Using Personal Monitors and Sensors to Characterize Individual Exposures

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Map of the Talk

- External exposures and the Five Ws of the Exposome
- Role of new technologies
- Time geographies of exposure
- Ubiquitous and participatory sensing
- Examples from ongoing studies
- Challenges and outlook
Understanding the Five 
Ws of the Exposome

Need to assess external exposures for 
several reasons:

1. **What?** Many important exposures have no 
biomarkers (e.g., noise)
2. **When and Where?** Personal location and 
activity influence dose (e.g., biking busy 
roads)
3. **Why and Who?** To protect public health, we 
must understand the pathways from source 
to effect and who is exposed (e.g., 
manganese from food vs. pesticide 
exposures)
Time Geographies of Exposure

• Hagerstrand’s “Time Geography”
• Exposure can be viewed as summation of travel through “hazard fields” in space over time
• Understanding human activity during interaction with the hazard field helps move from “exposure” to likely “dose”
Space-Time Prism: What Exposures and Activity Levels?

Source: Shaw (2005)
Lifelines of Exposures

• What is the activity level, activity type and physiology at the moment of contact?

Source: Briggs and Gulliver (2005)
Activity Space a Major Determinant of PM$_{2.5}$ Exposure

FIGURE 5. Intraurban distribution of fine particulates in Los Angeles (1999).

Source: Jerrett and Finkelstein (2005)
What is the Activity Level in the Hazard Field?
Air Pollutant Concentrations on Bike Routes in 3-D

**Measurements of Ultrafine Particulate Matter**

- **UFPM, High Traffic Route**
- **UFPM, Low Traffic Route**

**UFPM Ratio**

- Max/Min value for High Traffic Route = 543.78
- Max/Min value for Low Traffic Route = 135.87

*0.0025 is the factor used to convert layer elevation values to scene units*
# Inhalations During Exercise by Mode of Transport

<table>
<thead>
<tr>
<th>MODE</th>
<th>Mean concentrations by travel mode and urban fixed site monitor (London, UK)</th>
<th>Typical inhalation rate (L/min)*</th>
<th>Typical journey duration for a 4km trip (minutes)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PM2.5 (ug/m3)</td>
<td>CO (ppm)</td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>39</td>
<td>35</td>
<td>0.8</td>
</tr>
<tr>
<td>Car</td>
<td>36</td>
<td>38</td>
<td>1.3</td>
</tr>
<tr>
<td>Bicycle</td>
<td>29</td>
<td>34</td>
<td>1.1</td>
</tr>
<tr>
<td>Walking</td>
<td></td>
<td>35</td>
<td>0.9</td>
</tr>
<tr>
<td>Subway</td>
<td>202</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed site monitor</td>
<td>14</td>
<td>10</td>
<td>0.3</td>
</tr>
<tr>
<td>Reference</td>
<td>(Adams et al. 2001)</td>
<td>(Kaur et al. 2005)</td>
<td></td>
</tr>
</tbody>
</table>

Source: de Nazelle et al. 2011
Micro-Time Geographies
Affect Exposure

Source: Courtesy of E. Avol and Port of Long Beach (2005)
Estimate of In-Vehicle Fraction of Total UFP Exposure in LA

- **Typical UFP concs (1000s/cm³) and times:**

<table>
<thead>
<tr>
<th>Location</th>
<th>Time</th>
<th>Conc (25th %, 75th %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>11.5 hrs</td>
<td>7.6 (7.1, 8.9)</td>
</tr>
<tr>
<td>Residential (cooking)</td>
<td>0.5 hrs</td>
<td>20 (breakfast) (0, 25)</td>
</tr>
<tr>
<td></td>
<td>1.5 hrs</td>
<td>33 (dinner) (0, 50)</td>
</tr>
<tr>
<td>(Wallace et al., 2004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workplace (office)</td>
<td>8 hrs</td>
<td>5.3 (1.3, 11)</td>
</tr>
<tr>
<td>Outdoors</td>
<td>1 hr</td>
<td>21 (13 to 27)</td>
</tr>
<tr>
<td>In-vehicle, arterial</td>
<td>0.5 hr</td>
<td>58 (morning) (41 to 76)</td>
</tr>
<tr>
<td></td>
<td>0.5 hr</td>
<td>33 (afternoon) (24 to 53)</td>
</tr>
<tr>
<td>In-vehicle, freeway</td>
<td>0.25 hr</td>
<td>204 (morning) (126 to 253)</td>
</tr>
<tr>
<td></td>
<td>0.25 hr</td>
<td>90 (afternoon)</td>
</tr>
</tbody>
</table>

Wt’d avg. conc. of ~14,000/cm³

- **36% exposure from in-vehicle time (range 33% to 45%)**

- **Source:** Fruin et al. (2007) and personal communication
Time Geographies

- Important, but have remained more theoretical construct than empirical reality

- Or attempts to develop them have had to rely on simulation models which often have had weak data support

- New technologies offer the first realistic possibility of direct measurements on large numbers of subjects

- Opportunity to understand “micro-geographies” of personal exposure – which can be used in epidemiological studies and everyday life
Older Instruments

- Static Global Positioning Systems (GPS)
- Mobile GPS
- Accelerometers
- Personal pollution monitors (large back packs)
Earlier GPS Loggers (circa 2001)
Leading Current GPS Logger

- Highly accurate WAAS enabled
- 24 hour logging
- Bluetooth
Accelerometers

- Commercial accelerometer to measure activity earlier version 2 axel
- Newer version 3 axel – more sensitive to different kinds of movement
- Onboard logging 4 weeks
- No integration with other kinds of sensors

Old Model

New Model
Physical Activity and Location

Source
Almanza et al. (2011)
Traditional Personal Air Pollution Monitoring Backpack

- Bulky and heavy
- Limited logging to 48 hours
- Calibration usually needed by trained staff
- Restricts normal movement

Source: Choi et al. (2008)
Ubiquitous Sensing: Part of the Solution?

- Rapid evolution of ubiquitous cyber-social and physical systems presents new opportunities for exposure science

- Pervasive sensing of personal activity, physiological parameters and ambient conditions now possible

- “The future is already here, it’s just not very evenly distributed” Gibson 1999
A Ubicomp World

• Following the vision of Mark Weiser – ubiquitous computing or “ubicomp”

• The complete embedding of computational technology into our everyday lives

• Being driven by health care sector (e.g., field of telemedicine) and other commercial applications related to mobile phones (now 4.5 billion cell phones globally, 3.5 billion more than the next most popular computing platform – the PC)
Emerging Technologies Based on “Ubiquitous” Sensing with Cell Phones

Wireless body sensor network (2009)

Smartphone 2010-11
Ubiquitous Sensing Pilot Study in Barcelona Spain with CalFit Cell Phone GPS and Accelerometer

Pilot study:

1. Ubiquitous sensing with novel smart phone technology: CalFit

2. Objective measures of physical activity and activity location to test and validate a travel survey
Travel Survey Pilot and CalFit Validation

Thirty six volunteers

Travel questionnaire

During 5 days:
  • travel diary
  • three activity measurement devices:
    • CalFit
    • Actigraph
    • Bodymedia Sensewear
All GPS data from Calfit pilot study volunteers

On average 19% of daily waking hours missing per person.
MIT Personal Video Playback and Galvanic Skin Response

Source Laibouwitz et al. (2008)
Stress Modifies Effects of Air Pollution on Asthma

Effect of NOx (Total) on Incident Asthma Across Parental Stress Quartiles

Source Shankardass et al. (2009 PNAS)
Other Possibilities

1. A rest at campus gate
2. Walk through campus
3. A rest at campus gate
4. Walk along traffic arterial
5. Walk to downtown

(b) Histogram of KJ/min with density.
(d) Map overlay of routes with dots indicating points of interest.
Real-time CalFit and Micro-aethalometer or Aerocet Particle Counter
Pollution and Energy Expenditure

Seto et al. (2009)
Integrated Sensing
Common Sense: Enabling Distributed Air Quality Monitoring
http://www.citizensensing.org (Courtesy of Dutta 2009)

Sensors
- GSM/GPRS
- Bluetooth
- NOx Sensor
- O3 Sensor #2

Visualization

Empowerment
- GPS
- Wireless Sensors
- Temperature/Humidity
- CO Sensor
- O3 Sensor #1
Make-AQ air pollution sensing

- $Dose(t) = conc(t) \times minute_{ventilation}(t)$
Individual, Participatory, Groups: the Future?
Sensaris City Senspod

- Monitors ozone, carbon monoxide, nitrogen oxides, noise, UV exposure
- Uploads to social network of other participants via WWW
- Provides network of monitoring data and near real time info – launched in Paris this summer
Challenges

Ethical/Institutional
- Privacy issues
- Data ownership and protection

Analytical
- Massive amounts of data
- Models are computationally intensive
- Methods for analysis lagging
- Need to think about how to analyze too much data rather than too little!
Challenges (Contd.)

Technological

- Battery life and development of renewable energy sources
- Coordinating various embedded systems
- Adapting systems designed for telemedicine to exposure assessment
Future Trends

• Integrated activity, physiology, and exposure monitoring available in real time
• Shared networks of “senspods” that use social networks combined with real-time wireless communication
• Innovation fueled by numerous technological advances in micro-chips, power sources, and software engineering from telemedicine
• These “disruptive technologies” will change the way we conduct exposure science
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