Using Silicone Wristbands to Assess the Personal Chemical Exposome: Strengths and Limitations

Heather M. Stapleton, Ph.D.
Ronie-Richele Garcia-Johnson Distinguished Professor
Email: heather.stapleton@duke.edu

CENTER FOR ENVIRONMENTAL EXPOSOMICS

NICHOLAS SCHOOL OF THE ENVIRONMENT
DUKE UNIVERSITY
forging a sustainable future

Conflicts of Interest

- Serve as a Science Advisor for the San Franscisco Estuary Institute Regional Monitoring Plan Emerging Contaminants Workgroup

- Research funded by:
  - National Institutes of Health
  - Environmental Protection Agency
  - Housing & Urban Development
  - North Carolina Collaboratory Program
  - Michael & Annie Falk Foundation, V Foundation, Thyca
  - Duke University Cancer Institute

The Exposome

- Research on the exposome seeks to assess the totality of ***exposures over the life course*** and understand how these combined stressors impact health.
- Can we use wristbands and wearables to assess ***patterns of exposure***, particularly based on:
  - Behaviors
  - Housing characteristics/consumer products
  - Occupation
  - Temporal changes

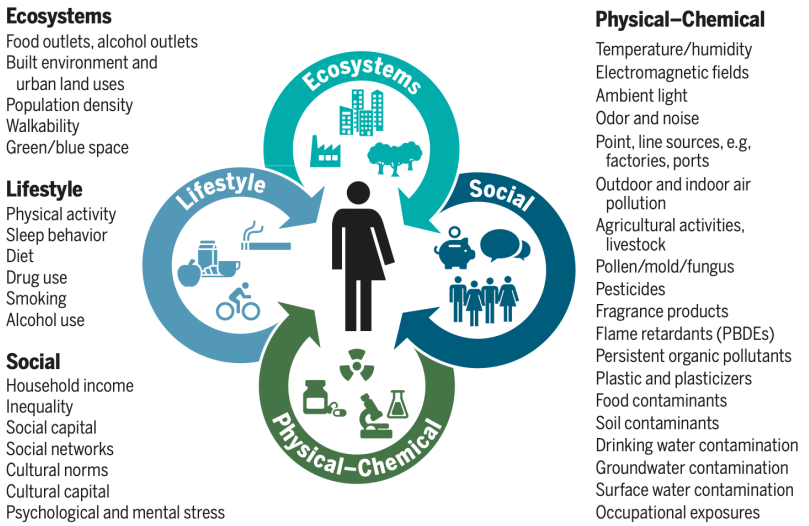
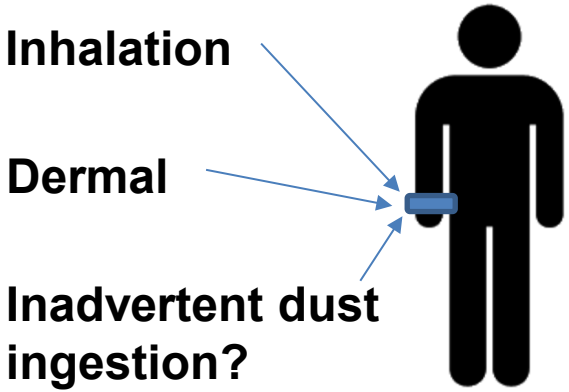


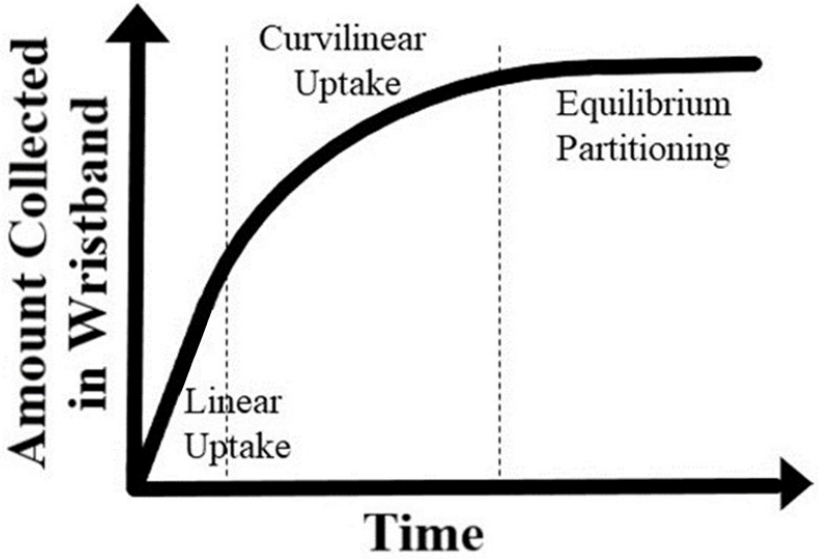
Fig. 1. The exposome concept. The exposome is an integrated function of exposure on our body, including what we eat and do, our experiences, and where we live and work. The chemical exposome is an important and integral part of the exposome concept. Examples of external stressors are adapted from (*39*). These stressors are reflected in internal biological perturbations (Fig. 3); therefore, exposures are not restricted to chemicals (toxicants) entering the body, but also include chemicals produced by biological and other natural processes.

Source: Vermeulen et al. 2020

Wearable Samplers:
The Silicone Wristband

Exposure Routes



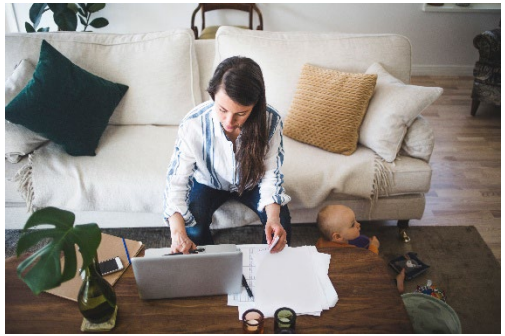


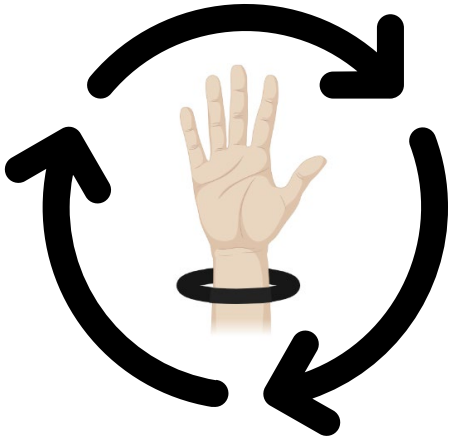
Samon et al. 2022

Integrates Exposure Measures Across Different Micro-environments & Over Time

Commuting

Home





Work

Or Focus on One Micro-Environment

Occupational

Overview

Wristband Analyses

Questions

- How well do wristband measurements correlate with internal dose?
- How long should you wear a wristband?
- Can children wear them?
- Do wristbands predict internal dose better than house dust?
- Is there variability in chemical levels around the wristband?

Wristband Studies

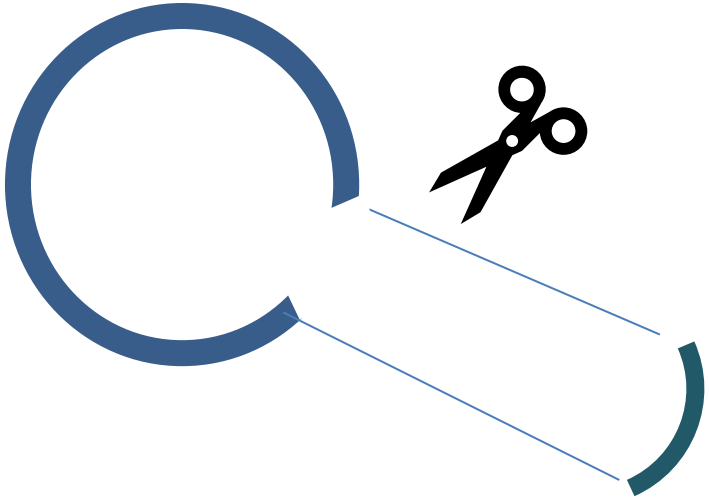
- Chemical exposures in firefighters

Strengths & Limitations

Wristband Analyses

Analytical Details

Wristband (WB)



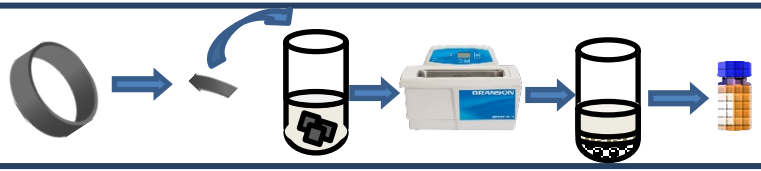
~1/5 of WB
(~0.7 grams)

Current Wristband Analysis Overview

Sample Preclean Treatment

Sample Deployment & Collection

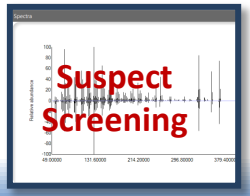
Laboratory Analysis



Methanol Extract

GC-HRMS EI

- 9 Brominated Flame Retardants (BFRs)
- 30 Organophosphate Esters (OPEs)
- 25 Polycyclic Aromatic Hydrocarbons
- 21 Pesticides
- 12 Phthalates
- 13 Polychlorinated Biphenyls (PCBs)
- 3 industrial and personal care chemicals



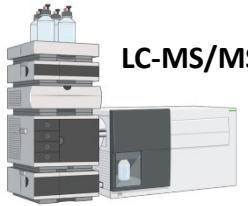
GC-MS ECNI

- 9 High Molecular Weight BFRs
  - e.g BEHTBP
  - BDE 209
  - DBDPE
- 17 dioxins/furans
- ....

GC-HRMS PCI

- 13 Volatile PFAS:
- n:2 Fluorotelomer Alcohols,
- n:2 Fluorotelomer Acrylate & Methacrylates
- Sulfonamidoethanols (i.e. MeFOSE)
- ...

LC-MS/MS

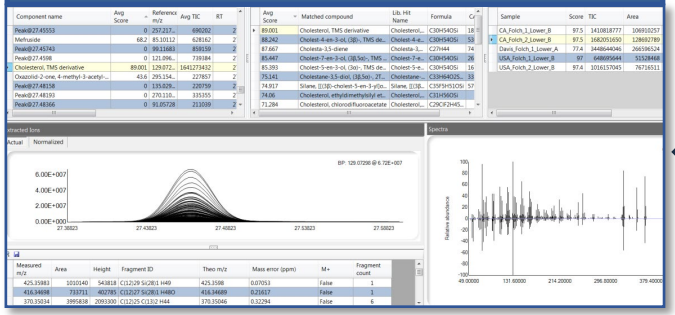


- LC Amenable targets:
- 48 PFAS: PFAAs, FTS, PAPs, FOSAA, Gen X, etc.
- Parabens (Methyl, Ethyl, Propyl)
- Triclosan, Triclocarban
- ...

Suspect Screening: Workflow Summary

Nicholas Herkert, PhD

Deconvolution, Alignment, & Library Matching



Libraries
- NIST
- Thermo Hi-Res
- In-house

Feature QA/QC
- Blank Subtraction
- Standard Normalization

PubchemLite
- Patent counts
- PubMed Entries

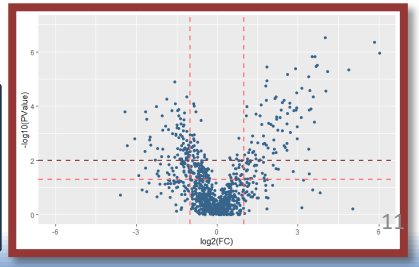
Product Uses
- Current **CPCAT**
- Soon to be **ChemExpo**

Feature Annotation
- Patent Counts
- Product Uses

Rank Matches
- Return top Match

Output

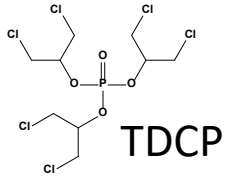
Feature Analysis
- Volcano Plots
- Summary Stats
- Correlations



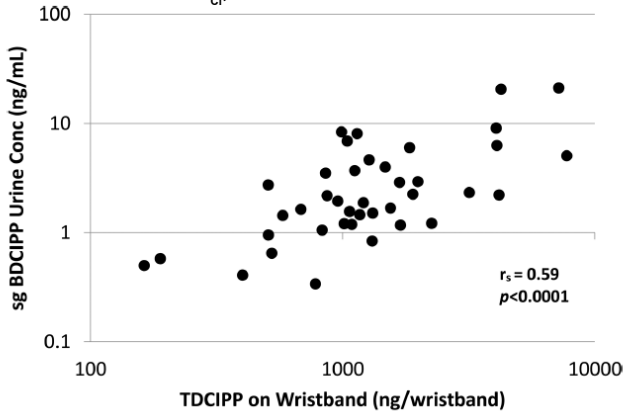
Herkert et al (2024) Environ. Sci. Tech

Are measurements of chemicals on wristbands correlated with internal dose?

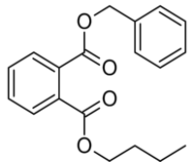
Wristbands correlated with urinary metabolites



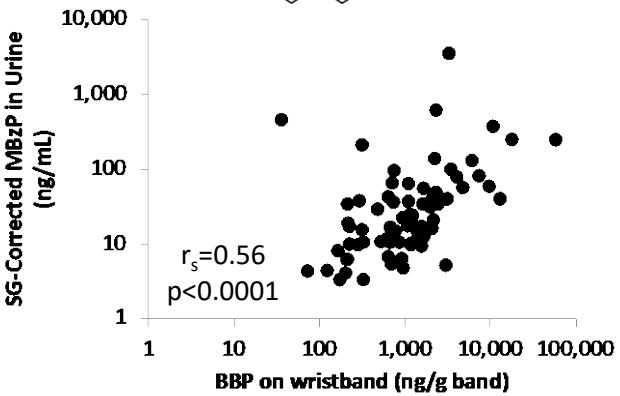
TDCPP



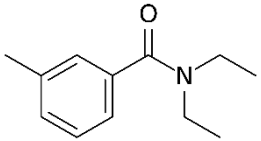
Hammel et al. 2016



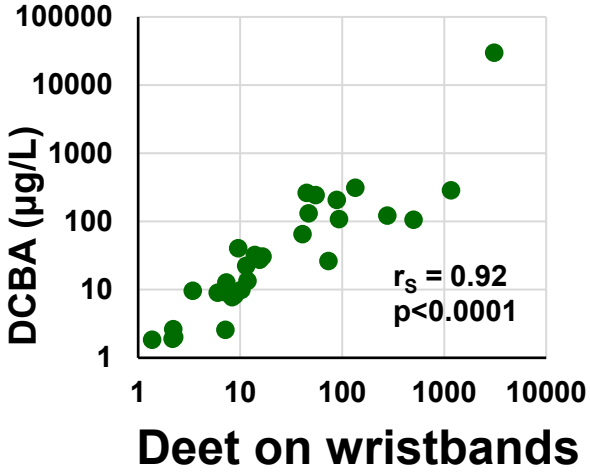
BBP



Hammel et al. 2020



DEET

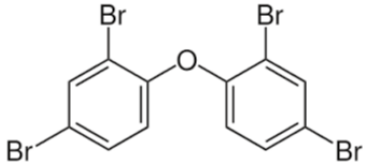


Wise et al. 2022

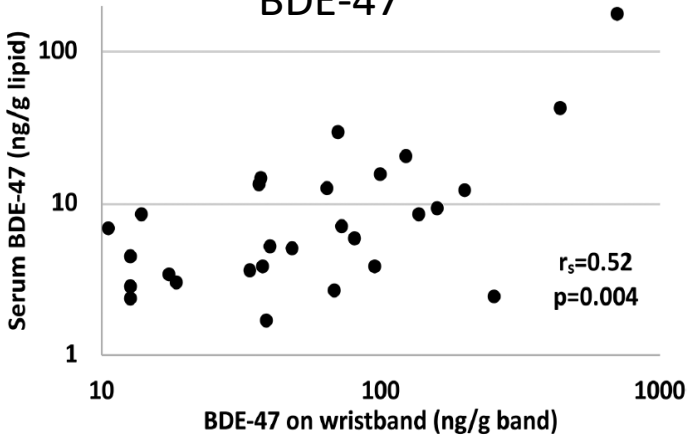
* All urine samples are pooled from three 1st morning voids

Wristband measurements correlated with blood

Brominated Flame Retardants

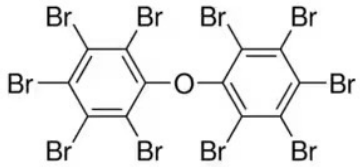


BDE-47

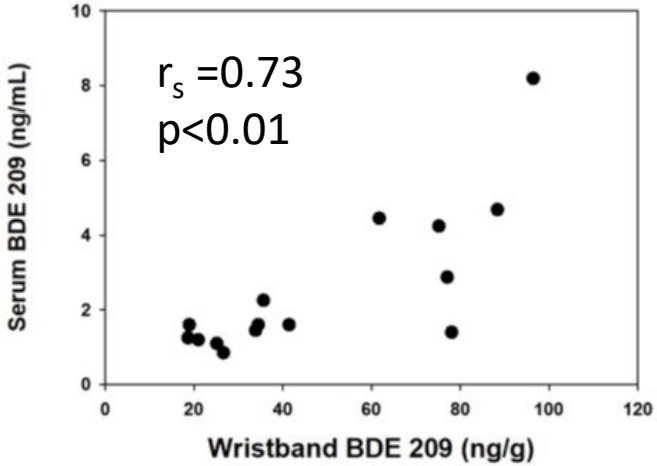


Hammel et al. 2018

Half- life ~ 1.8 years



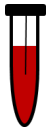
BDE-209

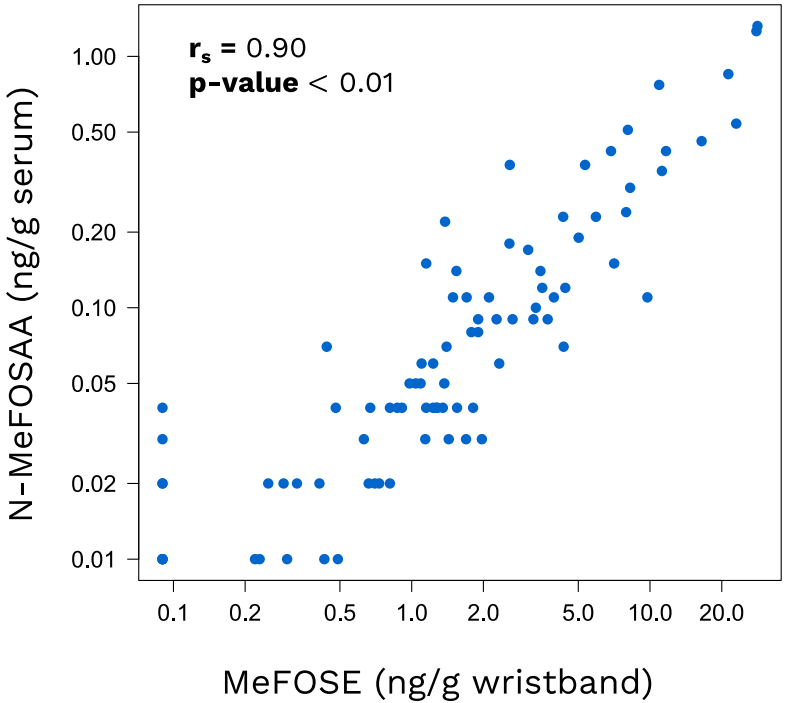


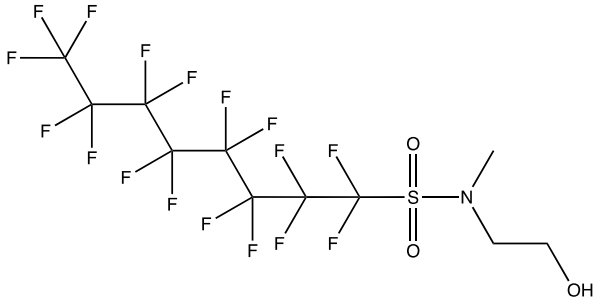
Hoffman et al. 2024

Half- life ~ 2 weeks

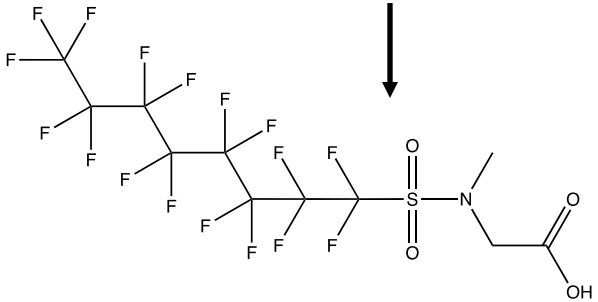
Volatile PFAS







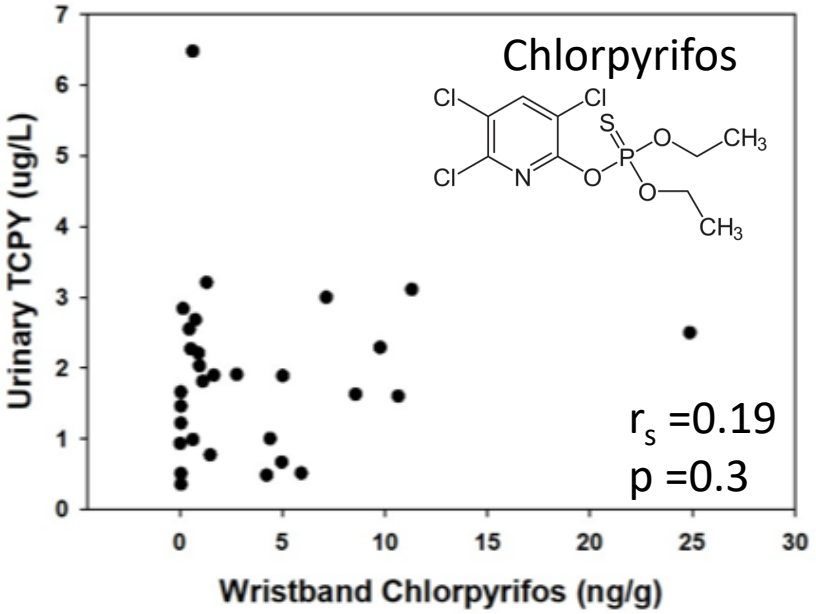
MeFOSE



N-MeFOSAA

Hoxie et al. 2024

Not all chemicals are correlated



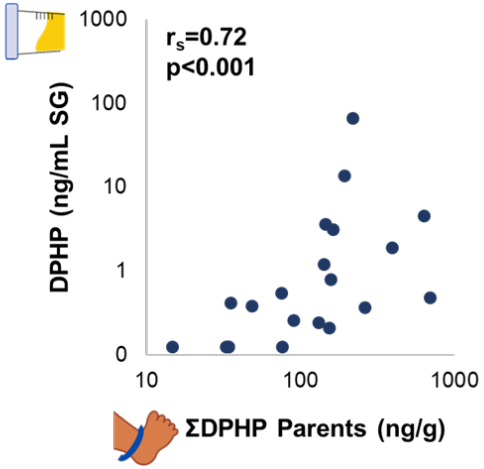
NC Data: Wise et al. 2022

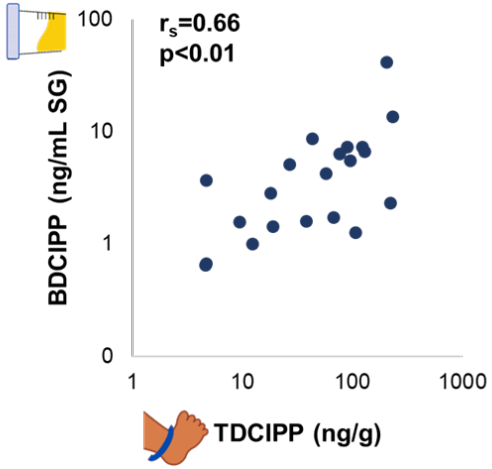
- Detection frequencies
  - Wristband = 83%
  - Urine = 100%
- Suggests diet is likely more important exposure route in NC
- **However, a significant & positive correlation was identified in Central America agricultural area (Tore, et al. In Draft)**

Use in Infants- Ankle Band

n = 21
6-18 months

3 days





Wise et al., Accepted

Do wristband levels correlate with internal dose better than house dust & hand wipes?

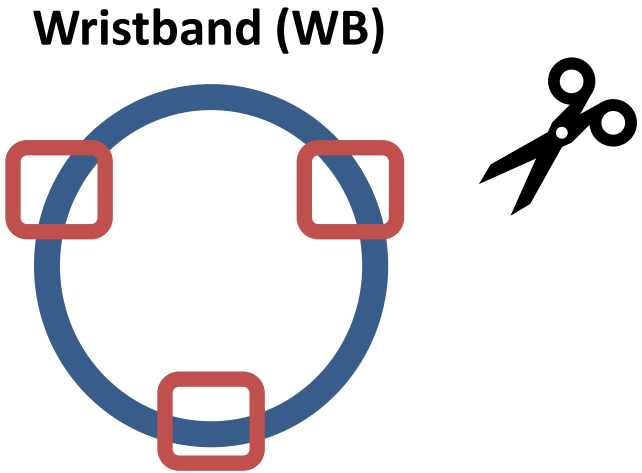
Spearman correlation coefficients

(with urine or serum biomarker; n=77) * - statistically significant

	Analyte Pair	Wristband	Handwipe	House Dust	
Organophosphate Flame retardants/ plasticizers	TDCPP - BDCIPP	0.52*	0.48*	0.13	Urine Correlations
	4tBDPP- tbPPP	0.35*	0.16	0.05	
Phenols	Ethyl paraben	0.66*	0.48*	0.34*	
	Triclosan	0.51*	0.50*	0.16	
Phthalate Plasticizers	Diethyl phthalate- MEP	0.41*	NA	0.17	
	Benzyl butyl phthalate- MBzP	0.56*	0.56*	0.23*	
Brominated Flame Retardant	BDE-47 (n=19)	0.73*	0.71*	0.57*	Serum Correlations

Phillips et al., 2018; Hammel et al., 2020; et al., 2021; Hoffman et al., 2024

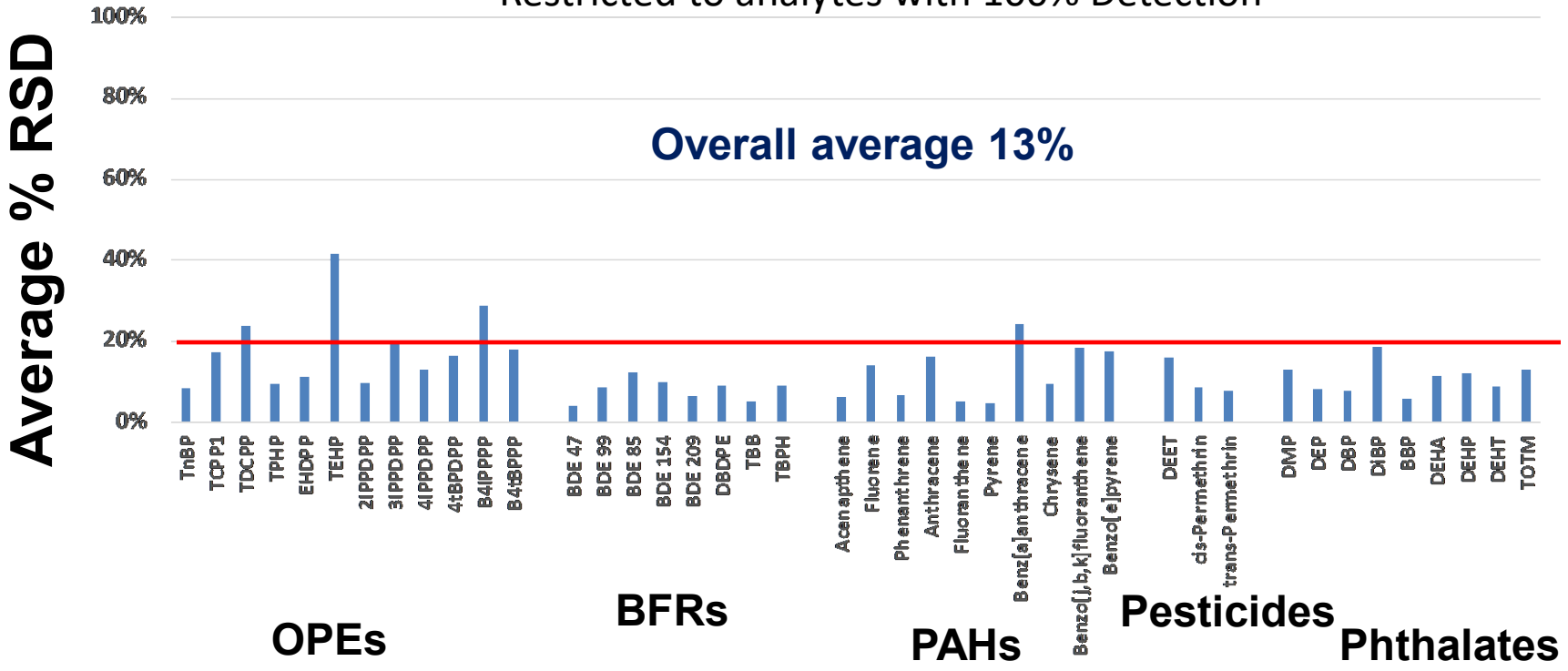
How variable are chemical measurements around the wristband?



Measurement precision around the wristband

N= 10 wristbands

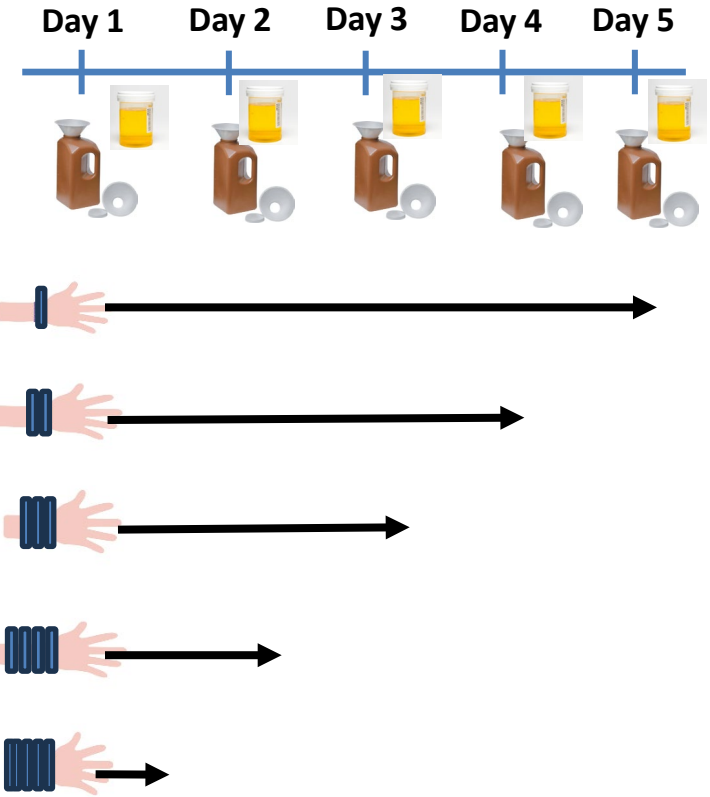
* Restricted to analytes with 100% Detection

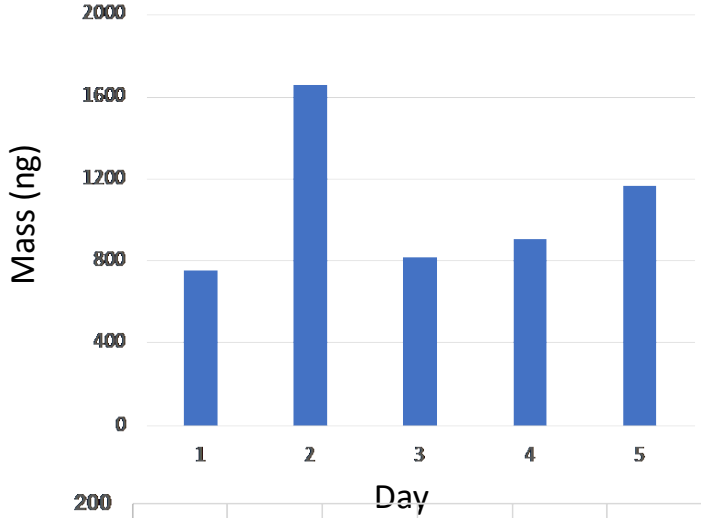


Levasseur et al., 2022

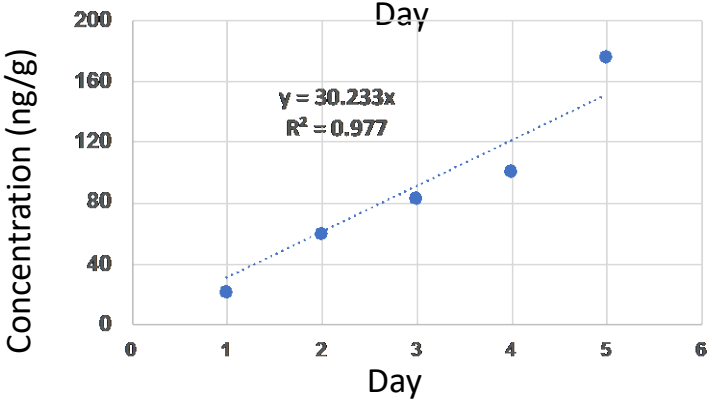
How do wristband levels compare to spot urine?

Experimental Design



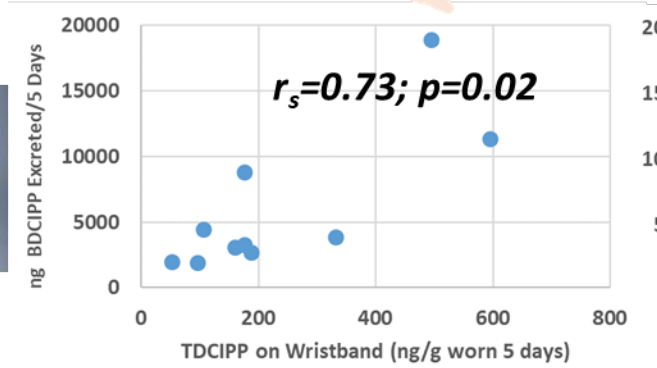


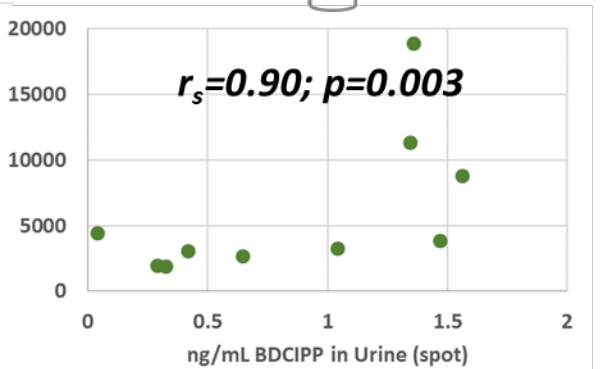
Urinary Metabolite

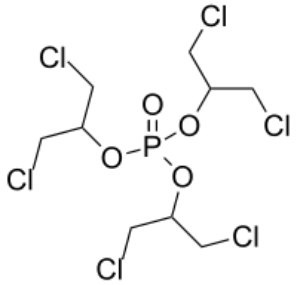


Parent Chemical

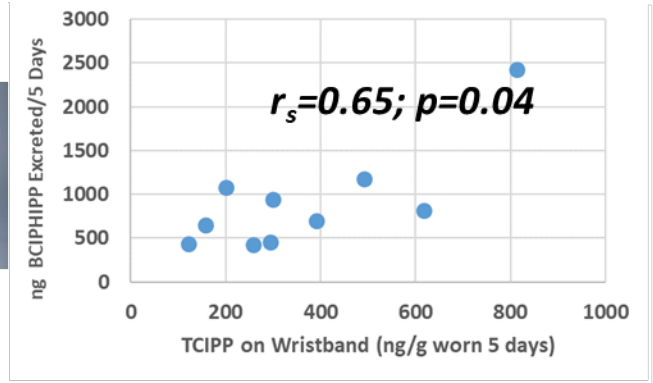
Wristbands or Spot Urine?

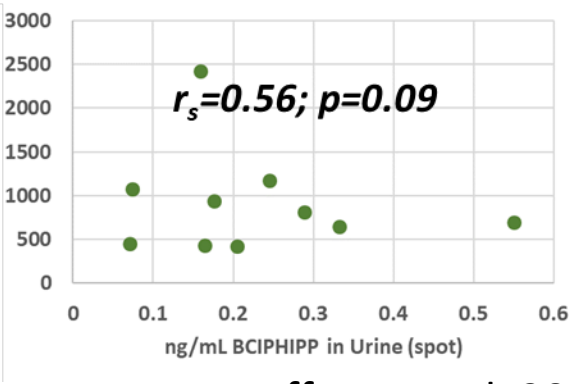


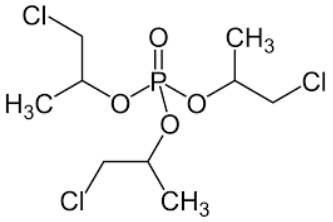




TDCIPP



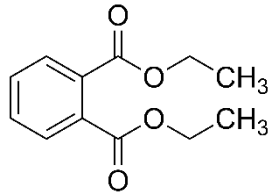




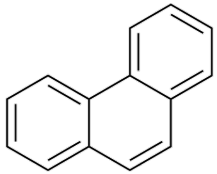
TCIPP

Hoffman et al. 2021, Levasseur et al. 2024

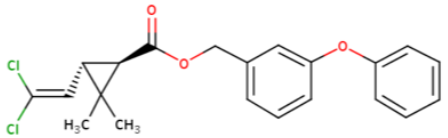
Chemical Accumulation Over 5 Days



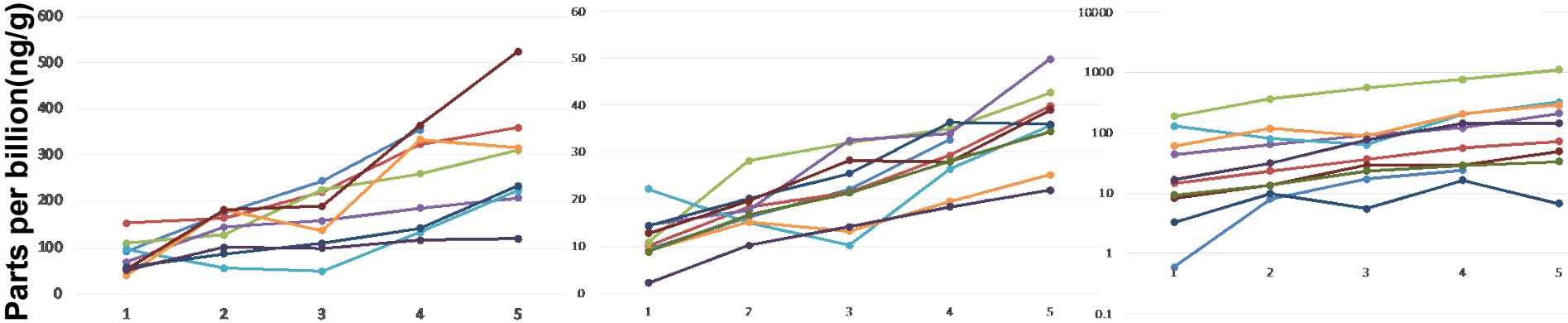
Diethyl phthalate



Phenanthrene



Trans-Permethrin



Sampling Days

Wristbands worn for 1, 2, 3, 4 or 5 days

Samon et al. 2024

Using Wristbands to Assess Firefighters Exposures

Characterizing Exposures in Firefighters

Jessica Levasseur PhD student

- Research collaboration with firefighters in Durham, NC
- Each firefighter was asked to wear silicone wristbands for 6 days while during the following three periods:

Home

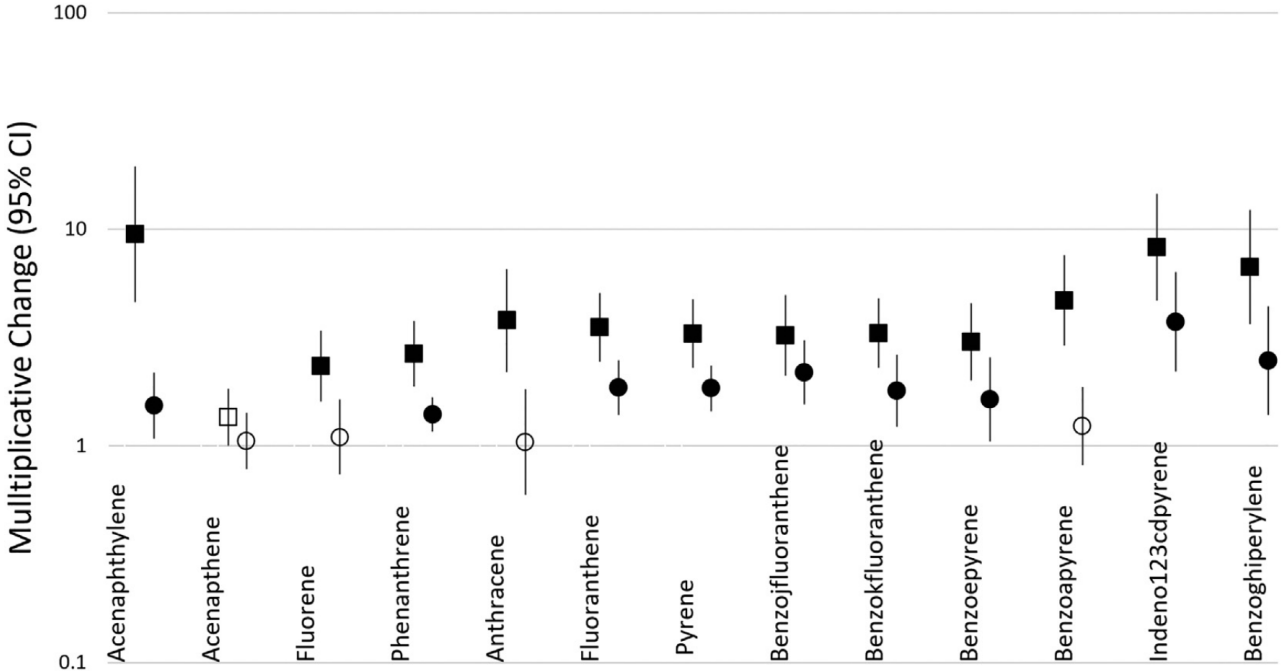
Work
(no fire event)

Work
(fire event)

Question: How do chemical exposures change on-duty vs off-duty? When responding to a fire?

Levasseur et al., 2022

PAH Exposures in Firefighters



On-Duty + Fire

On-Duty + No Fire

- PAHs exposure elevated during fires

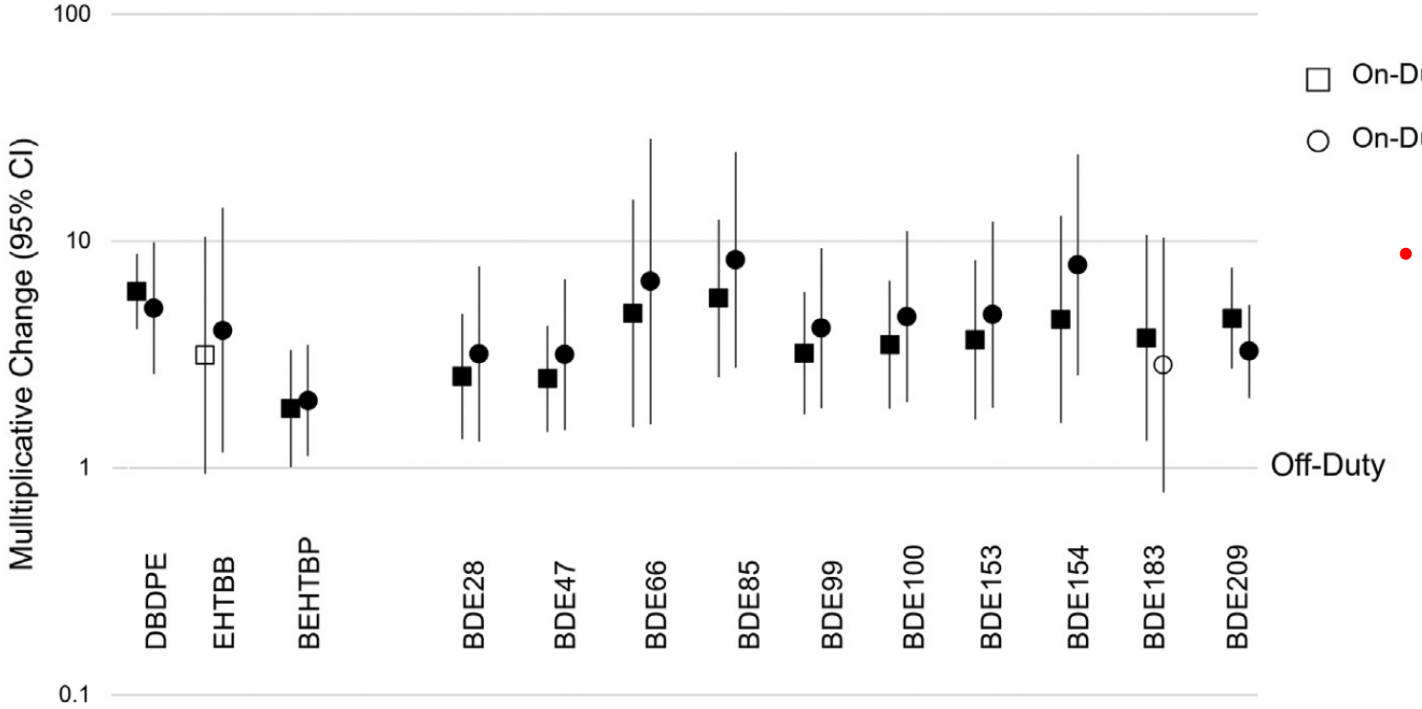
Off-Duty (reference)

- Why are PAH exposures higher when not responding to a fire?

* Filled symbols are statistically significant ($p<0.05$)

Levasseur et al., 2022

BFR Exposures in Firefighters

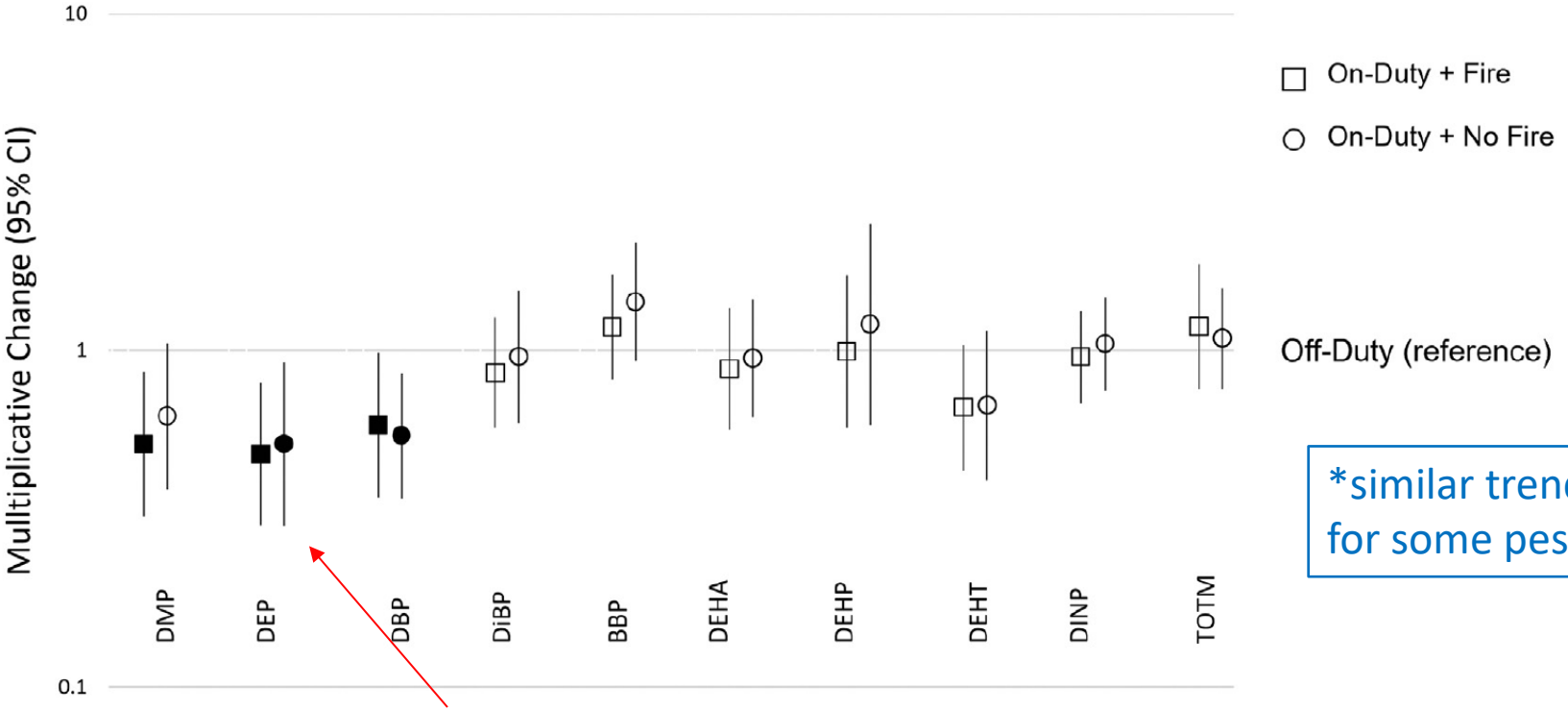


- Why are BFR exposures higher when not responding to a fire?

* Filled symbols are statistically significant ($p<0.05$)

Levasseur et al., 2022

Phthalate Exposures in Firefighters

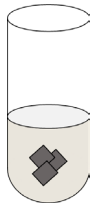


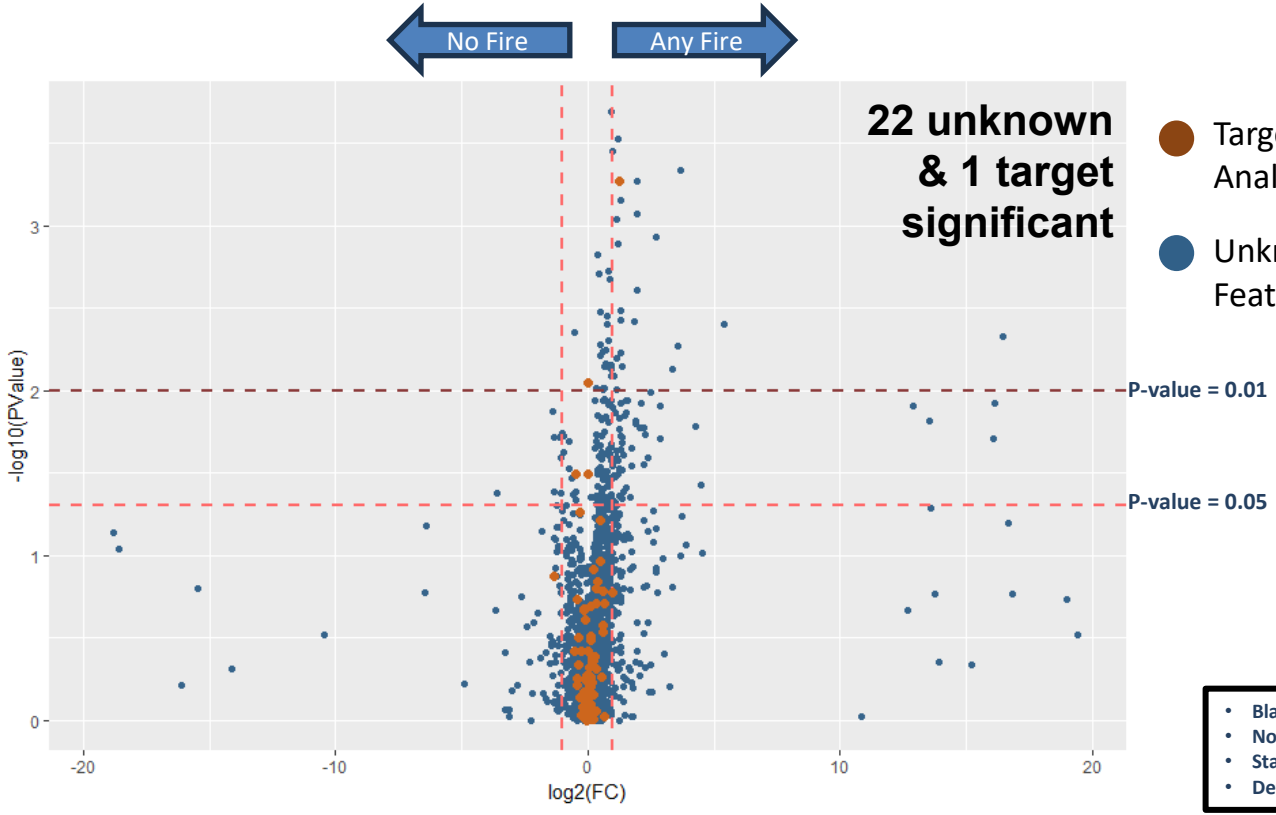
*similar trend for some pesticides

Used in personal care products

Levasseur et al., 2022

Bands with Any Fire Event

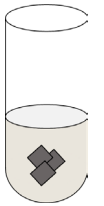




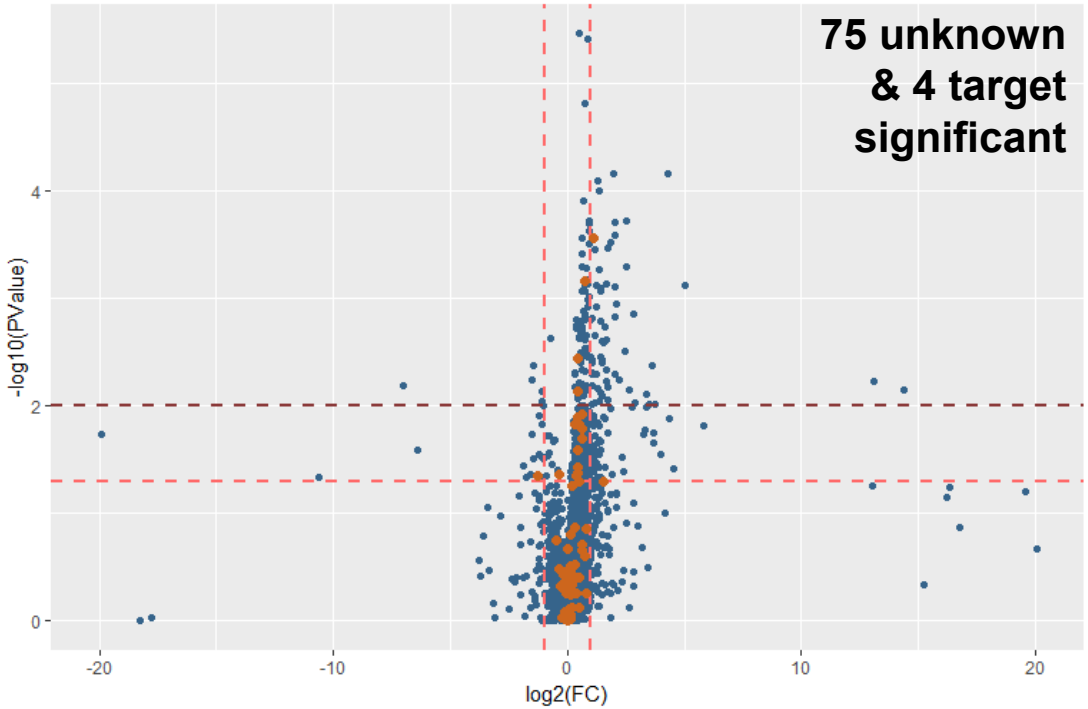
- Blank Subtracted (MDL/2)
- Nonparametric Test
- Standard Normalized
- Detected > 50% samples

Preliminary Data

Time Spent at Fire



Median – 0.75 hr



Target Analyte

Unknown Feature

Significance of difference between two conditions

P-value = 0.01

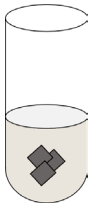
P-value = 0.05

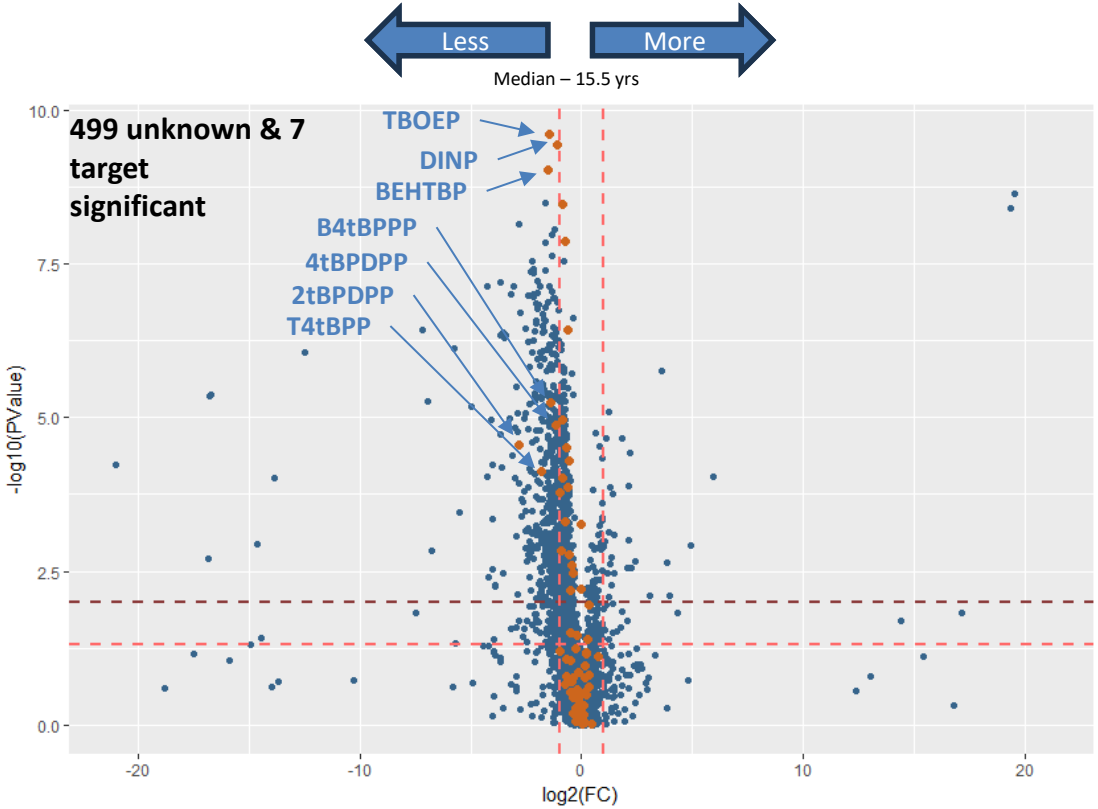
- Blank Subtracted (MDL/2)
- Nonparametric Test
- Standard Normalized
- Detected > 50% samples

Magnitude of Change between two conditions (i.e. fold change)

Preliminary Data

Years as a Firefighter





Significance of difference between two conditions

Magnitude of Change between two conditions (i.e. fold change)

Target Analyte

Unknown Feature

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P-value = 0.05

- Blank Subtracted (MDL/2)
- Nonparametric Test
- Standard Normalized
- Detected > 50% samples

Preliminary Data

Wristband Measurements: Using them in an Exposure Framework

Estimate Indoor Air Concentrations?

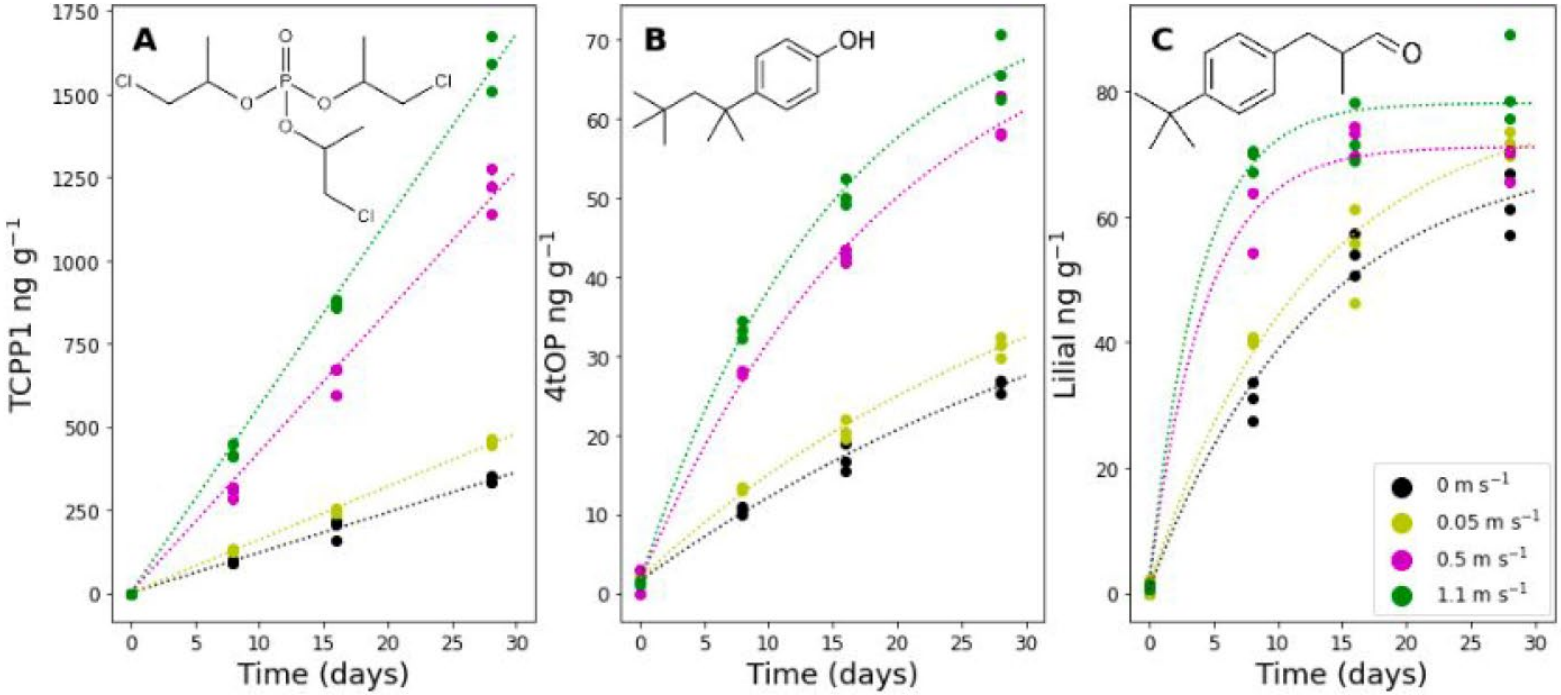
Estimate Internal Dose?

Are wristband measurements influenced by movement?

Heileen Hsu-Kim
Professor

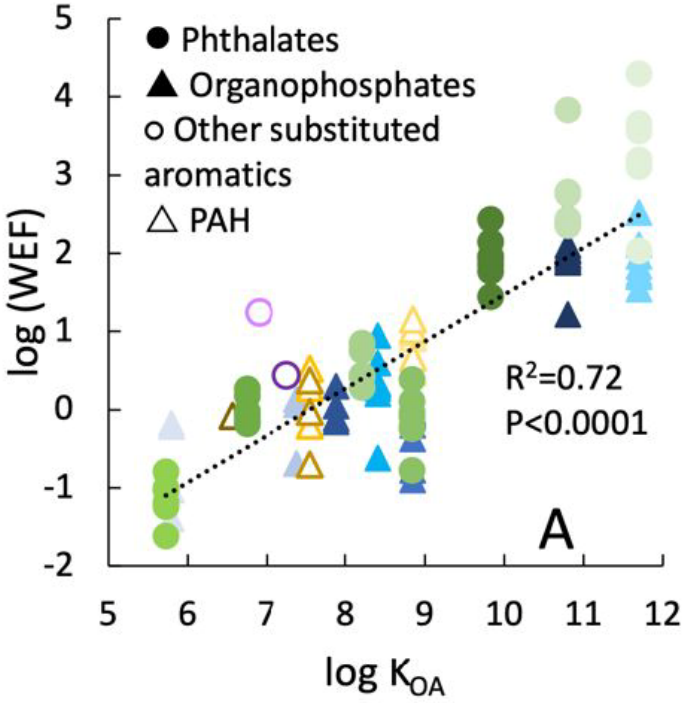
Josh Miller
PhD Student

Chemical accumulation as a function of movement



Miller et al., 2025

Implications



- Graph depicts enrichment of chemicals in worn wristbands compared to wristbands rotating at 1.1 m/sec
- Enrichment is a function of the Log K_{oa}
- Suggests that uptake on wristbands is a complex process, not driven solely by gas phase partitioning

Miller et al., 2025

Advantages of Using Silicone Samplers

- ✓ Non-invasive tool for measuring exposure to hundreds of chemicals using targeted & nontargeted approaches
- ✓ Integrate exposure to hundreds of chemicals ***over time***
- ✓ Can be easily mailed back and forth (no clinic visit!)
- ✓ Can help us understand patterns of exposure over space and time
- ✓ Wristbands can help reach & engage isolated communities

Behavior

Built Environment

Limitations of Using Silicone Samplers

- Not applicable for measuring metals
- Applicability may be limited for:
  - Very water soluble/ionic chemicals (e.g. glyphosate, PFBS)
  - Very volatile chemicals (e.g. toluene, MTBE)
- Unclear whether confounding occurs based on:
  - Hand dominance
  - Clothing (long sleeves vs short sleeves)
  - Physical activity
- Need more studies to determine at what point chemicals are no longer in the linear range of uptake

Ongoing Wristband Studies

CKDu CURE

CEECR
Cohorts for Environmental Exposures and Cancer Risks

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Corey Miller

Chief Wayne Cheek

National Institute of Environmental Health Sciences
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United States Environmental Protection Agency

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HHEAR Human Health Exposure Analysis Resource

U2C ES030851

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