0.44 | 1.53 ±0.35 | 0.61 | 0.44 | 0.50 | 0.43 |
| | | 2 | 1.70 ±0.49 | 1.71 ±0.53 | 1.71 ±0.47 | | | | |
| | Non-Sensitives | 1 | 1.63 ±0.39 | 1.58 ±0.39 | 1.60 ±0.38 | 0.44 | 0.52 | 0.37 | 0.52 |
| | | 2 | 1.74 ±0.42 | 1.74 ±0.43 | 1.72 ±0.39 | | | | |
| 3-Back | Sensitives | 1 | 1.48 ±0.40 | 1.48 ±0.46 | 1.48 ±0.39 | 0.57 | 0.52 | 0.39 | 0.51 |
| | | 2 | 1.56 ±0.42 | 1.60 ±0.51 | 1.54 ±0.37 | | | | |
| | Non-Sensitives | 1 | 1.56 ±0.44 | 1.57 ±0.51 | 1.51 ±0.36 | 0.59 | 0.11 | 0.64 | 0.11 |
| | | 2 | 1.70 ±0.55 | 1.64 ±0.50 | 1.70 ±0.49 | | | | |
| VSAT | Sensitives | 1 | 1.74 ±0.33 | 1.72 ±0.31 | 1.75 ±0.31 | 0.28 | 0.94 | 0.22 | 0.94 |
| | | 2 | 1.85 ±0.29 | 1.85 ±0.31 | 1.87 ±0.28 | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Non-Sensitives | 1 | 1.69 ±0.34 | 1.69 ±0.33 | 1.68 ±0.29 | 0.64 | 0.70 | 0.50 | 0.71 |
| | 2 | 1.78 ±0.32 | 1.83 ±0.36 | 1.79 ±0.31 | | | | |

[a] Adjusted for order; [b] p-values not adjusted for testing multiple endpoints; [c] adjusted for order, age, gender, BMI, caffeine intake, medication, (pre-) menstrual complaints, sleep quality and suffering from a cold.

Table 3: Correlations between perceived electric field strength and real exposure condition (sham, 1 V/m, 10 V/m). Two sensitive and 27 non-sensitive subjects perceived no field in all three conditions and were omitted from the analysis.

| | | Correlation between perceived and real field | | | |
|---|---|---|---|---|---|
| | N | positive | negative | zero | p-value[a] |
| All | 88 | 39 | 40 | 9 | 1 |
| Sensitive | 31 | 17 | 13 | 1 | 0.58 |
| Non-Sensitive | 57 | 22 | 27 | 8 | 0.56 |

[a] Sign Test

Table 4: Averaged SAR values ±SD of variations and the absolute uncertainty (CI, confidence interval) for an electric field strength of 1 V/m for whole body and brain, as well as peak spatial averaged SAR for whole body, brain, skin, and muscle (1 g and 10 g) of an average male (80 kg). To obtain SAR values at a field strength of 10 V/m, SAR values in the table have to be multiplied by 100.

| Tissue | Averaged SAR ±SD (μW/kg) | Uncertainty (95 % CI) (%) |
|---|---|---|
| Whole body | 6.2 ±1.8 | 41 |
| Whole body 10g (Peak Spatial) | 150 ±49 | 39 |
| Whole body 1g (Peak Spatial) | 320 ±130 | 41 |
| Brain | 11 ±2.4 | 48 |
| Brain 10g (Peak Spatial) | 45 ±13 | 45 |
| Brain 1g (Peak Spatial) | 73 ±16 | 44 |
| Skin 10g (Peak Spatial) | 230 ±48 | 50 |
| Skin 1g (Peak Spatial) | 380 ±76 | 39 |
| Muscle 10g (Peak Spatial) | 120 ±31 | 48 |
| Muscle 1g (Peak Spatial) | 190 ±62 | 39 |

Table 5: Ratio between organ or tissue averaged SAR values and whole-body (6.2 μW/kg at 1 V/m) for brain parts, ear, and eye of an average male (80 kg), as well as the ratio between the averaged SAR of the left and right part of the head.

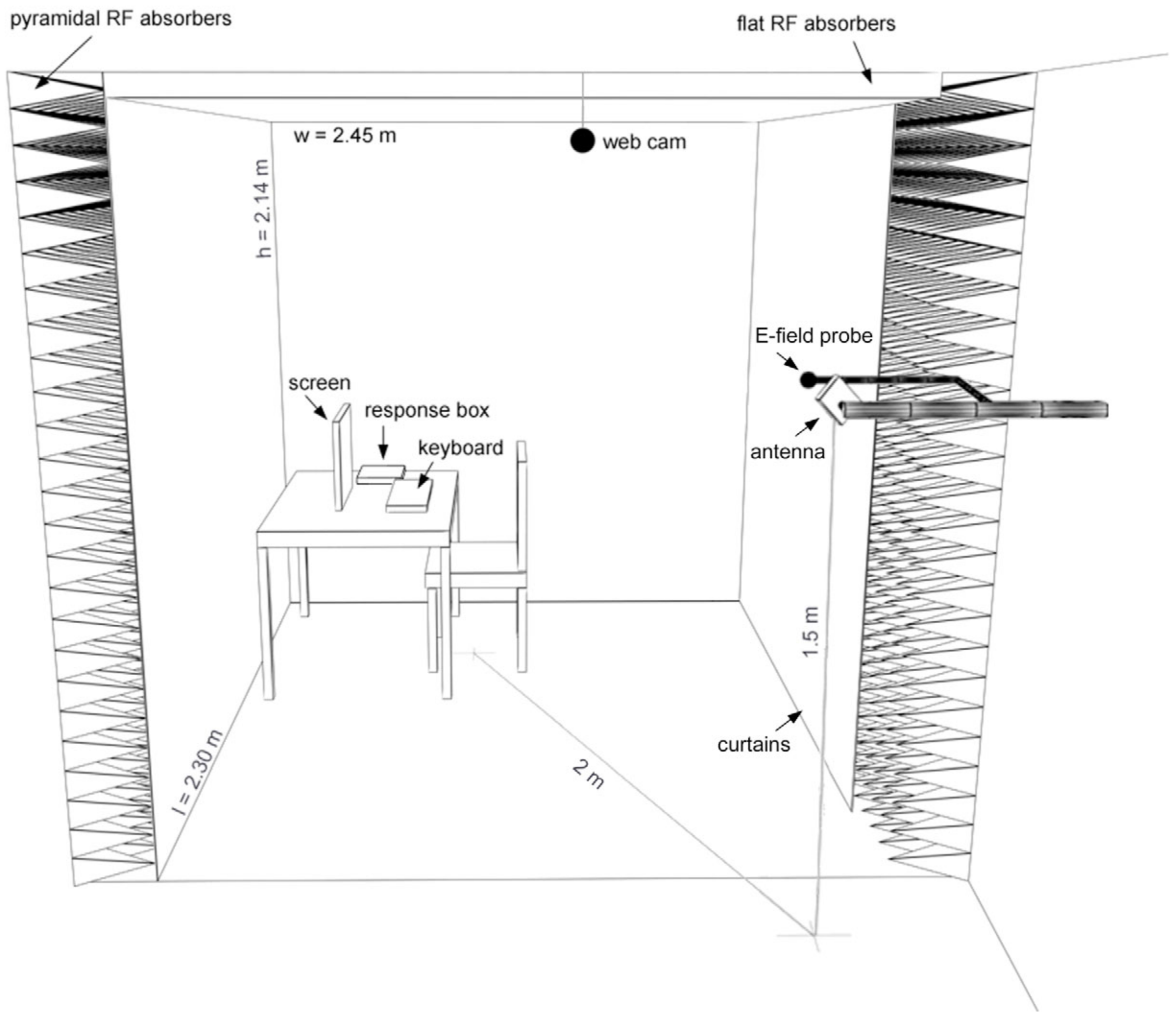
| Organ/Tissue | Ratio organ or tissue / whole body | Ratio left / right |
|---|---|---|
| Grey matter (left hemisphere) | 3.5 | 2.9 |
| White matter (left hemisphere) | 2.0 | 2.6 |
| Cerebellum | 0.52 | - |
| Hippocampus (left hemisphere) | 0.84 | 1.6 |
| Hypothalamus (left hemisphere). | 0.52 | 1.9 |
| Thalamus (left hemisphere) | 0.64 | 0.81 |
| Parotid gland | 4.6 | - |
| Ear pinna (left) | 17 | 18 |
| Eye ball (left) | 5.6 | 8.8 |

## Figure legends

Figure 1: Sketch of the exposure chamber. Walls covered by pyramidal RF absorbers and non-reflecting curtains. Ceiling covered by flat absorbers. Antenna, electric field probe, furniture, screen, keyboard, response box, and web cam, inner dimensions (w: width; h: height; l: length), and position of the antenna are indicated.

Figure 2: SAR distribution on the surface of a male (80 kg) in a sitting position (top view). 0 dB corresponds to 0.05 W/kg for an electric field strength of 1V/m. The orientation of the electric field ($\vec{E}$), the magnetic field ($\vec{H}$), and the propagation direction ($\vec{k}$) of the EMF are indicated.

Figure 1:



pyramidal RF absorbers
flat RF absorbers
w = 2.45 m
web cam
h = 2.14 m
E-field probe
screen
response box
keyboard
antenna
1.5 m
curtains
l = 2.30 m
2 m

Figure 2: