Radiofrequency exposure in the general population: sources and exposure levels

Martin Röösli; Swiss Tropical and Public Health Institute (Swiss TPH), University of Basel, Switzerland
Content

- Exposure assessment approaches
- Measurement surveys
- Personal exposure studies
- From exposure to dose
- Exposure trends in the last 10 years
RF-EMF: Two types of exposure

- **Close to body (near field):**
  - mobile phone (uplink)
  - cordless phone

- **Environmental (far field):**
  - W-LAN
  - broadcast transmitter
  - mobile phone base station (downlink)
  - Other people’s mobile and cordless phones (uplink)

Population RF exposure

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Radiofrequency exposure measure

- **Near-field exposure**
  SAR in W/kg: Specific absorption rate.
  Regulatory limits for mobile phones: 2 W/kg

- **Far-field exposure**
  Electric field (E) in V/m (sometimes called incident field)
  ICNIRP regulatory limits for mobile phone radiation: <61 V/m
How to combine to one single exposure measure?

- Complex, depends on the relevant exposure metric
  - Spatial average vs. Spatial peak
  - Temporal average vs. Temporal peak
  - Frequency dependence of absorption
  - etc.

1. Simplified approach: measured exposure = E-field at the place of a person if the person not were there

2. A cumulative dose approach
Three approaches for environmental EMF exposure assessment

1. Stationary Measurements
   - accurate temporal resolution
   - elaborate
   - Low spatial resolution

2. Modeling of fixed site transmitters
   - efficient, illustrative
   - no hotspots (W-Lan), femto/nano cells
   - No individual behavior
3. Portable measurements

3a. Personal volunteer measurements
- all sources including behavior
- data quality, manipulation
- selection bias
- No differentiation between own and other people’s mobile phone
- body shielding

3b. Microenvironmental survey
- data quality, efficient,
- minimized body shielding
- No individual behavior
- Private place measurements challenging

Population RF exposure
Overview measurement survey

Rowley et al., JESEE, 2012

Population RF exposure

E-field

- 60 V/m
- 6 V/m
- 0.6 V/m
- 0.06 V/m
- 0.006 V/m

Rowley et al., JESEE, 2012
Microenvironmental survey

- Measurements conducted between 2010 and 2012
- EME SPY 120: 12 frequency bands from 88 to 2500 MHz

Outdoor:
- Residential areas
- Downtown

Indoor:
- Train station
- Airport
- Shopping centers

Public transports:
- Trains
- Bus
- Tram/Metro
Reproducibility of microenvironmental measurements

Population RF exposure

Urbinello et al., *Env Int, 2014*
Exposure vs. Regulatory limits

Population RF exposure

Urbinello et al., *Env Int*, 2014

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Summary of 51 outdoor microenvironments in CH (+ public transport) conducted in 2014

Population RF exposure

Sagar et al., under review
Pilot measurements in South Africa from May 2016

See poster of Sagar et al.
Overview personal measurements

**Table 3.** Summary of the measurement data on the RF EMF exposure of individuals using PEM in Europe in mean total electric field strength in V/m or average exposure in % of the ICNIRP level.

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean total electric field strength (V/m)</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>0.12</td>
<td>Joseph et al.²¹</td>
</tr>
<tr>
<td>Switzerland</td>
<td>0.24</td>
<td>Frey et al.²²,²³</td>
</tr>
<tr>
<td>Slovenia</td>
<td>0.27</td>
<td>Trček et al.²⁴</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.10</td>
<td>Thuróczy et al.²⁶</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.15</td>
<td>Bolte et al.²⁷</td>
</tr>
<tr>
<td>France</td>
<td>0.21</td>
<td>Viel et al.³¹</td>
</tr>
<tr>
<td>UK</td>
<td>0.11</td>
<td>Mann³³</td>
</tr>
<tr>
<td>Germany⁵</td>
<td>0.09</td>
<td>Breckenkamp et al.³⁴</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.26</td>
<td>Bolte and Eikelboom³²</td>
</tr>
</tbody>
</table>

Gajsek et al. JESEE, 2015
ZüMe: Population based personal radiofrequency electromagnetic field exposure measurements in Zurich

- Random population sample from 12 communities from canton of Zürich (Switzerland) with various degrees of urbanity
- 42 pairs of one parent and adolescent (12-15 years) and 30 young adults (18-30 years)
- Measurement device ExpoM-RF: 14 frequency bands between 88 MHz – 2690 MHz
- Electronic diary app, GPS recorded by Expom-RF
Average source contributions (mean=0.18 V/m)

- Uplink: 18%
- Downlink: 4%
- Broadcast: 5%
- DECT: 35%
- WLAN: 38%

Röösli et al, 2016

Population RF exposure

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Comparison of the 3 study groups

- **Parents** (n = 42)
  - Electric field: 0.16 V/m

- **Adolescents** (n = 43)
  - Electric field: 0.16 V/m
  - Power flux density: 0.16 V/m

- **Young Adults** (n = 30)
  - Electric field: 0.22 V/m
  - Power flux density: 0.20 V/m

**Population RF exposure**

- **Uplink**
- **Downlink**
- **Broadcast**
- **DECT**
- **WLAN**
RF-EMF per activity

- At home (5089 h, n = 115)
  - 0.11 V/m
- School (465 h, n = 49)
  - 0.15 V/m
- Work place (561 h, n = 46)
  - 0.22 V/m
- Outdoor (387 h, n = 109)
  - 0.30 V/m
- Train (75 h, n = 44)
  - 0.33 V/m
- Tram (28 h, n = 30)
  - 0.39 V/m
- Bus (43 h, n = 34)
  - 0.29 V/m
- Car (190 h, n = 69)
  - 0.32 V/m
- Others (409 h, n = 91)
  - 0.55 V/m

Power flux density [µW/m²]

- Outdoor
  - 387 h, n = 109
- Work place
  - 561 h, n = 46
- School
  - 465 h, n = 49
- At home
  - 5089 h, n = 115
- Others
  - 409 h, n = 91
- Train
  - 75 h, n = 44
- Tram
  - 28 h, n = 30
- Bus
  - 43 h, n = 34
- Car
  - 190 h, n = 69
Weekend (WE) vs. workday (WD) exposure

Electric field [V/m]

0 0.1 0.15 0.2 0.25 0.27

Young Adults (n = 12)
WE
0.16 V/m
WD
0.22 V/m

Adolescents (n = 19)
WE
0.15 V/m
WD
0.16 V/m

Parents (n = 17)
WE
0.15 V/m
WD
0.21 V/m

All participants:
Mean weekend: 0.18 V/m
Mean workday: 0.18 V/m
Day vs night exposure

- **Young Adults** (n = 30)
  - Night: 0.12 V/m
  - Day: 0.26 V/m

- **Adolescents** (n = 43)
  - Night: 0.11 V/m
  - Day: 0.18 V/m

- **Parents** (n = 42)
  - Night: 0.09 V/m
  - Day: 0.18 V/m

Power flux density [µW/m²]

- Uplink
- Downlink
- Broadcast
- DECT
- WLAN

Population RF exposure
**Uplink exposure**

**Mobile internet use**

<table>
<thead>
<tr>
<th>Power flux density [µW/m²]</th>
<th>Electric field [V/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05 V/m</td>
</tr>
<tr>
<td>No mobile internet use</td>
<td>(n = 14)</td>
</tr>
<tr>
<td></td>
<td>0.11 V/m</td>
</tr>
<tr>
<td>Mobile internet use</td>
<td>(n = 101)</td>
</tr>
</tbody>
</table>

**Call duration (per day)**

<table>
<thead>
<tr>
<th>Power flux density [µW/m²]</th>
<th>Electric field [V/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05 V/m</td>
</tr>
<tr>
<td>Never</td>
<td>(n = 38)</td>
</tr>
<tr>
<td></td>
<td>0.09 V/m</td>
</tr>
<tr>
<td></td>
<td>0.10 V/m</td>
</tr>
<tr>
<td>1-5 min</td>
<td>(n = 54)</td>
</tr>
<tr>
<td></td>
<td>0.13 V/m</td>
</tr>
<tr>
<td>6-15 min</td>
<td>(n = 16)</td>
</tr>
<tr>
<td></td>
<td>0.14 V/m</td>
</tr>
<tr>
<td>31-60 min</td>
<td>(n = 2)</td>
</tr>
<tr>
<td>&gt;60 min</td>
<td>(n = 2)</td>
</tr>
</tbody>
</table>

Combine near and far field by dosimetric approach
Population RF exposure

RF-EMF dose

Near-field

Far-field

\[ \sum \text{dose} \]

\[ \text{dose} = \text{output power} \times \text{SAR} \times \text{use duration} \]

\[ \text{dose} = \text{incident field} \times \text{SAR} \times \text{exposure duration} \]

SAR = normalized Specific Absorption Rate
RF-EMF = radiofrequency electromagnetic fields

Roser et al., IJERPH, 2015
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Average use in Züme

- Calls with mobile phones: 5.2 Min/day (8% with headset/speaker)
- Calls with cordless phones: 4.8 Min/day
- Mobile data traffic on mobile phone: 19.0 Min/day
- WLAN data traffic on mobile phone: 33.3 Min/day
- Mobile phone transmission on the body in stand-by mode: 1.2 Min/day
- WLAN Use on computer: 9.8 Min/day; with Laptop: 50.2 Min/day; with Tablet: 15.6 Min/day; game console: 2.4 Min/day.
- Mean measured far field exposure as presented before
SAR values from the literature

Table 2. Near-field *brain* and *whole-body* SARs, corresponding derivation and references for the near-field predictors.

<table>
<thead>
<tr>
<th>Near-Field Predictor</th>
<th>Brain SAR</th>
<th>Derivation</th>
<th>Whole-Body SAR</th>
<th>Derivation</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM ¹ mobile phone calls without headset</td>
<td>3.198</td>
<td>–</td>
<td>0.411</td>
<td>–</td>
<td>[18]</td>
</tr>
<tr>
<td>GSM ¹ mobile phone calls with headset</td>
<td>$3.198 \times 10^{-3}$</td>
<td>$3.198 \times 0.001$</td>
<td>0.411</td>
<td>0.411 $\times 1$</td>
<td>[18,20]</td>
</tr>
<tr>
<td>UMTS mobile phone calls without headset</td>
<td>0.023</td>
<td>–</td>
<td>0.003</td>
<td>–</td>
<td>[18]</td>
</tr>
<tr>
<td>UMTS mobile phone calls with headset</td>
<td>$0.023 \times 10^{-3}$</td>
<td>$0.023 \times 0.001$</td>
<td>0.003</td>
<td>0.003 $\times 1$</td>
<td>[18,20]</td>
</tr>
<tr>
<td>DECT phone calls without eco mode</td>
<td>0.373</td>
<td>–</td>
<td>0.051</td>
<td>–</td>
<td>[18]</td>
</tr>
<tr>
<td>DECT phone calls with eco mode</td>
<td>0.0373</td>
<td>$0.373 \times 0.1$</td>
<td>0.0051</td>
<td>0.051 $\times 0.1$</td>
<td>[18,20]</td>
</tr>
<tr>
<td>mobile phone data traffic with mobile internet connection</td>
<td>$0.092 \times 10^{-3}$</td>
<td>$0.023 \times 4 \times 0.001$</td>
<td>0.012</td>
<td>0.003 $\times 4 \times 1$</td>
<td>[18,20–24]</td>
</tr>
<tr>
<td>mobile phone close to body (passive mobile phone data traffic)</td>
<td>$0.092 \times 10^{-3}$</td>
<td>$0.023 \times 4 \times 0.001$</td>
<td>0.012</td>
<td>0.003 $\times 4 \times 1$</td>
<td>[18,20–24]</td>
</tr>
<tr>
<td>mobile phone data traffic with WLAN</td>
<td>$0.092 \times 10^{-3}$</td>
<td>$0.023 \times 4 \times 0.001$</td>
<td>0.012</td>
<td>0.003 $\times 4 \times 1$</td>
<td>[18,20–24]</td>
</tr>
<tr>
<td>computer, laptop and tablet use with WLAN</td>
<td>$0.092 \times 10^{-3}$</td>
<td>$0.023 \times 4 \times 0.001$</td>
<td>0.012</td>
<td>0.003 $\times 4 \times 1$</td>
<td>[18,20–24]</td>
</tr>
</tbody>
</table>

¹ For calls with the mobile phone on the GSM network the mean of the SARs for the GSM900 and the GSM1800 network was used because there was no differentiation between GSM900 and GSM1800 network in the mobile phone operator data.

Roser et al., IJERPH, 2015

Population RF exposure
Average cumulative dose

**Brain**
- Close to body: 96.2% Dose [mJ/kg/day]
- Far field: 3.8%

**Whole body**
- Close to body: 89.8% Dose [mJ/kg/day]
- Far field: 10.2%

Population RF exposure:
- Mobile phone calls
- Cordless phone calls
- Mobile data traffic
- Mobile phone stand-by data traffic
- WLAN Computer, laptops, tablets
- Broadcasting
- Mobile phone base stations
- WLAN access points
- DECT cordless phone base stations
- Mobile phones

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Figure 1: Estimated mean and maximum and minimal exposures of wireless network devices compared to other wireless sources (red: near-field sources; blue: far-field sources). These were compiled for the purpose of comparison at the end of the project and are subject to technology, usage, and implementation changes.

Population RF exposure

Seawind, Final Report, FP7-ENV-2009-1

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UMTS phones emit **100-500 times less** than GSM phones!

**GSM:**

<table>
<thead>
<tr>
<th>Study centre</th>
<th>No of calls</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>Interoperator range</th>
<th>No of calls</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>Interoperator range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweden</td>
<td>4185</td>
<td>118.2 (95.2)</td>
<td>101.6</td>
<td>67.6–146.5†</td>
<td>2366</td>
<td>52.1 (47.4)</td>
<td>36.2</td>
<td>45.5–68.7</td>
</tr>
<tr>
<td>Total</td>
<td>46994</td>
<td>133.3 (91.7)</td>
<td>127.2</td>
<td>67.6–204.0‡</td>
<td>29505</td>
<td>64.2 (45.5)</td>
<td>57.8</td>
<td>44.7–99.0‡</td>
</tr>
</tbody>
</table>

**UMTS:**

<table>
<thead>
<tr>
<th>Location</th>
<th>Median</th>
<th>Mean</th>
<th>90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>0.04</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Suburban</td>
<td>0.02</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Urban</td>
<td>0.02</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Dense urban</td>
<td>0.008</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Indoor net</td>
<td>&lt;0.008</td>
<td>0.2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Adapted from Vreiheid, OEM, 2009

Persson et al., BioEM, 2012

Population RF exposure
Dose Züme: assuming UMTS call only

Brain

Whole body

Population RF exposure

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Dose Züme: assuming max. downlink (0.51 V/m)

Brain

- Brain: 69.9% dose from mobile phone calls
- Brain: 30.1% dose from mobile data traffic

Whole body

- Whole body: 52.3% dose from mobile phone base stations
- Whole body: 47.7% dose from mobile phones

Population RF exposure

- Mobile phone calls
- Cordless phone calls
- Mobile data traffic
- Mobile phone stand-by data traffic
- WLAN Computer, laptops, tablets
- Broadcasting
- Mobile phone base stations
- WLAN access points
- DECT cordless phone base stations
- Mobile phones

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Exposure change over time

Mobile phone subscribers per 100 inhabitants (ITU, 2015)
Temporal trends in measurement surveys

Rowley et al., JESEE, 2012

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Temporal Variability in microenvironmental surveys (Total RF-EMF)

Outdoor areas

Public transport

Population RF exposure

Urbinello et al., *Env Res, 2014*
Comparison of adult exposure in Qualifex and Zürich study

Qualifex (Basel), 2007/2008 (n=131)

Population RF exposure
Mean HF-EMF: 117 μW/m² (0.21 V/m)
Mean Downlink: 26 μW/m² (0.10 V/m)
Mean Uplink: 46 μW/m² (0.16 V/m)

Zürich 2014/2015 (n=72)

Mean HF-EMF: 90 μW/m² (0.18 V/m)
Mean Downlink: 32 μW/m² (0.11 V/m)
Mean Uplink: 38 μW/m² (0.12 V/m)

* without own phone use
Conclusions

- Far field exposure levels considerably below ICNIRP guidelines.
- Environmental exposure levels remarkably constant in the last 10 years.
- Own use of devices close to body most relevant for cumulative dose.
- For head dose: mobile phone use most relevant, but highly dependent on technology and connection quality.
- For whole body dose: data transmission very relevant.
- Several aspects of exposure not well understood: stand-by, different data transmission technology, etc.
- A better understanding of the link between technology and exposure would allow efficient exposure reduction.