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AND DISEASE REGISTRY

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CENTERS FOR DISEASE CONTROL AND PREVENTION

Synthetic Turf Field Recycled Tire Crumb Rubber Research Under the Federal Research Action Plan

FINAL REPORT PART 2– EXPOSURE CHARACTERIZATION VOLUME 1

Centers for Computational Toxicology and Exposure, Environmental Measurement and Modeling, Environmental Solutions and Emergency Response, and Public Health and Environmental

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Synthetic Turf Field Recycled Tire Crumb Rubber Research Under the Federal Research Action Plan

Final Report Part 2 – Exposure Characterization

Volume I

April 16, 2024

By

U.S. Environmental Protection Agency / Office of Research and Development (EPA/ORD)

Centers for Disease Control and Prevention / Agency for Toxic Substances and Disease Registry (CDC/ATSDR)

Disclaimer

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Foreword

The U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) and the Centers for Disease Control and Prevention (CDC) Agency for Toxic Substances and Disease Registry (ATSDR) have worked collaboratively to complete the research activities on synthetic turf playing fields under the "Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds" (FRAP). The Agencies have released the research activities' results in two parts. The Part 1 Report (U.S. EPA & CDC/ATSDR, 2019) summarizes the research effort to characterize tire crumb rubber, which includes characterizing the components of, and emissions from, recycled tire crumb rubber. The exposure characterization report (Part 2 – this report) summarizes the potential exposures that may be experienced by users of synthetic turf playing fields with recycled tire crumb rubber infill, such as how people come in contact with the materials, how often and for how long. It includes the results from a supplemental biomonitoring study conducted by CDC/ATSDR. This Part 2 exposure characterization report completes FRAP efforts with respect to playing fields.

The study is not a risk assessment; however, the results of the research described in the FRAP reports will advance our understanding of exposure to inform the risk assessment process. We anticipate that the results from this multi-agency research effort will be useful to the public and interested stakeholders to understand the potential for human exposure to chemicals found in recycled tire crumb rubber used on synthetic turf fields.

This report has been prepared to communicate to the public the research objectives, methods, results and findings for the exposure characterization research conducted as part of the Federal Research Action Plan. The report has undergone independent, external peer review in accordance with EPA and CDC policies. A response-to-peer review comments document accompanies the release of the Part 2 report.

The mission of the EPA is to protect human health and the environment so that future generations inherit a cleaner, healthier environment that supports a thriving economy. Science at EPA provides the foundation for credible decision-making to safeguard human health and ecosystems from environmental pollutants. ORD is the scientific research arm of EPA, whose leading-edge research helps provide the solid underpinning of science and technology for the Agency. ORD supports six research programs that identify the most pressing environmental health research needs with input from EPA offices, partners and stakeholders.

CDC works 24/7 to protect America from health, safety and security threats, both foreign and in the United States. ATSDR is a non-regulatory, environmental public health agency that was established by Congress under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980. ATSDR protects communities from harmful health effects related to exposure to natural and man-made hazardous substances by responding to environmental health emergencies; investigating emerging environmental health threats; conducting research on the health impacts of hazardous waste sites; and building capabilities of and providing actionable guidance to state and local health partners.

Maureen Gwinn
Principal Deputy Assistant Administrator for Science
EPA Office of Research and Development

Aaron Bernstein
Director
Agency for Toxic Substances and Disease Registry

Authors, Contributors, and Reviewers

Lead Authors:

Kent Thomas	U.S. EPA, Office of Research and Development, Center for Public Health and Environmental Assessment (EPA/ORD/CPHEA)
Elizabeth Irvin	Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry (CDC/ATSDR)
Annette Guiseppi-Elie	U.S. EPA, Office of Research and Development, Immediate Office of the Assistant Adminstrator (EPA/ORD/IOAA)
Angela Ragin-Wilson	Centers for Disease Control and Prevention, Agency for Toxic Substances and Disease Registry (CDC/ATSDR)
José Zambrana, Jr.	U.S. EPA, Office of Research and Development, Center for Environmental Measurement and Modeling (EPA/ORD/CEMM)

Collaborating Federal Organizations:

U.S. Consumer Product Safety Commission

U.S. Defense Centers for Public Health-Aberdeen (former U.S. Army Medical Command, Army Public Health Center)

Contributing Authors:

Authors	Affiliation
Kelsey Brady, Michael Lewin, Zheng Li, Teresa Wang	CDC/ATSDR
Nichole Brinkman	EPA/ORD/Center for Environmental Solutions and Emergency Response (CESER)
Matthew Clifton, Carry Croghan, Kasey Kovalcik, Georges-Marie Momplaisir, Karen Oliver, Gene Stroup, Mark Strynar, Xiaoyu Liu, Brian Schumacher	EPA/ORD/CEMM
Peter Egeghy, Monica Linnenbrink	EPA/ORD/Center for Computational Toxicology and Exposure (CCTE)
Marsha Morgan	EPA/ORD/CPHEA
Barbara Jane George, Steven Gardner, Edward Heithmar, Ashley Jackson, Jianping Xue, Donald Whitaker, Larissa Hassinger (Student Services Contractor [SSC], Oak Ridge Associated Universities [ORAU]), Linda Phillips	Formerly with the U.S. EPA, Office of Research and Development
Chris Carusiello, Ksenija Janjic	U.S. EPA, Office of Land and Emergency Management, Office of Resource Conservation and Recovery (EPA/OLEM/ORCR)
Brandon Law, Aleksandr Stefaniak	CDC, The National Institute for Occupational Safety and Health (CDC/NIOSH)

Contributors:

Contributors	Affiliation
Emily Adler, Tyra Barrett, Carol Cusack, Michelle Dittrich, John Marr, Miranda Mitchell, Christopher Mugford, Chris Poulet, Nykiconia Preacely, Tara Serio, Timothy Turner, Aaron Grober, Britnee Bailey, Julianne Botelho, Antonia Calafat, Joaudimir (Joy) Castro Georgi, Alfonsina (Sina) De Leon Salazar, Christopher Hamilton, Rebecca Hunt, Erin (Nikki) Pittman, Debra Trinidad, Denise Tevis, Hubert Vesper, Neelam Zahoor, Enada Archibold, Yuesong Wang, Cynthia D. Ward, Kathleen Caldwell	CDC/ATSDR
Lillian Alston (Senior Environmental Employee [SEE]), Andrea Clements, Scott Keely, Asja Korajkic, James McCord, Larry McMillan (SEE), Brian McMinn, Gary Norris, Margie Vazquez (QA), Richard Walker (SEE), Alan Williams, Libby Nessley (QA)	EPA/ORD/CEMM
Elin Ulrich, Ann Richard, Antony Williams	EPA/ORD/CCTE
Christine Alvarez (Quality Assurance [QA]), Maliha Nash, Holly Ferguson (QA), Emily Snyder	EPA/ORD/CPHEA
Susan Burden, Michelle Henderson (QA), Sania Tong-Argao (QA)	EPA/ORD/Office of Science Advisor, Policy & Engagement (OSAPE)
Brittany Stuart (QA), James Noel (QA)	EPA/ORD/Office of Science Information Management (OSIM)
Marisol Figueroa, Megan Maguire	EPA/ORD/IOAA
Gregory Grissom (ORISE Participant), Jacqueline McQueen, Fu-Lin Chen, Kathleen Hibbert, Tammy Jones-Lepp, Myriam Medina-Vera, Sandra Utile-Okechukwu (ORISE Participant), Kelly Widener, Ron Williams	Formerly with the U.S. EPA, Office of Research and Development
Matt Allen, Tamira Cousett, Christopher Fuller, Denise Popeo-Murphy, Mary Wright, Patrick Lawler, Guy Fazzio	Jacobs Technology Incorporated (JTI)
Julia Campbell, Justicia Rhodus, Samantha Shattuck	Pegasus Technical Services

Reviewers:

Reviewers	Affiliation
Eric Hooker	U.S. Consumer Product Safety Commission
Kiran Alapaty, Kevin Oshima	EPA/ORD/CEMM
Geoffrey Braybrooke, Michael R. Bell, Debra C. Colbeck, Jarod M. Hanson, Sherri L. Hutchens, Mark S. Johnson, Jeffrey G. Leach, Charles E. McCannon, Robert L. von Tersch	APHC, now the U.S. Defense Centers for Public Health-Aberdeen
Bob Thompson	Formerly with the U.S. EPA, Office of Research and Development
Michael Firestone, Kathleen Schroeder (SEE)	Formerly with the U.S. EPA, Office of the Administrator, Office of Children's Health Protection
Nicole Villamizar	EPA/OLEM/ORCR
Marcus Aguilar	U.S. Environmental Protection Agency, Region 9

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- **Alesia Ferguson, MPH, Ph.D.:** Associate Professor, College of Public Health, University of Arkansas Medical Sciences
- **Panagiotis Georgopoulos, Ph.D**.: Professor, School of Public Health, Rutgers University
- **Tee L. Guidotti, MD, MPH**: Consultant, Occupational and Environmental Health
- **Maria Llompart, Ph.D.:** Professor, Department of Analytical Chemistry, University of Santiago de Compostela, Spain
- **Martin Reinhard, Ph.D.:** Professor Emeritus, Stanford University
- **P. Barry Ryan, Ph.D.:** Professor, Rollins School of Public Health, Emory University
- **Clifford P. Weisel, Ph.D.:** Tenured Professor, Environmental and Occupational Health Sciences Institute (EOHSI), Rutgers University

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACH	Air change per hour
AIC	Akaike information criterion
ANOVA	Analysis of variance
APHC	U.S. Army Public Health Center
API	Analytical profile index
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BLP	Bacteria-like particles
BSD	Backscattered electron detector
BTEX	Benzene, toluene, ethylbenzene, xylenes
°C	Degrees Celsius
CalEPA	California Environmental Protection Agency
CalOSHA	California Division of Occupational Safety and Health
CAS	Chemical Abstracts Service
CCTE	Center for Computational Toxicology and Exposure
CDC	Centers for Disease Control and Prevention
CFU	Colony forming units
CICAD	Concise International Chemical Assessment Documents
cm	Centimeter
CEMM	Center for Environmental Measurement and Modeling
CESER	Center for Environmental Solutions and Emergency Response
COC	Chain of custody
CP	Carcinogenic potency
CPHEA	Center for Public Health and Environmental Assessment
CPSC	Consumer Product Safety Commission
CVAA	Cold vapor atomic absorption
DAD	Diode array detector
DBA + ICDP	Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene
ddPCR	Droplet digital polymerase chain reaction
DNA	Deoxyribonucleic acid
DNPH	Dinitrophenyl hydrazine
dNTP	Deoxyribonucleotide triphosphate
dsDNA	Double-stranded DNA
DSSTox	EPA's Distributed Structure-Searchable Toxicity Database
EI	Electron impact
EOHSI	Environmental and Occupational Health Sciences Institute
EPA	U.S. Environmental Protection Agency
EPMA	Electron probe microanalysis
ESI	Electrospray ionization
eV	Electronvolt
FLM	Fence line monitor
FRAP	Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds

g	Gram
GC/MS	Gas chromatography/mass spectrometry
GC/TOFMS	Gas chromatography/time-of-flight mass spectrometry
GS/MS/MS	Gas chromatography/tandem mass spectrometry
h	Hour
HDPE	High density polyethylene
HEAST	Health Effects Assessment Summary Table
HPLC	High performance liquid chromatography
HR-ICPMS	High resolution magnetic sector inductively coupled plasma mass spectrometer
HS	High-sensitivity
Hz	Hertz
IAC	Internal amplification control
IARC	International Agency for Research on Cancer
ICP/AES	Inductively coupled plasma-atomic emission spectrometry
ICP/MS	Inductively coupled plasma/mass spectrometry
ICR	Information Collection Request
in	Inch
IOAA	Immediate Office of the Assistant Administrator
IPCS	WHO International Programme on Chemical Safety
IRB	Institutional Review Board
IRIS	U.S. EPA Integrated Risk Information System
IS	Internal standard
ISO	International Standards Organization
IUR	Inhalation unit risk
JTI	Jacobs Technology, Inc.
kg	Kilogram
kV	Kilovolt
L	Liter
LC/MS	Liquid chromatography/mass spectrometry
LC/TOFMS	Liquid chromatography/time-of-flight mass spectrometry
LOD	Limit of detection
LOQ	Limit of quantitation
lpm	Liters per minute
LRGA	Literature Review and Data Gaps Analysis
mg	Milligram
m/z	Mass-to-charge ratio
MADL	Maximum allowable dose levels
Max	Maximum
mecA	Gene for methicillin resistance
MFE	Molecular feature extraction
min	Minute
Min	Minimum
mL	Milliliter
mm	Millimeter
mM	Millimolar
Mohm	Megaohm

mol	Mole
MQL	Minimum quantifiable limit
MRL	Minimum risk level
MRM	Multiple reaction monitoring
MRSA	Methicillin-resistant *Staphylococcus aureus*
MSD	Mass selective detector
N/A	Not applicable/Not available
NAM	New approach methods
ng	Nanogram
NIEHS	National Institutes of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
nM	Nanomolar
NR	Not reported
NSRL	No significant risk level
ns	Nanosecond
NTP	National Toxicology Program
OCHP	U.S. EPA Office of Children's Health Protection
OEHHA	California Office of Environmental Health Hazard Assessment
OEM	Original equipment manufacturer
OLEM	U.S. EPA Office of Land and Emergency Management
OMB	U.S. Office of Management and Budget
ORAU	Oak Ridge Associated Universities
ORCR	U.S. EPA Office of Resource Conservation and Recovery
ORD	U.S. EPA Office of Research and Development
ORISE	Oak Ridge Institute for Science and Education
OSAPE	Office of Science Advisor, Policy and Engagement
OSF	Oral slope factor
OSHA	Occupational Safety and Health Administration
OTU	Operational taxonomic unit
PAH	Polyaromatic hydrocarbon
PCDL	Personal compound database list
PCR	Polymerase chain reaction
PEL	Permissible exposure limit
pM	Picomolar
ppbv	Parts per billion by volume
ppm	Parts per million
PPRTV	Provisional peer-reviewed toxicity value
PSA	Particle size analysis
psi	Pounds per square inch
PUF	Polyurethane foam
QA	Quality assurance
QC	Quality control
REL	Recommended exposure limit/Reference exposure levels
RF	Radio frequency
RfC	Reference concentration

RfD	Reference dose
RH	Relative humidity
RIVM	Netherlands National Institute for Public Health and the Environment
RNA	Ribonucleic acid
RPM	Revolutions per minute
rRNA	Ribosomal ribonucleic acid
%RSD	Percent relative standard deviation
s	Second
SBR	Styrene-butadiene rubber
SD	Standard deviation
SEE	Senior Environmental Employee
SEM	Scanning electron microscopy
SF	Slope factor
SOP	Standard operating procedure
SSC	Student Services Contractor
STEL	Short term exposure limit
Sum15PAH	Sum of 15 of the 16 EPA ‘priority’ PAHs
SumBTEX	Sum of benzene, toluene, ethylbenzene, m/p-xylene, and o-xylene
SVOC	Semi-volatile organic compound
S-W	Shapiro-Wilk
TCR	Tire crumb rubber
TD	Thermal desorption
TIC	Total ion current
TIFF	Tagged image file format
TLV	Threshold limit value
TOFMS	Time-of-flight mass spectrometry
TPE	Thermoplastic elastomers
TSA	Technical systems audit
TSP	Total suspended solids
TWA	Time weighted average
µm	Micrometer
µL	Microliter
UR	Unit risk
U.S.	United States of America
U.S. EPA	United States Environmental Protection Agency
UV	Ultraviolet spectrometry
VID	Video identification number
V	Volt
VOC	Volatile organic compound
W	Watt
WHO	World Health Organization
XRF	X-ray fluorescence spectrometry

Executive Summary

The goal of the research under the Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (FRAP) is to characterize potential human exposures to the substances associated with recycled tire crumb rubber used on synthetic turf fields. Results of the effort are being reported in two parts. Part 1 communicates the research objectives, methods, results, and findings for the tire crumb rubber characterization research (i.e., what is in the material?). Part 2 (this document) characterizes potential human exposures to the chemicals found in the tire crumb rubber material while using synthetic turf fields. Neither Part 1 nor Part 2 of this study, separately or combined, constitutes an assessment of the risks associated with playing on synthetic turf fields with recycled tire crumb rubber infill. The results of the research described in both Part 1 and Part 2 of the final report can be used to inform risk assessments.

In the United States, synthetic turf fields are used at municipal and county parks; schools, colleges, and universities; professional sports stadiums and practice fields; and military installations. The fields are designed to simulate the experience of practicing and playing on grass fields.[1] First introduced in the 1960s, synthetic turf fields have evolved over time from first-generation systems made of tightly curled nylon fibers to third-generation systems typically made of polyethylene yarn fibers. These third-generation systems typically use small pieces of recycled tires, referred to as "recycled tire crumb rubber" (or simply "tire crumb rubber"), to fill the space between the polyethylene yarn fibers. The recycled tire crumb rubber (sometimes mixed with sand or other raw materials) is added for ballast, support for the synthetic grass blades, and as cushioning for field users. Third-generation synthetic turf field systems are widely used today. There are between 18,000 and 19,000 synthetic turf fields in the United States, with 1,200 – 1,500 new installations each year, about half of which are replacements.[2] It is estimated that millions of people use and/or work at these fields.

KEY RESEARCH ACTIVITIES DISCUSSED IN PART 2

- Collect human activity data using video and questionnaires.
- Pilot study collection of air, dermal wipe, and biomarker samples from people using synthetic turf fields.
- Pilot study collection of air, surface wipe, and dust samples from fields.
- Conduct an exposure modeling assessment.

Some parents, athletes, schools, and communities have raised concerns about the use of recycled tire crumb rubber on synthetic turf fields. To help address these concerns, the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR) and the U.S. Environmental Protection Agency (EPA), in collaboration with the Consumer Product Safety Commission (CPSC), launched a multi-agency research effort in February 2016.

This multi-agency research effort, known as the Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (FRAP)[3], is focused on assessing potential human exposure,

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[1] More information on the intended uses of synthetic turf can be found at: https://www.syntheticturfcouncil.org/page/About_Synthetic_Turf.

[2] Personal communication with the Synthetic Turf Council.

[3] The multi-agency research effort, called the *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds* (FRAP), was launched in February 2016. Prior to initiating the study, federal researchers developed a research protocol, *Collections Related to Synthetic Turf Fields with Crumb Rubber Infill*, that describes the study's objectives, research design, methods, data analysis techniques and quality assurance/quality control (QA/QC) measures. These documents are available at: http://www.epa.gov/TireCrumb. CPSC is conducting the work on playgrounds and results

which includes conducting research activities to characterize the chemicals associated with recycled tire crumb rubber and to identify the ways in which people may be exposed to those chemicals based on their activities on synthetic turf fields. Also, the FRAP includes characterizing emissions and bioaccessibility to differentiate what is present in the recycled tire crumb rubber from what people may actually be exposed to from recycled tire crumb rubber.

The research laid out in the FRAP is not intended to be a risk assessment. Like other studies, this research has limitations, and risks cannot be inferred from the information and conclusions found in this study. Prior to initiating the FRAP, most studies examining these potential risks have been considered inconclusive or otherwise incomplete. Based upon available literature, this research effort represents the largest tire crumb rubber study conducted in the United States. The information and results from the effort will fill specific data gaps about the potential for human exposure to chemical constituents associated with recycled tire crumb rubber used in synthetic turf fields.

A status report was previously released describing FRAP activities as of December 2016 (EPA/600/R-16/364, available at: http://www.epa.gov/TireCrumb). The status report included a summary of stakeholder outreach, an overview of the tire crumb rubber manufacturing industry, progress on the research activities, and the final peer-reviewed literature review/gaps analysis (LRGA) white paper. The results of the research activities under the FRAP are being documented in two parts. The previously released Part 1 Report (EPA/600/R-19/051, available at: http://www.epa.gov/TireCrumb) documents the tire crumb characterization activities and results. This Part 2 report documents the results from the pilot exposure characterization research study conducted by EPA and CDC/ATSDR and includes the supplemental biomonitoring study conducted by CDC/ATSDR (Appendix A). Part 2 also includes future research recommendations that could provide additional insights into potential exposures to recycled tire crumb rubber used on synthetic turf fields.

This Executive Summary provides a synopsis of the exposure characterization research (Part 2 of the study). Section 1 of this report provides introductory information; Section 2 provides a more complete technical summary of these activities and the study’s key findings; Sections 3 and 4 describe the methods and contain detailed results for the exposure characterization activities; and Section 5 provides information on exposure pathway modeling assessment. Results from the supplemental biomonitoring study, quality control/quality assurance assessments, and information about methods are provided in the Appendices (Volume 2 of this report).

RECAP: RECYCLED TIRE CRUMB RUBBER CHARACTERIZATION

- As expected, a range of metals, semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs) and bacteria were measured in and on recycled tire crumb rubber infill.
- Many chemicals were found at similar concentrations in other studies of recycled tire crumb rubber, where comparable data are available.
- Emissions of most SVOCs and many VOCs were low when tested at 25 °C, while emissions were higher for some, but not all at 60 °C.
- The amount of metals released into simulated biological fluids was low, on average about 3% in gastric fluid and less than 1% in saliva and sweat plus sebum.

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from that effort will be reported separately. While artificial turf is also used at residences, that turf does not typically include tire crumb rubber; as a result, the use of artificial turf at residences is not part of the FRAP study.

Exposure Characterization

A small-scale pilot study was conducted to better understand the ways in which people may be exposed to chemicals associated with recycled tire crumb rubber (Figure ES-1). As part of the pilot study, human activity data were collected using video and questionnaires. Personal air and dermal wipe samples were collected from 25 people participating in soccer or football practices at synthetic turf fields. Surface wipe, air, and dust samples were also collected from fields. The analyses of these samples provided additional data for assessing inhalation exposures and new data for better understanding exposures through dermal and ingestion pathways. Technical details are provided in Section 4, which contains detailed assessment results for the exposure characterization.

While the results from these studies are not generalizable to all other situations and activities, our field and dermal measurements (while limited) indicate that people can be exposed to chemicals associated with recycled tire crumb rubber infill material when they use synthetic turf fields. A range of chemicals associated with recycled tire crumb rubber was found in air, field surface, field dust, and in dermal exposure media collected from the participants, including metals and organic chemicals.

For many analytes measured during active play at the outdoor fields, next-to-field concentrations in air did not differ from background samples. Other chemicals, such as methyl isobutyl ketone, benzothiazole, 4-tertbutyl phenol, and several PAHs, were somewhat higher. Exposures may be higher for people using indoor synthetic turf fields than outdoor fields. Many chemicals were measured in next-to-field air samples at the indoor field at higher concentrations compared to those at the two outdoor fields. This aligns with findings from the Tire Crumb Characterization Part 1 report where most organic compounds were found in tire crumb rubber at higher levels at indoor fields compared to outdoor fields, and higher emissions from tire crumb rubber were observed for most organic chemicals at indoor fields compared to outdoor fields. Results from the personal air sampling for volatile organic chemicals (VOCs) are not available, as the method was not successful.

In the biomarker measurements, of the 25 participants, 14 provided urine samples and 13 provided blood samples. Participants providing blood and urine were 11 – 21 years old. The participants provided blood and urine samples before and after practice on synthetic turf fields with tire crumb rubber infill. The blood samples collected before and after practice, and the serum derived from the blood, were analyzed for metals. An increase in metal concentration was not observed after practice. However, blood selenium levels, both pre- and post-activity, were higher than the geometric mean for participants aged 11 – 21 in the 2013-2014 National Health and Nutrition Examination Survey (CDC NHANES 2013 – 2014). Selenium was not found above detection limits in tire crumb and other field environment matrices. With the exception of blood selenium, body burden levels of metals in these study participants were consistent with those found for the general population (CDC NHANES 2013 – 2014, participants aged 11-21).

AIR SAMPLING FINDINGS

- Potential for overall exposures is expected to be low.
- For many analytes measured during active play at the outdoor fields, next-to-field concentrations in the air did not differ from background samples.
- Other chemicals, such as methyl isobutyl ketone, 4-tertbutyl phenol, benzothiazole and several PAHs, were somewhat higher.
- Many chemicals were measured in air samples at the indoor field at higher concentrations compared to those at the two outdoor fields.

Urine samples were analyzed for seven polycyclic aromatic hydrocarbon (PAH) metabolites. The unadjusted urinary PAH metabolite concentrations were significantly higher post-activity compared to pre-activity, and all of the unadjusted post-activity PAH metabolite concentrations were higher than those found in the general population (NHANES 2013-2014, participants aged 11-21), with the exception of 1-hydroxypyrene. The creatinine-adjusted urinary PAH metabolites showed no difference in concentration in samples collected before and after practice, with the exception of 2-hydroxynaphthalene. When comparing creatinine adjusted pre- and post- activity concentrations, there was a significant increase post activity (34%) for 2-hydroxynaphthalene. For specific gravity-adjusted metabolite concentrations, all post-activity concentrations were statistically higher than pre-activity concentrations, and all differences were statistically significant using the signed-rank test. The creatinine adjusted 2-hydroxynaphthalene concentration was higher pre- and post-activity when compared to the general US population (CDC NHANES 2013-2014, participants aged 11-21). However, only low levels of the parent compound, naphthalene, were found in the tire crumb rubber, field air, dust, field wipe, and dermal wipe samples. It is important to note that the biomonitoring study that was conducted as part of the exposure measurement study was a pilot-scale effort with several limitations. The sample size was very small (n=14) and individuals who participated in the pilot-scale biomonitoring study were recruited at only two outdoor fields.

A supplemental biomonitoring study was conducted to expand the pilot-scale study results using a larger sample size (Appendix A). Among 161 participants, 82% (n=132) played on synthetic turf with tire crumb rubber infill, and the remaining 18% (n=29) played on natural grass. 25% (n=41) played on an indoor synthetic turf field, and 75% (n=120) played on outdoor fields where synthetic turf and natural grass fields were co-located. Recycled tire crumb rubber infill field users and natural grass field users experienced similar differences in pre- and post-activity PAH concentrations, including for 2-hydroxynaphthalene.

PILOT BIOMONITORING STUDY FINDINGS

- An increase in metal concentrations in blood samples was not observed after practice.
- However, blood selenium levels, both pre- and post-activity, were higher than the geometric mean for participants aged 11 – 21 in the 2013-2014 National Health and Nutrition Examination Survey (CDC NHANES 2013 – 2014). Selenium was not found above detection limits in tire crumb and other field environment matrices.
- With the exception of blood selenium, body burden levels of metals in these study participants were consistent with those found for the general population (CDC NHANES 2013 – 2014, participants aged 11-21).
- In comparing pre- and post-activity **creatinine-adjusted** measurements for these PAH metabolites in urine, there was no significant difference in pre- and post-activity concentrations, except for 2-hydroxynaphthalene.

An exposure pathway modeling assessment was included in this exposure characterization study to complement the measurement activities and evaluate the availability and robustness of data needed to support modeling. Modeling was conducted for athletes using synthetic turf fields with recycled tire crumb rubber infill, using extant exposure information (from previous synthetic turf field studies) and then updated with information collected in this exposure characterization study. The estimation used six (6) chemicals (pyrene, benzo[a]pyrene, benzothiazole, methyl isobutyl ketone, lead, and zinc), chosen to provide a range of physical and chemical properties for which data were available. In general, estimated daily exposures were $<5 \times 10^{-5}$ mg/kg-day for most chemicals and pathways, with inhalation being the dominant pathway for more volatile chemicals and ingestion being dominant for metals and less volatile chemicals. While the data collected from the exposure characterization study improved the estimates, the results still carry a degree of uncertainty associated with limited data for factors like ingestion rates and dermal adhesion values for tire crumb rubber and field dust, along with airborne particle sizes.

SUPPLEMENTAL BIOMONITORING STUDY FINDINGS

- Pre- and post-activity differences in urinary PAH concentrations were **not** associated with field type (synthetic turf fields with tire crumb rubber infill vs natural grass fields).
- Except for 2-hydroxynaphthalene, pre-activity PAH concentrations were lower than those in the U.S. population (NHANES 2015-2016).

Exposures at synthetic turf fields should also be considered in context, since the chemicals in recycled tire crumb rubber are present in other products and/or environmental media that people use or contact. To provide this context, exposure from other typical sources (such as, residential and dietary “background”) were compared to those of field users. Residential (i.e., exposures expected through typical residential media, such as indoor air and dust) plus dietary ‘background’ exposures were estimated for a subset of four chemicals associated with tire crumb rubber (pyrene, benzo[a]pyrene, zinc and lead) for which data are available. Modeled estimates for this limited set of PAHs and metals expected in recycled tire crumb suggest that synthetic turf field users may have pyrene and benzo[a]pyrene exposures similar to, or somewhat lower than, typical background exposures. Exposures to zinc and lead are expected to be substantially lower than background. Data are sparse for estimating background exposures for many of the chemicals associated with tire crumb rubber for comparison with synthetic turf field user exposure estimates. Such estimates also carry a degree of uncertainty due to limited numbers of studies.

Conclusions

In general, the findings from the entire playing fields portion of the FRAP activities (both the Tire Crumb Characterization Part 1 and the Tire Crumb Exposure Characterization Part 2 combined) support the conclusion that although chemicals are present (as expected) in the tire crumb rubber and exposures can occur, they are likely limited; for example:

- Generally, only small amounts of most organic chemicals are released from tire crumb rubber into the air through emissions. For many analytes measured during active play at the outdoor fields, next-to-field concentrations in air were not different than background samples while others were somewhat higher.

- For metals, only small fractions are released from tire crumb rubber into simulated biological fluids (average mean about 3% for gastric fluid and <1% for saliva and sweat plus sebum) compared to a default assumption of 100% bioaccessibility.

- In the biomonitoring pilot study, concentrations for metals measured in blood were similar to those in the general population.

- No differences in PAH metabolites in urine were observed in the supplemental biomonitoring study between study participants using natural grass fields and those on synthetic turf fields with tire crumb rubber infill.

Risk is a function of both hazard (toxicity) and exposure. Understanding what is present in the material (Part 1 Report) and how individuals are potentially exposed (Part 2 Report) is critical to understanding potential risk. It is important to note that the study activities completed as part of this multi-agency research effort were not designed, and are not sufficient by themselves, to directly answer questions about potential health risks. Other studies may aid in this regard. The FRAP supports the findings of limited exposure, as reported in studies from RIVM and ECHA as well as the chemical assessments from the NTP.[4] More specifically:

- The Netherlands National Institute for Health and Environment (RIVM) released a December 2016 report, updated in March 2017, titled "Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate" (RIVM, 2017). The RIVM collected rubber infill from 100 synthetic turf fields and performed analyses for selected chemicals of interest. Exposure estimates were performed for five exposure scenarios using assumed exposure parameters for different ages and player categories. Exposure estimates and toxicological information were used to evaluate potential health risks. RIVM reported: *"The results of this research indicate that playing sports on these fields is safe. The risk to health from playing sports on these synthetic turf fields is virtually negligible. While rubber granulate contains harmful substances, these substances are only released from the rubber granulate in very small quantities after ingestion, contact with the skin or evaporation in hot weather. RIVM recommends adjusting the standard for rubber granulate to one that is closer to the standard applicable to consumer products."*

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[4] Other research studies by the California Office of Environmental Health Hazard Assessment (OEHHA) will provide tire crumb rubber characterization data for additional fields in California. They will also characterize additional synthetic turf field component materials and particles in the air above the synthetic fields as a result of simulated activities and measure the bioaccessibility of inorganic and organic chemicals from tire crumb rubber.

- The European Chemicals Agency (ECHA) released a report in February 2017 titled "Annex XV Report; An Evaluation of the Possible Health Risks of Recycled Rubber Granules Used as Infill in Synthetic Turf Sports Fields" (ECHA, 2017). ECHA evaluated human health risks for chemicals found in tire crumb rubber used on outdoor and indoor synthetic turf football (soccer) fields. ECHA compiled information for PAHs, metals, phthalates, VOCs, and SVOCs primarily from European studies. ECHA then created several exposure scenarios for children, adults, and workers installing or maintaining fields, and estimated inhalation, dermal, and ingestion exposures. Conclusions from the ECHA reported: *"ECHA has found no reason to advise people against playing sports on synthetic turf containing recycled rubber granules as infill material. This advice is based on ECHA's evaluation that there is a very low level of concern from exposure to substances found in the granules. This is based on the current evidence available. However, due to the uncertainties, ECHA makes several recommendations to ensure that any remaining concerns are eliminated."*

- The National Toxicology Program (NTP, 2019) has conducted chemical assessments and short-term toxicity studies on the recycled tire crumb rubber material itself, not specific chemical constituents found in the material. Findings from the NTP research included: *"There was no evidence of toxicity in mice from ingestion of crumb rubber. Analysis of the animals' blood and urine showed that internal levels of crumb rubber chemicals were very low. No health problems were observed. For tests using human cells, NTP found that crumb rubber, under certain experimental conditions such as high heat, leached chemicals, some of which caused cell death. The NTP studies did not assess individual chemicals of crumb rubber, although they did confirm that it contains many substances, such as polycyclic aromatic hydrocarbons (PAHs), metals, plasticizers, such as phthalates, and bisphenol A (BPA)."*

OVERALL CONCLUSIONS FOR THE PLAYING FIELDS STUDY

- In general, the findings from the FRAP activities on playing fields (Parts 1 and 2 combined) support the conclusion that although chemicals are present (as expected) in the tire crumb rubber and exposures can occur, they are likely limited; for example:
  - Generally, only small amounts of most organic chemicals are released into the air through emissions. For many analytes measured during active play at the outdoor fields, next-to-field concentrations in air were not different than background samples while others were somewhat higher.
  - For metals, only small fractions (average mean about 3% for gastric fluid and <1% for saliva and sweat plus sebum) are released from tire crumb rubber into simulated biological fluids compared to a default assumption of 100% bioaccessibility.
  - In the biomonitoring pilot study, concentrations for metals measured in blood were similar to those in the general population.
  - In the supplemental biomonitoring study, no differences in PAH metabolites in urine were observed between study participants using natural grass fields and those using synthetic turf fields with tire crumb rubber infill.

Overall, we anticipate that the results from this multi-agency research effort will be useful to the public and interested stakeholders for understanding the potential for human exposure to chemicals associated with recycled tire crumb rubber infill material used on synthetic turf fields.

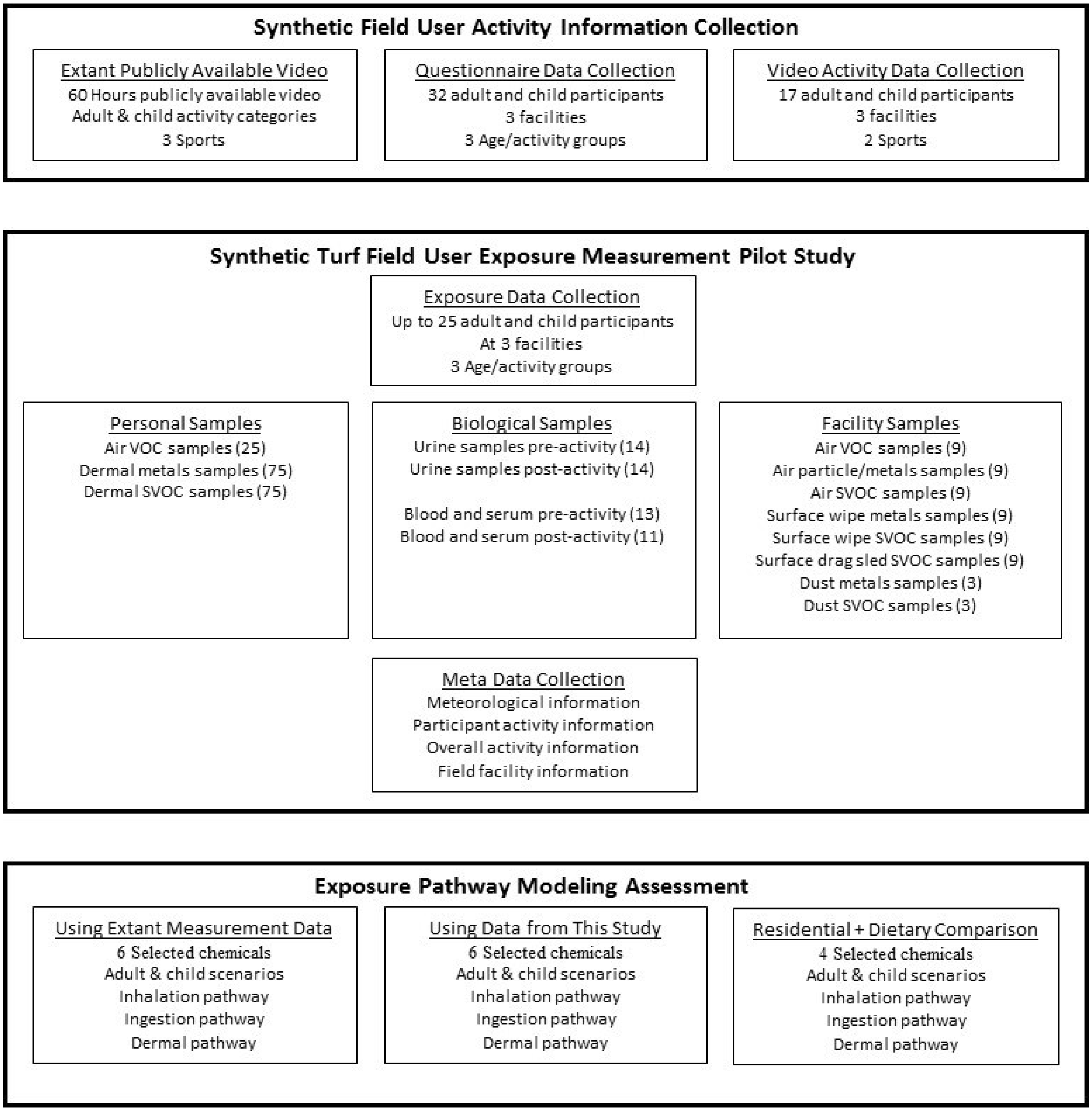

Figure ES-1. Pilot exposure characterization research schematic overview.

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1.0 Introduction

1.1 Background

While research efforts have tended to focus on characterizing tire crumb rubber constituents and environmental concentrations of related chemicals, less research has been performed to examine human exposures and potential risks to people using synthetic turf fields and playgrounds. With respect to exposure characterization, human exposure measurement data for synthetic turf field users are limited. There are significant data gaps in human activity parameters for various synthetic turf field activities, and this information is essential for estimating exposures and evaluating risks from contact with tire crumb rubber constituents. While the potential for inhalation exposures has been characterized for some constituents, there is far less information for characterizing dermal and ingestion exposures. Improved exposure factor information is needed to estimate and model exposures from the inhalation, dermal, and ingestion pathways. There are also significant limitations in the methods that have been developed and used to characterize human exposure from activities on synthetic turf fields. These include challenges collecting relevant surface, dust, and personal air samples; limited measurements of dermal exposures; and limited collection of urine or blood samples, which could be used for measuring biomarkers of exposure to chemicals in crumb rubber infill.

To support the Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (FRAP), a Research Protocol was developed (U.S. EPA and CDC/ATSDR, 2016). Some elements of the research design outlined in the Research Protocol were intended to fill these knowledge gaps and address the limitations of prior studies. The data collection components of the tire crumb rubber exposure study went through the Office of Management and Budget (OMB) Information Collection Request (ICR) review process. On August 5, 2016, the U.S. Environmental Protection Agency (EPA), Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR), and Consumer Product Safety Commission (CPSC) received final approval to begin the research. The results of the FRAP research described in the Part 1 Report (U.S. EPA & CDC/ATSDR, 2019) and this Part 2 Report can be useful for improving exposure and risk assessment and for designing and conducting larger scale exposure and biomonitoring studies.

Scientists identified various exposure scenarios (i.e., ways in which people may be exposed to tire crumb rubber infill based on their activities on synthetic turf fields) and then designed and conducted a pilot-scale exposure study. As defined in the Research Protocol (U.S. EPA and CDC/ATSDR, 2016), there were two primary aims or objectives for the exposure characterization research:

> **Aim 1**: Collect human activity data for synthetic turf field users that will reduce the reliance of default exposure factor assumptions in exposure and risk assessment; and,
>
> **Aim 2**: Conduct an exposure measurement sub-study for people using synthetic turf fields with tire crumb rubber infill, in what are likely to be among the higher exposure scenarios to improve understanding of potential exposures, particularly for the dermal and ingestion exposure pathways.

To meet the first objective, researchers used questionnaires to collect information from adults and youth (or the parents of youth) who use synthetic turf fields with crumb rubber infill. Video data collection was used for a subset of these participants while they engaged in activity on synthetic fields to obtain objective information about important dermal and ingestion contact rates. In addition, extant videography of individuals engaged in activities on synthetic turf fields was acquired to provide additional data on contact rates for a wider group of people and activities that could not be captured otherwise just using the questionnaires. The human activity information provided data for the parameters used in characterizing and modeling exposures associated with the use of synthetic turf fields and improves upon the information currently available in the literature for the dermal and ingestion exposure pathways.

To meet the second objective, a pilot-scale human exposure measurement sub-study was implemented to further develop and deploy appropriate sample collection methods and generate data to better understand potential exposures that may occur when individuals frequently use synthetic turf fields. A subset of the participants that provided questionnaire responses were asked to participate in the exposure measurement pilot study based on their field usage. Field use scenarios anticipated to be among those with relatively high potential exposures due to frequency and duration of time spent on the field and the potential for contact with synthetic field materials were the focus of the study. A set of personal, biological, and field environmental samples was collected around a sport or training activity performed on a participating synthetic turf field. Personal and environmental samples were analyzed for metals, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). For the biomonitoring pilot, blood and urine samples collected before and after participant practice sessions were analyzed for selected metal and polycyclic aromatic hydrocarbon (PAH) metabolites, respectively. Following the pilot-scale biomonitoring effort, ATSDR designed and conducted a supplemental biomonitoring study measuring PAH urinary metabolites for a larger number of synthetic field users and included athletes playing on natural grass fields for comparison (Appendix A).

Researchers utilized information from the literature and data collected in this study to conduct exposure pathway modeling on six selected chemicals for athletes using synthetic turf fields with tire crumb rubber infill. This effort aimed to elucidate which exposure pathways are likely to be the biggest contributors to total exposure for different types of tire crumb rubber constituents; explore whether data produced in this study can improve our exposure estimates, particularly for the dermal and ingestion pathways; assess the availability, robustness, and adequacy of tire crumb and exposure measurement data, and data for exposure model parameters in the context of accuracy and uncertainty for exposure estimation; and prepare examples of modeled estimates of background exposures from residential and dietary sources for comparison with exposure estimates for synthetic turf field users.

The study was performed in accordance with all required human subjects reviews and protections specified in the Code of Federal Regulations (45 CFR 46 for the U.S. Department of Health and Human Services [HHS]; 40 CFR 26 for the EPA) and in other applicable policies on human subjects at the EPA and CDC/ATSDR. Prior to the recruitment and collection of data, the study protocol was submitted to the CDC Human Research Protection Office. The study protocol was reviewed and approved by the CDC Institutional Review Board (CDC IRB), and then the EPA Human Subjects Research Review Official (HSRRO). Information and details on the consenting process, forms, and protocols was previously published (U.S. EPA and CDC/ATSDR, 2016). On August 2, 2017, the OMB approved the Information Collection Request that enabled EPA and CDC/ATSDR to conduct the field work associated with the exposure characterization research (OMB Control Number 0923-0058); the field work was concluded in Fall 2017. Following a delay due to the COVID-19 pandemic, the supplemental biomonitoring study was conducted in 2022.

1.2 Report Organization

This report is organized into two volumes – Volume I contains the body of the report and Volume II contains the appendices. Volume I consists of five sections:

- **Section 1** provides a short introduction to the exposure characterization portion of the federal research action plan.
- **Section 2** provides a summary of the research results and main conclusions from the exposure characterization study, along with important limitations.
- **Section 3** provides detailed methods for the exposure characterization.
- **Section 4** provides detailed assessment results for the exposure characterization.
- **Section 5** contains the results of exposure pathway modeling and modeling approach assessments.
- **Section 6** contains the references.

Volume II of this report consists of eight appendices:

- **Appendix A** describes the methods and results for the supplemental biomonitoring study.
- **Appendix B** contains the Quality Assurance/Quality Control section.
- **Appendices C** contains the standard operating procedures (SOPs) used for the exposure characterization studies.
- **Appendix D** contains the facility user study questionnaires.
- **Appendix E** contains the exposure characterization meta-data collection forms.
- **Appendix F** contains the blood metals and serum metals analysis protocols.
- **Appendix G** contains the results from the video activity data.
- **Appendix H** contains the feasibility assessment for silicone wristband passive samplers at synthetic turf fields.

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2.0 Summary of Results and Findings

This section provides both an overview and detailed summary of the results of individual components of this research study, specifically focusing on the exposure characterization and the associated findings based on those results. A discussion of the findings is provided along with limitations and recommendations for next steps.

Technical details of the methods and detailed research results are provided in subsequent sections (3–5) and their associated appendices. Quality assurance and quality control results can be found in Appendix B. The research standard operating procedures (SOPs) are provided in Appendix C.

2.1 Summary of Research Activities

The federal research described in this report provides new and additional data needed for improved exposure estimation for athletes using synthetic turf fields with recycled tire crumb rubber infill. Specific activities undertaken and described in this report are summarized in Table 2-1.

Table 2-1. Topic Area and Specific Activities Described in This Report

Topic Area	Activities
Exposure Characterization Pilot Study for Youth and Adult Athletes Using Synthetic Turf Fields with Tire Crumb Rubber Infill	Recruiting youth and adult participants for sample and data collection around their usual sport activities at synthetic turf fields
	Using questionnaire data collection to obtain data for field use duration and frequency of use, activity patterns on fields, and hygiene to improve exposure scenario development and exposure modeling for youth and adult athletes using synthetic turf fields
	Using extant video data and participant video data collection approaches to provide data for contact types and frequencies, and activity levels for improving exposure modeling for youth and adult athletes using synthetic turf fields
	Performing measurements to provide additional data on particles, metals, SVOCs and VOCs in the air at synthetic turf fields during periods of activity on the field and during warm to hot ambient air conditions for assessing exposure through the inhalation pathways
	Developing methods and providing initial data on inorganic and organic chemicals on field surfaces, in field dust, and on athlete skin needed to better understand and estimate both child and adult exposures, particularly for the dermal and ingestion exposure pathways
	Developing, applying and assessing methods and approaches for personal air sample collection
	For the pilot-scale biomonitoring effort, collecting and analyzing blood and urine samples for measurement of selected metals and PAH biomarkers before and after the monitored participant sport activities at synthetic turf fields
	Assessing silicone wristbands as potential sampling devices for future use in field air and personal sampling assessments of exposure at synthetic turf fields
	Applying and assessing exposure pathway models to examine differences in exposure levels across pathways, and to identify where lack of data (or lack of robust data) may be limiting accuracy and/or resulting in potentially large uncertainties in exposure estimation for synthetic turf field users
Supplemental Biomonitoring Study	Expanding upon the FRAP's pilot-scale effort by including a larger sample size of synthetic turf with recycled tire crumb rubber infill users and a comparison group of natural grass field users
	Examining potential associations with pre- and post-activity urinary PAH biomarker concerntrations with field type

Topic Area	Activities
	Comparing study participants' urinary PAH concentrations to those found in the noninstitutionalized general U.S. population

2.2 Exposure Characterization: Overview of Research Approach, Results and Key Findings

2.2.1 Research Approach

The exposure characterization study was a pilot-scale effort to: (a) collect information on human activity for synthetic turf field users that may affect exposures to tire crumb rubber and its constituents; and (b) implement a human exposure measurement study to further develop and test appropriate sample collection methods and to generate data for improved exposure characterization, including exposures from dermal and ingestion pathways.

For the human activity data collection, questionnaires were administered to adults and youth (or the parents of children) who participated in athletic activities on synthetic turf fields with tire crumb rubber infill. Information was collected to help better understand the frequency and duration of play on synthetic fields, the variety of activities performed, and specific activity and hygiene factors that might influence contact with field materials and chemical exposures. Video data were also collected on a subset of participants performing physical activity on synthetic turf fields. In addition, publicly-available videos of users engaged in activities on synthetic turf fields were used to provide objective assessment of contact rates and types that are difficult to capture consistently using questionnaires.

A subset of participants providing questionnaire responses also participated in an exposure measurement study. A set of personal, biological and field environmental samples were collected around a sport practice activity performed on synthetic turf fields. Personal (air and dermal wipe) samples and environmental samples were analyzed for metal, VOC and SVOC analytes. Urine and blood samples were also collected from a subset of participants as part of pilot exposure characterization research activities. Exposure pathway models were constructed and assessed for select chemicals and exposure scenarios, first using existing measurement data from other studies and then again with data from this study.

Participants for the exposure characterization pilot study were adult and youth soccer or American football (hereafter described only as football) players (≥ 7 years of age) recruited from sport teams practicing at several of the synthetic turf fields sampled in the tire crumb rubber characterization study. Thirty-two (32) athletes from two outdoor fields and one indoor field participated in the questionnaire component of the exposure characterization pilot study, and 25 of those 32 participated in the exposure measurements activities. Seventeen (17) of the 25 exposure measurement study participants took part in the video data collection. For the pilot-scale biomonitoring portion, 14 of the 25 provided urine samples, and 13 of the 25 provided blood samples.[5] Seven of the exposure characterization pilot study participants were between seven to 10 years of age, 18 participants were ages 11 to 17 years of age, and seven were adults (18+). Additional activity information was obtained from 34 publicly-available videos of 60 athletes (adults and youth) engaged in soccer, football, and field hockey sports.

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[5] See Appendix A for the supplemental biomonitoring study.

2.2.2 Overview of Results and Key Findings

Human activity data were collected using both video and questionnaire approaches to gain more information about the ways people use and come into contact with synthetic turf fields and tire crumb rubber infill. Video data analysis provided objective data for important exposure factors, including hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contact rates. Children and adults were found to have similar contact rate frequencies. Some types of exposure contacts were observed more frequently for football players compared to soccer players, such as object-to-mouth contact due to the use of mouth guards. Previous exposure evaluations had not been performed for football player exposure scenarios on synthetic turf with tire crumb rubber infill.

Study participants reported via the questionnaires that they engaged in athletic activities through most seasons at both synthetic turf fields and at grass fields. Physical contact with synthetic turf was frequently reported by participants. Participants also frequently reported finding tire crumb rubber on their bodies and in their cars and homes after playing on synthetic turf fields with recycled tire crumb rubber infill. There were no consistent exposure patterns across age groups, except older participants were more likely to report finding tire crumb rubber on their bodies. Note that the questionnaire did not include questions about potential exposures before participants came to a synthetic turf field. The data from the questionnaires helped inform our knowledge of factors that may affect exposure to recycled tire crumb rubber infill used on synthetic turf fields, and the questionnaire developed and used in this pilot effort can help in the design of activity data collection approaches in larger future studies.

Air samples were collected for VOC, SVOC, metal and total suspended particulate (TSP) analysis at three synthetic turf fields during warm to hot weather, while athletic teams practiced. For many analytes at the outdoor fields, next-to-field concentrations were not different than background samples; exceptions included methyl isobutyl ketone, 4-tert-octylphenol, benzothiazole and several PAHs, for which next-to-field measurements for most were modestly above background levels. Air concentrations of many analytes were higher in the indoor field facility compared to background levels.

To assess the potential availability of residues and dust for exposures, SVOCs and metals were analyzed in field dust samples and field surface wet wipe samples, and SVOCs were also analyzed in field surface drag sled samples. Field dust was obtained by placing infill from the synthetic turf field surface into a sieve and collecting particles < 150 μm for analysis. On average, SVOCs were present in field dust at concentrations similar to, but lower than, those measured in the tire crumb rubber infill. Zinc and cobalt, two tire crumb rubber metal constituents, were measured in field dust at lower levels than in tire crumb rubber. Other metals, such as lead, were present in field dust at levels higher than those measured in the tire crumb rubber, suggesting potential sources other than the rubber. Given the small particle sizes, field dust may be an important medium for inhalation, dermal and ingestion exposures. SVOCs were measured at low levels in field wipe and drag sled samples, with average transferrable levels generally below 0.2 ng/cm^2. Many metals were measured in field surface wipes at average values below 2 ng/cm^2, while zinc and metals typically found in soil were measured at higher levels.

Personal dermal wipe sample collection was performed for youth and adult participants. SVOCs and metals were analyzed using wet wipes that were applied to the hand, arm, and leg of study participants following their usual athletic practice sessions on synthetic turf fields. All metals except selenium were found at measurable levels in dermal wipe samples. Many metals were measured in dermal wipe samples at median values below 1 ng/cm^2, while zinc and other metals typically found in soil were measured at 4.1 to 140 ng/cm^2. About half of the SVOCs were measured in dermal wipe samples at levels above the method detection limit. Most SVOCs had median values below 0.2 ng/cm^2, with up to 0.21 ng/cm^2 for 4-tert-octylphenol, 0.69 ng/cm^2 for n-hexadecane, and several phthalates with median levels up to 7.0 ng/cm^2. The phthalates may have been present from other sources in addition to, or instead of, field materials. Few clear differences in dermal levels were observed between age groups or between football and soccer groups. The dermal measurements have limitations (e.g., samples were collected only post-activity, sampling efficiency is uncertain), but provide information that can be used in exposure models to avoid highly uncertain transfer rate estimates for dermal exposures.

Collecting personal air samples for research participants engaged in active athletic activities is challenging. The concentration of analytes of interest are generally low, the activity durations are short, and player safety must be a priority in collecting samples, particularly for children. In this study, a small, passive VOC air sampler with high effective sampling rates was attached to the upper backs of a practice jersey worn by each study participants during their usual athletic practice sessions on synthetic turf fields. When collecting air samples from the football players, one sampler was destroyed and another damaged during vigorous tackling activities; all other samples were successfully collected. The samplers did not perform as desired, however, with inconsistent effective sampling rates measured in testing based on both laboratory chamber and field conditions, and low recoveries of the two highest concentration analytes, benzothiazole and methyl isobutyl ketone. Additional research would be required to determine if any personal air sampling devices can be successfully used in research studies with youth participants. It may be necessary to limit personal air sampling to adult volunteers willing to wear more bulky samplers with pumps and certain types of activities.

A total of 14 individuals, aged 11 – 21, consented to participate in the pilot-scale biomonitoring portion of the exposure measurement study. For the biomarker measurements pilot-scale biomonitoring study, blood and urine samples were collected from study participants before and after their sports activities on the field. Of the 25 exposure measurement study participants, 14 provided urine samples and 13 provided blood samples. The participants providing blood and urine samples were 11 – 21 years old. The urine samples were analyzed for seven PAH metabolites, and the blood and serum samples were analyzed for metals. The laboratory analyses were performed by the CDC's National Center for Environmental Health Division of Laboratory Sciences. For the pilot-scale study, significant differences in mean concentrations were observed when comparing pre- and post-activity levels for the unadjusted PAH metabolites. For the unadjusted concentrations, the post-activity geometric mean was significantly higher (p-value < 0.05) for all urinary PAH metabolites than the pre-activity geometric mean (Figures 2-1 and 2-2). For example, the unadjusted post-activity geometric mean for 2-hydroxynaphthalene (geometric mean= 18.6 µg/L; 95% CI: 12.6 – 27.4) is significantly greater than the unadjusted pre-activity geometric mean (geometric mean= 7.69 µg/L; 95% CI: 4.61 – 12.8). When compared with PAH analytes reported in NHANES 2013-2014 (CDC 2013-2014) for participants aged 11 to 21, the geometric mean for all unadjusted urinary PAH metabolites post-activity was higher than the NHANES geometric mean, with the exception of 1-hydroxypyrene.

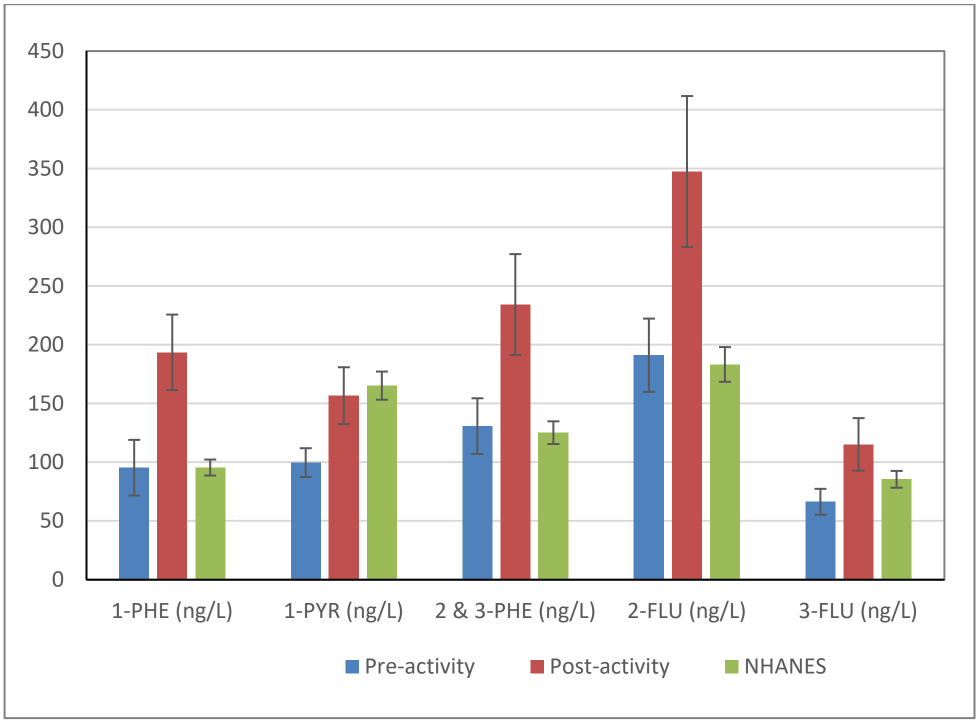

Figure 2-1. Geometric mean of unadjusted urinary PAH concentrations (ng/L) for exposure pilot study participants, pre-activity and post-activity, compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [PAH = polycyclic aromatic hydrocarbon; NHANES = National Health and Nutrition Examination Survey; 1-PHE = 1-Hydroxyphenanthrene; 1-PYR = 1-Hydroxypyrene; 2 & 3-PHE = 2- & 3-Hydroxyphenanthrene; 2-FLU = 2-Hydroxyfluorene; 3-FLU = 3-Hydroxyfluorene]

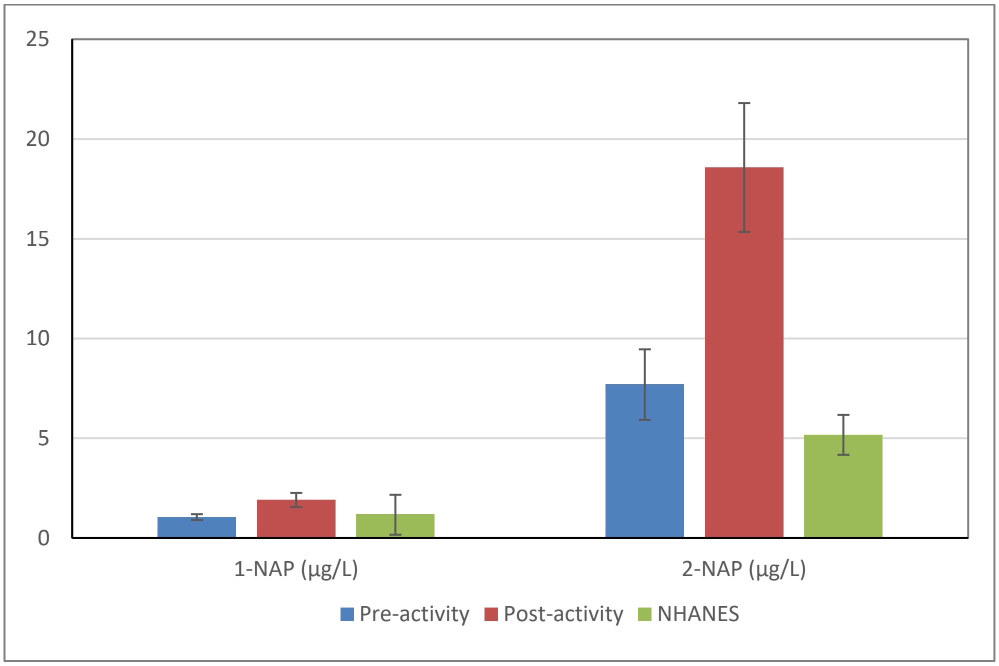

Figure 2-2. Geometric mean of unadjusted 1-hydroxynaphthalene and 2-hydroxynaphthalene concentrations (µg/L) for exposure pilot study participants, pre-activity and post-activity, compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [NHANES = National Health and Nutrition Examination Survey; 1-NAP = 1-Hydroxynaphthlaene; 2-NAP = 2-Hydroxynaphthlaene]

The NHANES urinary PAH metabolite concentrations adjusted for creatinine and the creatinine-adjusted concentrations pre- and post-activity were compared. In comparing pre- and post-activity creatinine-adjusted measurements for these PAH metabolites in urine, most results were similar. There was no significant difference in pre- and post-activity concentrations, except for 2-hydroxynaphthalene. For 2-hydroxynaphthalene, there was a statistically significant increase in the post-activity mean concentrations when compared to the pre-activity mean concentrations (p-value = 0.041). The difference was greater for football players (p-value = 0.016). When compared with PAH analytes reported in NHANES 2013-2014 for participants aged 11 to 21, the synthetic turf field user group had similar mean concentrations of PAH analytes (Figure 2-3). The measured NHANES geometric means were similar, except for 1-hydroxypyrene, 2-hydroxynaphthalene, and 3-hydroxyfluorene (Figures 2-3 and 2-4). The NHANES geometric mean for both 1-hydroxypyrene and 3-hydroxyfluorene was greater than the pre- and post-activity geometric mean for this study. The NHANES geometric mean for 2-hydroxynaphthalene was less than the pre- and post-activity geometric means for this study. It should be noted that field measurements of naphthalene (a parent compound to 2-hydroxynaphthalene) in tire crumb rubber infill, field air, field dust, field wipe and drag sled samples were all low, and only 17% of the dermal wipe (personal) naphthalene measurements were above the quantifiable limit for football players. In addition, napthalene was 4 to over 100 times lower than phenanthrene and pyrene in these media, yet metabolites of these PAHs were lower than their NHANES values. Specific gravity measurements were also performed, and the PAH concentrations were adjusted. Specific gravity (SG) adjusted pre- and post-activity PAH concentrations in urine were compared. Post-activity concentrations were statistically higher than pre-activity concentrations for all metabolites, and all differences were statistically significant using the signed-rank test. Median differences were larger for soccer players than for football players. Comparing this result to the same analysis of creatinine-adjusted concentrations shows how the choice of urine-dilution method can profoundly affect study conclusions. Because SG-adjusted concentrations were only collected in the 2007-2008 NHANES cycle, and because PAH concentrations have changed over time, a comparison to study concentrations would not be meaningful. CDC/ATSDR conducted a supplemental biomonitoring study which elucidated the findings of the pilot biomonitoring efforts; results for the supplemental biomonitoring study can be found in Appendix A.

The concentrations of metals in whole blood and serum were compared in samples collected from study participants pre- and post-activity. Significant differences were not observed in the means and geometric means between the pre- and post-activity samples for football or soccer players. When compared with blood and serum metal concentrations reported in NHANES 2013-2014, participants aged 11 to 21, the geometric mean concentrations for whole metals in blood and serum for the synthetic turf field users were similar, with the exception of blood selenium (Figures 2-5 and 2-6). The pre-activity and post-activity geometric mean concentrations for blood selenium were greater than the NHANES geometric mean. However, selenium was below the detection limits in the tire crumb rubber analyses, field air, field wipe, field dust, and dermal wipe samples. Selenium was also measured in serum. Serum selenium geometric mean concentrations reported in NHANES 2013-2014 were similar to the mean concentrations measured for the study participants.

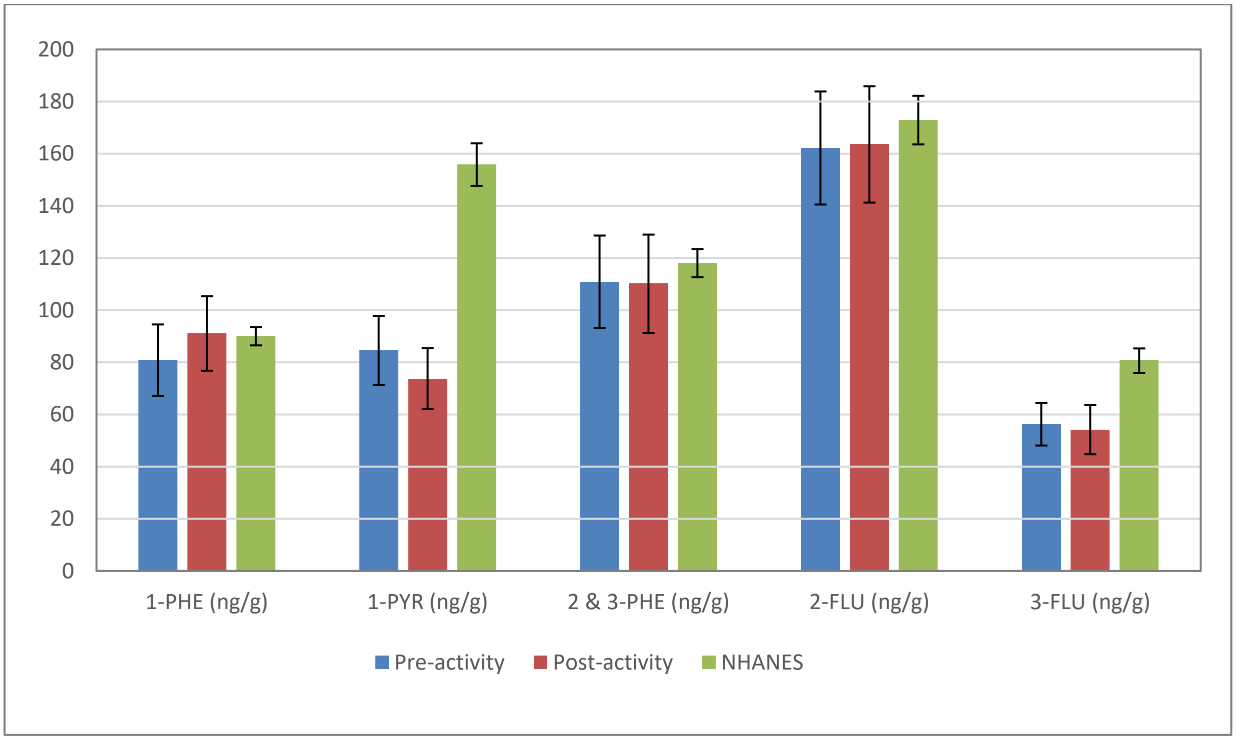

Figure 2-3. Geometric mean of creatinine-adjusted urinary PAH concentrations (ng/g) for exposure pilot study participants, pre-activity and post-activity, compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [PAH = polycyclic aromatic hydrocarbon; NHANES = National Health and Nutrition Examination Survey; 1-PHE = 1-Hydroxyphenanthrene; 1-PYR = 1-Hydroxypyrene; 2 & 3-PHE = 2- & 3-Hydroxyphenanthrene; 2-FLU = 2-Hydroxyfluorene; 3-FLU = 3-Hydroxyfluorene]

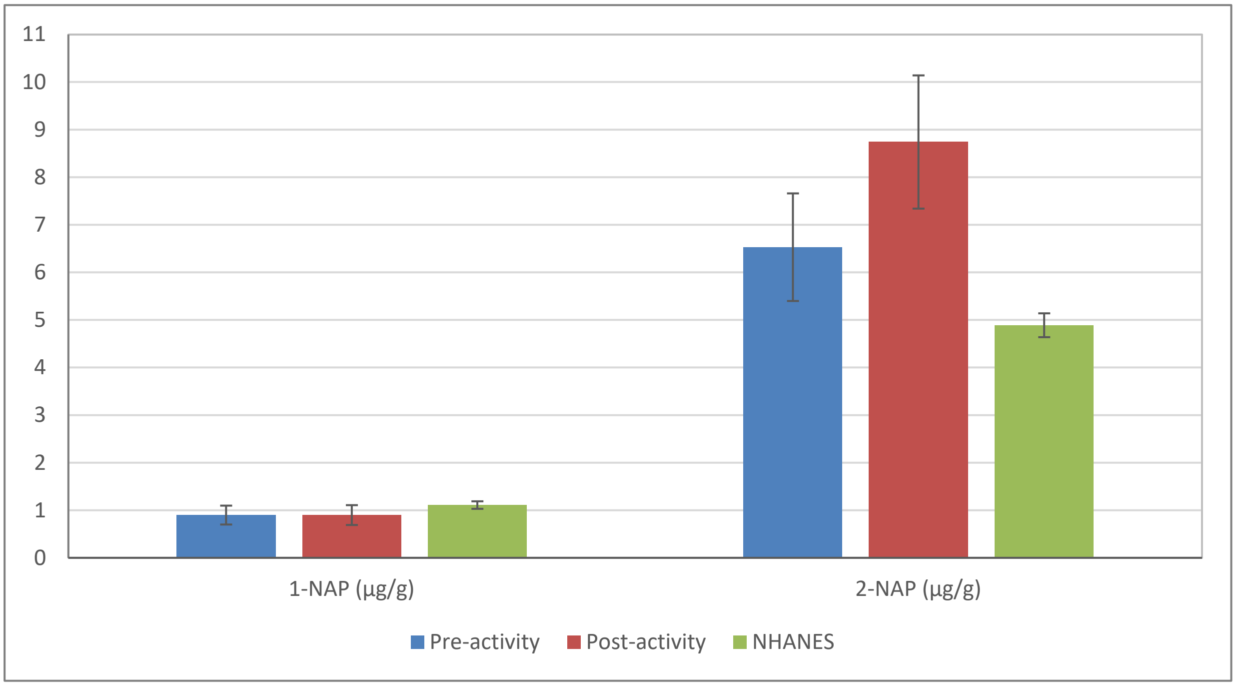

Figure 2-4. Geometric mean of creatinine-adjusted 1-hydroxynaphthalene and 2-hydroxynaphthalene concentrations (µg/g) for exposure pilot study participants, pre-activity and post-activity, compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [NHANES = National Health and Nutrition Examination Survey; 1-NAP = 1-Hydroxynaphthlaene; 2-NAP = 2-Hydroxynaphthlaene].

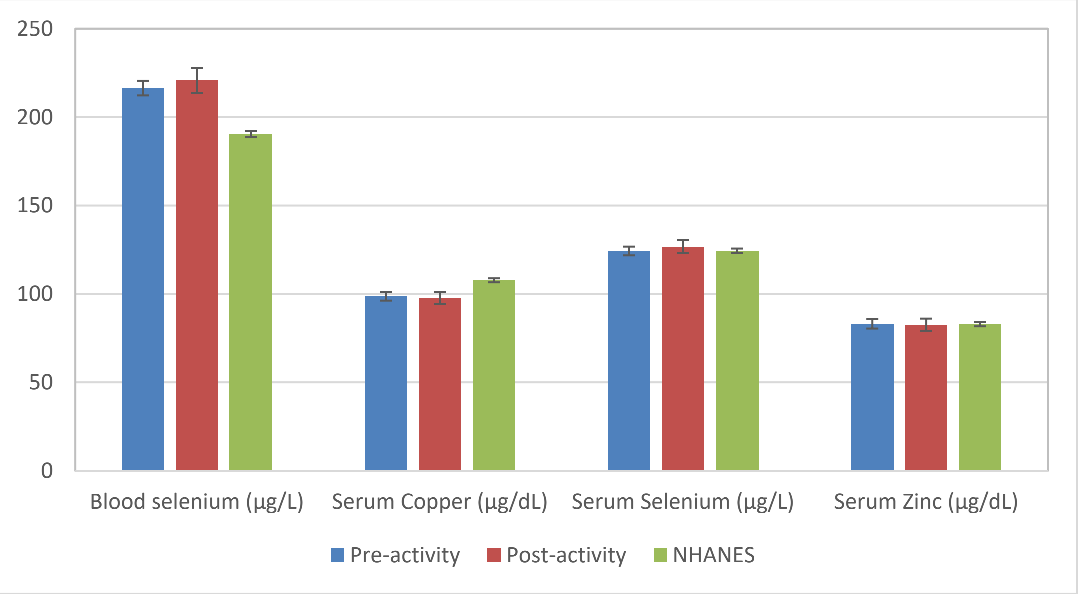

Figure 2-5. Exposure pilot study, pre-activity and post-activity, blood selenium, serum copper, serum selenium, and serum zinc geometric mean levels compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [NHANES = National Health and Nutrition Examination Survey]

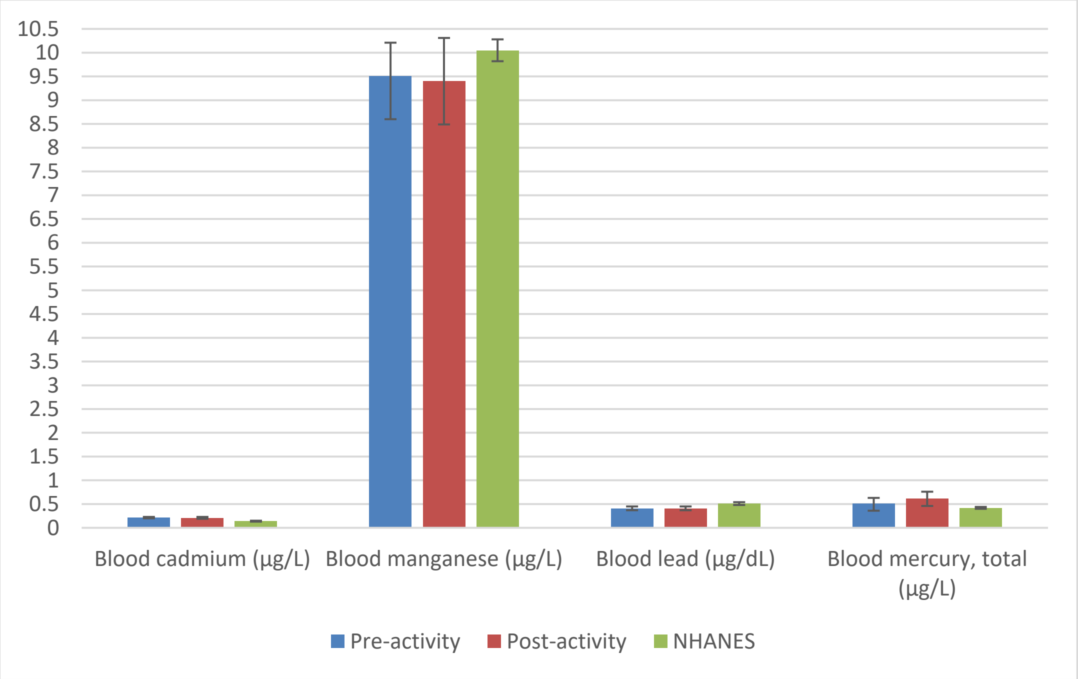

Figure 2-6. Exposure pilot study, pre-activity and post-activity, blood cadmium, blood manganese, blood lead and total blood mercury geometric mean levels compared to NHANES 2013-2014 weighted and design-adjusted values for ages 11-21. [NHANES = National Health and Nutrition Examination Survey]

As a complement to exposure measurements, modeling can provide information on potential exposures. Exposure pathway modeling for athletes using synthetic turf fields with recycled tire crumb rubber infill was performed. By way of example, six chemical substances (pyrene, benzo[a]pyrene, benzothiazole, methyl isobutyl ketone, lead and zinc) were evaluated using data available from the literature and supplemented with data collected in this study. In general, estimated daily exposures were < 5 x 10^{-5} mg/kg-d for most chemicals and pathways. Inhalation was the most dominant pathway for the more volatile chemicals, with inhalation exposure estimates reaching up to 5 x 10^{-3} mg/kg-d for methyl isobutyl ketone at indoor fields. Ingestion was estimated to be the most dominant pathway for metals and less volatile chemicals. Ingestion estimates for zinc were as high as 5 x 10^{-3} mg/kg-d when estimates were made using existing measurement data, and 2 x 10^{-4} mg/kg-d when using data from this study.

To provide context, exposure from other typical sources (such as residential and dietary “background”) were compared to those of field users. Residential (e.g., indoor air and dust) plus dietary ‘background’ exposures were estimated for four chemicals associated with tire crumb rubber. For pyrene and benzo[a]pyrene, residential plus dietary exposure estimates were 1.5 to 3 times higher than average exposures estimated for synthetic field users using data generated in this study. For zinc and lead, residential plus dietary exposure estimates were over 100 times higher than average exposures estimated for synthetic field users based on data produced in this study and over 10 times higher than estimates using literature results to model exposures for synthetic turf field users. When using literature data and different model parameters, synthetic turf field users were estimated to have at most 1.5 times higher pyrene exposures than those from residential plus dietary background. However, there is likely considerable uncertainty in these exposure estimates.

2.2.3 In Summary

- Pilot study measurements were made in air, surface wipe, dust and dermal media for a wide range of chemicals for 25 participants participating in soccer or football practices at synthetic turf fields. The measurements provided additional data for assessing inhalation exposures and new data for better understanding exposures through dermal and ingestion pathways. Many of the chemicals that were associated with tire crumb rubber were found in the environmental or dermal samples. Most SVOCs were found at low concentrations in the field wipe and drag sled samples, and many SVOCs had a high percentage of dermal wipe measurements below quantifiable limits. In air samples collected next to outdoor fields with active play, several chemicals were measured at levels modestly above background air concentrations, while many chemicals were not found above background levels. Higher levels of many chemicals were measured in the air at the indoor field compared to the levels at the outdoor fields or in the background air samples.
- This study has provided important new and additional information about chemicals in tire crumb rubber and the ways field users may come into contact with this material and its chemicals; however, the magnitude of potential exposures is still somewhat uncertain, in part due to incomplete information regarding the amounts of field dust that adhere to the skin of synthetic turf field users and the amounts of dust and tire crumb rubber ingested.
- When compared with NHANES 2013-2014 data for individuals age 11-21, the geometric mean concentrations of metals in blood and serum were similar, with the exception of blood selenium. The unadjusted urinary PAH metabolite concentrations were higher post-activity than pre-activity and higher post-activity than concentrations reported for individuals age 11-21 in NHANES 2013-2014. When adjusted for creatinine, urinary PAH metabolite concentrations showed no difference in concentrations pre- and post-activity, with the exception of 2-hydroxynaphthalene. However, generally low

concentrations of naphthalene were found in the tire crumb rubber, field measurement, and dermal wipe samples. Specific gravity was not collected in the 2013-2014 NHANES cycle. Comparing our SG results to the 2007-2008 NHANES cycle could be inappropriate due to changes in PAH levels over time.

- Modeled estimates suggest that synthetic turf field users may have pyrene and benzo[a]pyrene exposures similar to or somewhat lower than estimated background exposures, and exposures to zinc and lead that are substantially lower than background. Taking into account the pilot nature of this study and related uncertainties, neither of these observations on their own can provide definitive answers that exposures may be low; together they are consistent with results of recent studies.
- Video data analysis approaches were tested and, along with questionnaires, applied in this pilot study. These video and questionnaire approaches were found to be effective for generating information on human activity patterns of youth and adult synthetic turf field users that may affect their exposures to tire crumb rubber and its constituents. This information can be used to further develop and improve exposure scenario generation and exposure modeling; however, more data are needed for a wider range of on-field activities and for athletes with higher field contact rates. Most assessments to date have been performed for soccer player scenarios; data produced in this study suggests football players may have higher frequencies of certain types of contacts that may increase exposure. An increase in blood metal concentration was not observed after practice.
- Blood selenium levels, both pre- and post-activity, were higher than the geometric mean for participants aged 11 – 21 in the 2013-2014 National Health and Nutrition Examination Survey (CDC NHANES 2013 – 2014). However, selenium was not found above detection limits in tire crumb and other field environment matrices.
- With the exception of blood selenium, body burden levels of metals in these study participants were consistent with those found for the general population (CDC NHANES 2013 – 2014, participants aged 11-21).
- Significant differences in mean concentrations were observed when comparing pre- and post-activity levels for the unadjusted urinary PAH metabolites.
- In comparing pre- and post-activity creatinine-adjusted measurements for these PAH metabolites in urine, there was no significant difference in pre- and post-activity concentrations, except for 2-hydroxynaphthalene.
- When compared with PAH analytes reported in NHANES 2013-2014 for participants aged 11 to 21, the geometric mean for all unadjusted urinary PAH metabolites post-activity was higher than the NHANES geometric mean, with the exception of 1-hydroxypyrene. The geometric mean for creatinine-adjusted urinary PAH metabolites was similar to the NHANES geometric mean, with the exception of 1-hydroxypyrene and 3-hydroxyfluorene which had higher geometric means in NHANES.
- The supplemental biomonitoring study (Part 2 Report Appendix A) further elucidates the initial pilot findings. In general, no differences in PAH metabolites in urine were observed between study participants using grass and synthetic turf fields with tire crumb rubber infill in the supplemental biomonitoring stud

2.3 Detailed Summaries of Research Results

2.3.1 Exposure Characterization Pilot Study for Athletes Using Synthetic Turf Fields with Tire Crumb Rubber Infill

2.3.1.1 Participant Recruitment

Children and adults participating on sports teams that practiced on community synthetic turf fields that participated in the tire crumb rubber characterization study were recruited to participate in the questionnaire, exposure measurement, and video activity components of the exposure characterization pilot study.

- In-person recruitment was conducted Monday through Thursday immediately prior to, during, and after field activities.
- Recruited participants included 32 for the questionnaire component, 25 for the exposure measurements sub-study, and 17 for the video activity. For the biomonitoring pilot study, fourteen participants provided urine samples and 13 participants provided blood samples.[6]
- Participants were a variety of ages; specifically, seven participants were between seven to less than 11 years of age, 18 participants were ages 11 to less than 18 years of age, and seven were adults (18+).
- Participants were recruited and sampling was conducted during two sport activities, football and soccer practice sessions.

2.3.1.2 Field Measurements

- Air samples were collected for VOC, SVOC, metal, and total suspended particulate analysis at three synthetic turf fields (i.e., two outdoors fields and one indoor field) during warm to hot weather during athletic team practices. For many analytes at the outdoor fields, next-to-field concentrations were not different than background ambient air samples; exceptions included next-to-field levels of methyl isobutyl ketone, 4-tert-octylphenol, benzothiazole, and several PAHs. For most of these analytes, differences at outdoor fields between next-to-field and background levels were modest. It is not clear how well air samples collected next to the field represent personal inhalation exposures, however, collecting accurate breathing zone air samples for the wide range of chemicals present in tire crumb rubber is a challenge.
- Air concentrations of many VOC, SVOC and metal analytes associated with tire crumb rubber were higher in the indoor field facility compared to outdoor fields and background levels.
- On average, SVOCs were present in field dust at concentrations similar to, but somewhat lower than, those measured in the tire crumb rubber infill. It is not clear whether the amounts of SVOCs in field dust were lower than the amounts in the tire crumb rubber or were a result of relatively low extraction efficiencies from the dust. Zinc and cobalt were measured in dust at somewhat lower levels than in tire crumb rubber. Other metals, such as lead, were present in dust at levels higher than those measured in the tire crumb rubber.

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[6] See Appendix A for the supplemental biomonitoring study.

- SVOCs were measured at low levels in field wipe and drag sled samples, with average transferrable levels generally below 0.2 ng/cm^2.
- Many metals were measured in field surface wipes at average values below 2 ng/cm^2, while zinc and metals typically found in soil were measured at higher levels. Zinc in tire crumb rubber likely contributed to the levels measured in the field surface wipes.

2.3.1.3 Personal Measurements

- Personal dermal wipe sample collection was performed for exposure measurement sub-study participants. SVOCs and metals were analyzed using wet wipes collected from the hand, arm, and leg of study participants following their usual athletic practice sessions on synthetic turf fields. (Pre-practice dermal samples were not collected due to time and participant availability constraints).
- All metals except selenium were found at measurable levels in the dermal wipes. Many metals were measured in dermal wipes at median values below 1 ng/cm^2, while zinc and other metals typically found in soil were measured at 4.1 to 140 ng/cm^2.
- About half of the SVOCs were measured in dermal wipe samples at levels above the method detection limit. Most SVOCs had median values below 0.2 ng/cm^2, with up to 0.21 ng/cm^2 for 4-tert-octylphenol, 0.69 ng/cm^2 for n-hexadecane, and several phthalates with median levels up to 7.0 ng/cm^2. The phthalates may have been present from other sources in addition to or instead of field materials.
- Few clear differences in dermal levels for the different analytes were observed between age groups or between football and soccer groups.
- In this study, a small passive VOC air sampler with high effective sampling rates was attached to the upper backs of each study participants during their usual athletic practice sessions on synthetic turf fields. For the football players, one sampler was destroyed and another damaged during vigorous tackling activities. Otherwise, all remaining samples were successfully collected.
- The personal air samplers did not provide usable measurement results. Inconsistent effective sampling rates were measured under laboratory chamber and field conditions, and low recoveries were observed for the two highest concentration analytes, benzothiazole and methyl isobutyl ketone.
- For the pilot-scale biomonitoring study, all unadjusted urine PAHs showed PAH metabolites were higher after practice, and the after practice geometric means were greater than the NHANES 2013-2014 geometric mean for the same age group. For the creatinine-adjusted urinary PAH metabolite concentrations, no difference in concentration was observed before or after practice on a synthetic turf field with tire crumb rubber infill, except for 2-hydroxynaphthalene. Both the pre-activity and post-activity geometric mean for 2-hydroxynaphthalene was greater than the NHANES 2013-2014 geometric mean for the same age group.
- For specific gravity-adjusted metabolite concentrations, all post-activity concentrations were statistically higher than pre-activity concentrations, and all differences were statistically significant using the signed-rank test.
- The whole blood and serum metals results showed no significant difference in concentrations before or after practice on a synthetic turf field with tire crumb rubber infill. A majority of the pre- and post-activity geometric mean concentrations were

similar to NHANES 2013-2014 geometric mean concentrations for the same age group, with exception of selenium. Selenium concentrations were slightly higher in the pilot study participants than the NHANES comparison group. It is important to note that the biomonitoring study that was conducted as part of the exposure measurement study was a pilot-scale effort with several limitations. The sample size was very small (n=14) and individuals who participated in the pilot-scale biomonitoring study were recruited at only two outdoor fields. A larger sample size was needed in order to confirm the pilot-scale study results. See Appendix A for the report of the supplemental biomonitoring study.

2.3.1.4 Activity Data Collection

Participant Questionnaires – Questionnaires were administered to 32 participants – adults (age 18+), youth (11 to 18 years of age), and the parents of children (7 to 10 years of age) – to obtain information on the frequency, duration, and activities performed on various types of fields, along with other information on hygiene and activities that may affect exposures to tire crumb rubber and associated chemicals.

- A majority of participants reported playing on synthetic turf fields at least once a week in the past year (63%) and past five years (56%). A majority also reported playing on natural grass fields at least once a week in the past year (59%) and past five years (56%).
- For all participants, diving, falling, sitting, and drinking on turf fields were commonly reported, especially in the summer.
- Commonly reported activities occurring on synthetic turf fields every time or often included drinking (81% of participants), hands touching the turf (78% of participants), and body parts (other than hands) touching turf (75% of participants).
- A majority of participants reported finding tire crumb rubber, dirt or debris every time or often on their body (66% of participants), in their car (75% of participants), or at home (59% of participants) after using a synthetic turf field.

Video Data Collection and Analysis – Video recordings were used to generate objective information on exposure-related micro-activity events for youth and adult athletes participating in sports activities on athletic fields. Two approaches were applied, using existing, publicly-available videos and videos recorded for a subset of exposure characterization pilot study participants.

- Publicly-available videos of 30 youth and 30 adults participating in soccer, football, or field hockey allowed generation of frequency counts for hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events.
- In data from the publicly-available videos, there were no significant differences in the frequency of youth and adult micro-activity events. There were significantly higher hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events for football players compared to soccer and field hockey players, however.
- Video recording and activity analysis was performed for 17 youth and adult participants engaging in soccer or football practice sessions during the exposure characterization pilot study. Micro-activity frequencies and information on physical activity levels and physical activity duration was captured from the videos.
- Because of the use of mouth guards, football players had a four-fold higher frequency of object-to-mouth events than soccer players in the exposure pilot study videos, and they had a two-fold higher frequency of body-to-turf events. Soccer players had significantly

higher average duration in the high physical activity category, while football players had significantly higher average duration in the resting category during practice sessions.

- These types of contact frequency and physical activity level information, when combined with questionnaire data on duration and frequency of field uses, could be used in future work to refine exposure scenarios and improve exposure models for synthetic field users.

2.3.1.5 Exposure Pathway Modeling

Exposure pathway modeling for athletes using synthetic turf fields with tire crumb rubber infill was performed using data available from the literature and supplemented with data collected in this study. The primary purposes of this modeling exercise were to:

- Elucidate which exposure pathways are likely to be the biggest contributors to total exposure for different types of tire crumb rubber constituents.
- Explore whether data produced in the federal study can improve our exposure estimations, particularly for the dermal and ingestion pathways.
- Assess the availability, robustness and adequacy of tire crumb rubber data, exposure measurement data and the data needed for exposure model parameters to determine the accuracy and uncertainties in exposure estimations for athletes using synthetic turf fields.
- Prepare modeled estimates of background exposures from residential and dietary sources for comparison with exposure estimates for synthetic turf field users.

Six chemical substances associated with synthetic turf fields and tire crumb rubber were selected for exposure pathway modeling. They were selected based on the availability of previous measurement data and represent a range of physical and chemical properties. Adult and child pathway-specific exposure estimates were calculated for each of the six chemical substances and were compared to identify the predominant pathway for each chemical substance.

- Pathway algorithms were first run using previously-reported measurement values.
- In general, chemicals of like or similar classifications (i.e., VOCs/SVOCs, metals) followed the same pattern of exposure for each age group.
- Ingestion of tire crumb rubber appears to be the most significant pathway of exposure for the PAHs pyrene and benzo[a]pyrene, and exposure decreases with age due to an assumed decrease in tire crumb rubber ingestion with age.
- Exposure to metals, namely lead and zinc, is highest in the 6 to 10 age range, with a predominant route of ingestion. The results show a significant decrease in exposure in the other age groups due to an assumed decrease in tire crumb rubber ingestion.
- The main exposure pathway for benzothiazole and methyl isobutyl ketone appears to be inhalation, with much higher inhalation exposures at indoor fields than outdoor fields; however, this is based only on a very small number of indoor field air measurements.
- Dermal exposures are estimated to be lower than ingestion exposures for the metals and PAHs and much lower than the inhalation exposures for benzothiazole. However, there are large uncertainties in the model adherence and dermal absorption parameters.

Using tire crumb rubber, metals bioaccessibility, field environment measurement data, and exposure measurement data from this tire crumb rubber and exposure characterization study (including measurements in field dust and in dermal wipes), the exposure pathway models were re-run. Dermal wipe measurements from the exposure pilot study provided the ability to calculate the amount of chemical directly in contact with the exposed skin, avoiding more uncertain adherence assumptions. Field dust measurements were used in place of those for the tire crumb rubber, as these measurements were likely more relevant for the ingestion pathway. Field air measurements from the exposure pilot study were used for the inhalation pathway.

- Similar exposure pathway patterns were seen using the exposure pilot study data and the extant data. The assumed amounts of tire crumb rubber ingested were the key drivers for age-related differences.
- Ingestion estimates were slightly lower using the exposure pilot study data, based on slightly lower metal and PAH levels in field dust compared to tire crumb rubber.
- There are no objective data for assessing tire crumb rubber or field dust ingestion amounts for synthetic field turf scenarios, resulting in highly-uncertain ingestion exposure estimates.
- Dermal exposure estimates using dermal measurements from the exposure pilot study were lower than those estimated from extant data and an assumed adherence factor. Metals estimates were also lower when using the lower absorption values applied from the bioaccessibility measurements from this study.

Estimates of ‘background’ exposures from residential and dietary sources were compared to modeled estimates for synthetic turf field users for benzo[a]pyrene, pyrene, lead and zinc as an example of how this type of comparison might be approached. Modeling ‘background’ exposures may also inform approaches for estimating total exposures that synthetic turf field users may experience from all sources. Total exposure estimates would best be performed over an appropriate time interval, for example over a year, rather than the comparison of daily exposures that was performed here.

- Benzo[a]pyrene and pyrene exposures estimated from residential plus dietary sources were estimated to be 1.5 to 3 times higher than modeled exposure estimates for synthetic turf field users based on data produced in this study.
- When using literature results for synthetic turf fields and somewhat different model parameters, benzo[a]pyrene exposures from residential plus dietary sources were similar to those for synthetic turf field users. Pyrene exposures were at most 1.5 times higher for synthetic turf field users using literature data compared to residential plus dietary sources.
- Lead and zinc exposures estimated from residential plus dietary sources were estimated to be over 100 times higher than modeled exposure estimates for synthetic turf field users based on data produced in this exposure pilot study, and over 10 times higher than estimates using extant data from the literature to model exposures for synthetic turf field users.

Based on these modeling exercises, we report the following observations regarding the adequacy of the data for exposure estimation for athletes using synthetic turf fields:

- The data are not adequate to support probabilistic exposure modeling approaches. For many chemicals found to be associated with tire crumb rubber infill on synthetic turf fields, there is a lack of robust data for many exposure media, including air (particularly in athlete breathing zones for particulate matter), field surfaces and field dust, and dermal residue loadings. This lack of robust data likely results in increased uncertainty in exposure estimation.

- Current exposure estimates are somewhat limited by the lack of exposure scenarios that more fully account for actual activity levels and types and frequencies of contact, and their differences among sport types (e.g., football vs. soccer) and specific positions that may involve higher rates of contact with turf materials (e.g., soccer goalies and football running backs).
- More information on activity patterns and micro-activity events related to exposures were collected in this study. This information can be used to help fill gaps in some exposure parameters and perhaps allow improved exposure estimates across age groups and sports through development of more detailed exposure pathway algorithms.
- There are limited or no data for some of the important parameters needed to estimate exposures for athletes using synthetic turf fields with tire crumb rubber infill. The lack of parameter data leads to applications of assumed values or values applied from non-equivalent scenarios, both of which can lead to considerable uncertainties in exposure estimates. In some cases, conservative parameter values have been applied in order to inform conservative and protective assessments, but that could lead to exposure over-estimation. For example, RIVM applied a conservative tire crumb rubber ingestion rate of 0.2 g/event, which is higher than the 24-hour soil and dust ingestion values ranging from 0.01 to 0.06 g/day commonly used for residential exposure estimation. RIVM and ECHA also applied a conservative soil/dust dermal adherence factor of 0.001 g/cm^2, which is higher than reported amounts measured for residential or other relevant scenarios. In other cases, important exposure mechanisms may not be correctly accounted for, that could lead to exposure under-estimation. For example, the amount of airborne tire crumb rubber fine particles could be higher in the direct breathing zones of some athletes than existing measurements suggest, potentially resulting in an underestimation of inhalation exposures.
- There are a large number of chemical substances associated with tire crumb rubber infill that have not been included in most exposure assessments. Lack of certainty in the identification of many of these chemicals and lack of quantitative measurements inhibits a more complete cumulative exposure assessment.
- Data are likely to be sparse for estimating background exposures for many chemicals associated with tire crumb rubber for comparison with estimates for synthetic turf field users and for preparing total exposure estimates combining field-related and background exposures.

2.4 Research Limitations

2.4.1 Research Design Constraints

The exposure characterization pilot study was not based on a representative sampling design and is underpowered for assessing differences among potential exposure factors. However, the exposure characterization study was intended as a pilot-scale effort to further develop measures and approaches suitable for providing relevant exposure information in larger studies. Another design constraint was a decision to focus characterization research on the recycled tire crumb rubber infill and not to include other synthetic turf field materials (e.g., synthetic grass blades and backing material) due to the expanded scope that would be needed for a high-quality characterization of all these materials. In regards to the biomonitoring pilot study, design limitations did not allow for control of exposures that occur from off-field activities and/or exposures when urine, blood and dermal wipe sampling take place. Therefore, relating these exposures to measures of exposure from tire crumb fields includes a degree of uncertainty.

2.4.2 Planned Work Not Completed in this Study

Not all research goals for this study were completely met. Exposure pilot study goals included collecting samples at six synthetic turf fields, administering questionnaires to 60 participants, and performing personal exposure measurements of 45 participants. Only three fields were sampled, 32 participants completed questionnaires, and 25 participants underwent personal exposure measurements. Timing issues as to when fields and/or athletes could be available and study-specific deadlines were the primary reasons for not fully meeting the intended sample size for the exposure pilot study. No full-time soccer goalies or football running backs, athletes that may have higher field contact rates, participated in the measurement study.

2.4.3 Multi-source and Pathway Exposure Characterization

People are exposed to many of the chemicals of interest at synthetic turf fields (e.g., metals, PAHs, phthalates, VOCs, and SVOCs) from other sources and environmental media, including ambient and indoor air, soil, house dust, food, and water. Synthetic turf field users may have more specific exposures to other types of chemicals used in tire manufacturing (e.g., rubber vulcanization agents or accelerators, antioxidants) that are not typically found in the general environment. However, people are likely exposed to tire wear particles in the environment, as well. Additionally, many rubber products are used in buildings and transportation systems. In any risk assessment or epidemiological investigation, it would be important to try to understand the relative exposures from all sources and pathways, including synthetic turf fields. This study provides examples of how multi-source and multi-pathway comparative modeling assessments might be performed for chemicals with sufficient data. Expanding this work to other chemicals and scenarios was beyond the scope and timeframe for this research.

Exposure pathway modeling was performed for several chemicals associated with tire crumb rubber to assess potential exposures for adult and youth athletes using synthetic turf fields, to better understand which exposure pathways might be the most important, and to assess the extent and quality of information needed for successful modeling. Ideally, probabilistic modeling approaches would have been used to develop distributions of exposure estimates. However, only point estimates of exposure were developed through modeling in this study due to the sparseness of data for several important exposure media and exposure parameters. Limitations in available data and exposure parameter values for synthetic turf field exposure scenarios result in uncertainties in the accuracy of the point estimates. The ability to interpret modeled exposures for exposure and risk assessments is limited by the lack of a more complete understanding of the distribution of exposures for people using synthetic turf fields with tire crumb rubber infill.

2.4.4 Other Limitations

The research described in this report was exclusively aimed at synthetic turf fields with recycled tire crumb rubber infill. While it may be desirable for reasons noted below to include other types of fields, it was beyond the scope of this study to investigate other types of fields (e.g., natural grass, synthetic fields with natural product infill, or synthetic fields with ethylene propylene diene terpolymer [EPDM] or thermoplastic elastomer [TPE] infill). It was also beyond the scope of this study to evaluate the use of recycled tire crumb rubber as a soil amendment or natural grass top dressing. While there is concern about chemical exposures resulting from the use of recycled tire and other materials in synthetic fields, it is important to recognize that some of the chemicals are present in other types of fields, including natural grass fields. For example, metals (including lead) and PAHs (including benzo[a]pyrene) of concern at synthetic turf fields with tire crumb rubber infill are also often found in surface soil in the United States and may be present at natural grass playing fields. Insecticides and herbicides may be used on some natural grass fields, leading to exposures that may not be experienced by synthetic turf field users. Because many recreational and sports field users usually spend time on both natural grass and synthetic fields (either concurrently or during different life stages), characterization of chemical and microbiological agents at all relevant field types and an understanding of relative exposures across the different field types would be needed for risk assessment and epidemiological investigations.

The study did not address potential heat exposure and injury concerns for athletes on synthetic turf fields. In the dermal measurements performed as part of the exposure characterization study, it would have been ideal to collect both pre- and post-activity samples; however, given the time and complexity for collecting wipe samples and the participant time needed, we judged the participant burden too large in the current assessment and prioritized the pre-activity time available with participants towards urine and blood sample collection for the pilot-scale biomonitoring study.[7]

2.5 Future Research Recommendations

While this study added considerable new information for better understanding tire crumb rubber to inform exposures to chemical substances associated with tire crumb rubber material and microbes at synthetic turf fields, additional research could be performed to further inform and improve future exposure and risk assessments.

- Given the complex nature of tire crumb, it is not unexpected that many chemicals were observed during characterization testing. The ability to resolve which, if any, of those that were tentatively identified are relevant for further evaluation is further complicated by the potential dearth of toxicity information. Approaches for whole material toxicity testing, such as those used by the National Toxicology Program, could be further developed and applied for assessing potential effects of the material.
- Results in this study and other studies suggest that exposures to chemicals associated with recycled tire crumb rubber infill are likely to be higher for users of indoor synthetic turf fields as compared to users of outdoor fields. Exposures at indoor facilities may represent the highest exposure scenarios, based on the higher levels of many organic chemicals observed in indoor tire crumb rubber infill (in the absence of weathering and other mechanisms thought to lower the concentration of these chemicals over time) and reduced ventilation rates, which can lead to higher air concentrations. Future studies might be directed at collection of more air and exposure measurements at indoor facilities.
- Exposure modeling approaches have been applied in other studies for exposure estimation and were examined in this study for the inhalation, dermal and ingestion exposure pathways. There is a lack of parameter value data for some key model parameters for synthetic field users, however. For example, the amounts of tire crumb rubber and field dust that adhere to the skin and the amounts of tire crumb rubber and field dust that are ingested are not currently available. Future work could be aimed at

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[7] See Appendix A for the supplemental biomonitoring study.

improving exposure pathway models and cumulative exposure assessment methods for synthetic turf field exposure scenarios.

- The exposure pilot study provided field and personal measurement results for a small number of youth and adults engaged in athletic activities at synthetic turf fields. Building off methods developed and tested in this and other studies, future larger studies could be performed to collect additional exposure measurement data. Research aimed at certain sports positions (e.g., soccer goalies and football running backs) and indoor turf field users could provide insight into exposures for some of the athletes potentially facing the greatest exposures. More studies could also be performed for young child bystanders and field installation and maintenance workers.
- Sample collection methods and questionnaire data collection methods applied in this study could be considered for use in future epidemiological investigations, should it be determined that such investigations are warranted.

2.6 Conclusions

This part of the Tire Crumb Research Study report communicates the research objectives, methods, results and findings for the exposure characterization and fill specific gaps about potential human exposures to the chemicals found in the tire crumb rubber material while using synthetic turf fields. A range of chemicals was found in air, field surface, field dust, and in dermal exposure media, including metals and organic chemicals. Exposures may be higher for people using indoor synthetic turf fields than outdoor fields.

In general, the findings from the entire synthetic turf field portion of the FRAP activities (both the Tire Crumb Characterization Part 1 and the Tire Crumb Exposure Characterization Part 2 combined) support the conclusion that although chemicals are present (as expected) in the tire crumb rubber and exposures can occur, they are likely limited; for example:

- Generally, only small amounts of most organic chemicals are released from tire crumb rubber into the air through emissions. For many analytes measured during active play at the outdoor fields, next-to-field concentrations in air were not different than background samples while others were somewhat higher.

- For metals, only small fractions are released from tire crumb rubber into simulated biological fluids (average mean about 3% for gastric fluid and <1% for saliva and sweat plus sebum) compared to a default assumption of 100% bioaccessibility.

- In the biomonitoring pilot study, concentrations for metals measured in blood were similar to those in the general population.

- No differences in PAH metabolites in urine were observed in the supplemental biomonitoring study between study participants using natural grass and those on synthetic turf fields with tire crumb rubber infill.

Risk is a function of both hazard (toxicity) and exposure. Understanding what is present in the material (Part 1 Report) and how individuals are potentially exposed (Part 2 Report) is critical to understanding potential risk. It is important to note that the study activities completed as part of this multi-agency research effort were not designed, and are not sufficient by themselves, to directly answer questions about potential health risks. Other studies may aid in this regard.

Overall, we anticipate that the results from this multi-agency research effort will be useful to the public and interested stakeholders for understanding the potential for human exposure to chemicals associated with recycled tire crumb rubber infill material used on synthetic turf fields.

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3.0 Exposure Characterization Methods

3.1 Overall Research Design

As described in the Federal Research Action Plan (U.S. EPA, CDC/ATSDR, and CPSC, 2016a) and in the Research Protocol, *Collections Related to Synthetic Turf Fields with Crumb Rubber Infill* (U.S. EPA and CDC/ATSDR, 2016), this portion of the research was a pilot-scale effort aimed at providing information and data for characterizing exposures to chemical constituents for users of synthetic turf fields with tire crumb rubber infill. A goal was to recruit participants from among those thought to be in one or more higher-exposure scenarios based on the frequency and duration of synthetic turf field use, as well as specific activities that may be involved in higher levels of contact with synthetic turf field materials including tire crumb rubber. There were two primary components in the exposure characterization research: a) information collection from synthetic turf field users on human activity parameters that may affect potential exposures to tire crumb rubber constituents, and b) human exposure measurement study to further develop and deploy appropriate sample collection methods and to generate data for improved exposure characterization. A schematic outline of the tire crumb rubber characterization research, as implemented, is shown in Figure 3-1.

Several different age groups were included in the exposure characterization pilot study, including adults (≥ 18 years old), adolescents (13 to 17 years old), youth (10 to 12 years old), and children (7 to 9 years old). The research design goals included recruitment and participation via questionnaire, exposure measurement, and videographic data collections.

Human activity data collection included the use of questionnaires administered to adult and adolescent (or the parents of youth and child) study participants who used synthetic turf fields with tire crumb rubber infill and videography of users engaged in activities on synthetic turf fields. Information was collected to provide data about relevant parameters for characterizing and improved modeling of exposures associated with the use of synthetic turf fields. In addition to answering the questionnaire, video data collection was performed for a subset of participants during a physical activity on a synthetic turf field to provide information about exposure-related contact rates and activity levels. Publicly-available videography of users engaged in activities on synthetic fields was also used to provide objective assessment of contact rates and activity types, which are difficult to capture consistently using questionnaires. A subset of the participants that provided questionnaire responses were asked to participate in an exposure measurement pilot study.

Exposure measurement activities included sample collection and analysis and metadata collection to help inform exposure measurement interpretation. As part of a pilot-scale biomonitoring study, a set of personal, biological, and field environment samples were collected around a sport or training activity performed on a synthetic turf field.[8] Personal and environmental samples were analyzed for the metal, VOC, and SVOC analytes described in Tables 3-1 through 3-3.

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[8] See Appendix A for the supplemental biomonitoring study.

The exposure characterization research activities are summarized in Table 3-1.

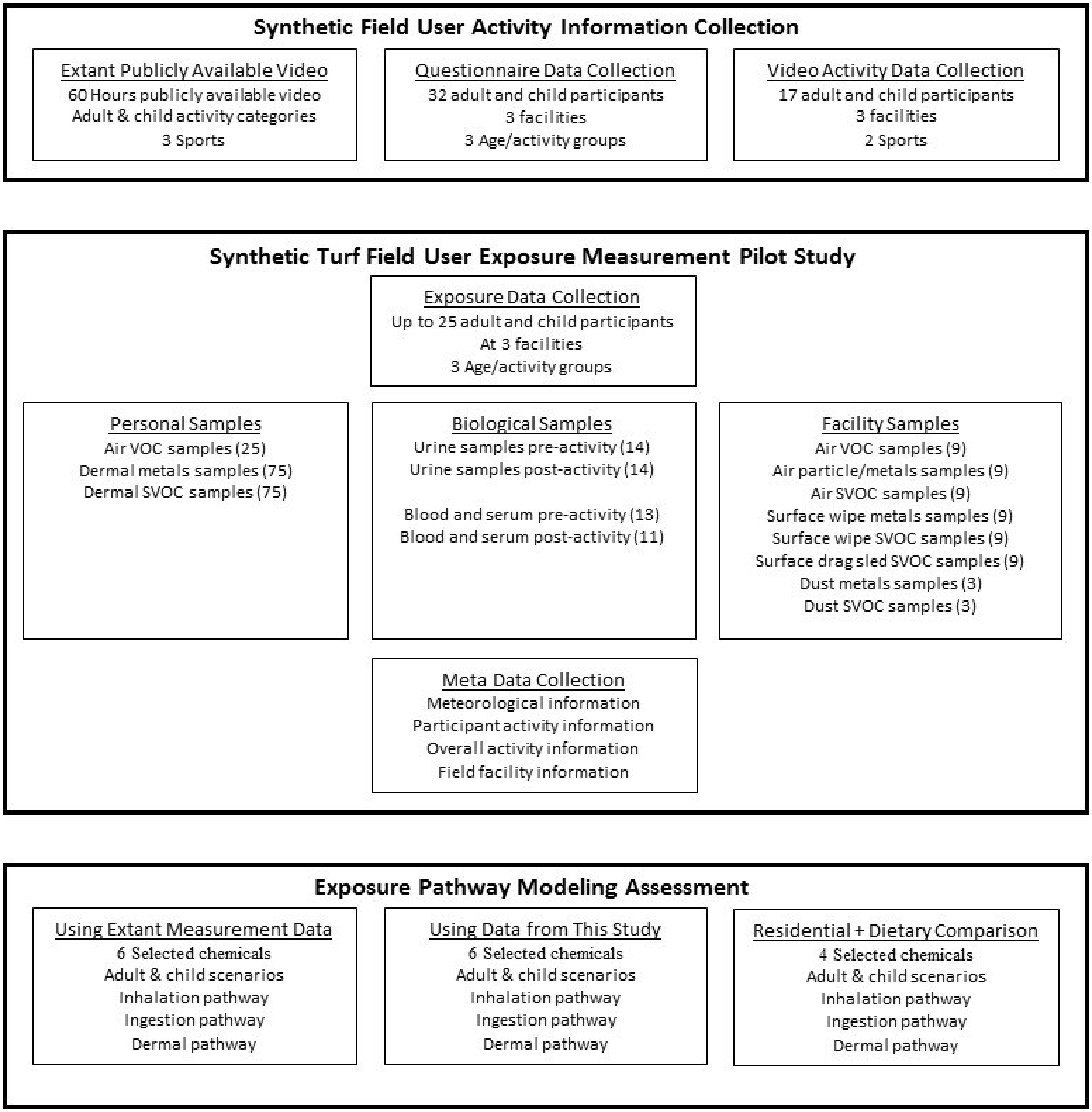


Figure 3-1. Pilot exposure characterization research schematic overview.

Table 3-1. Exposure Characterization Research Areas and Specific Research Activities

Research Area	Research Activities
Exposure Characterization Pilot Study for Youth and Adults Athletes Using Synthetic Turf Fields with Tire Crumb Rubber Infill	Recruiting youth and adult participants for sample and data collection around their usual sport activities at synthetic turf fields
	Using questionnaire data collection to obtain data for field use duration and frequency of use, activity patterns on fields, and hygiene to improve exposure scenario development and exposure modeling for youth and adult athletes using synthetic turf fields
	Using video data from online sources and participant video data collection approaches to provide data for contact types and frequencies, and activity levels for improving exposure modeling for youth and adult athletes using synthetic turf fields
	Performing measurements to provide additional data on particles, metals, SVOCs, and VOCs in the air at synthetic turf fields during periods of activity on the field and during warm to hot ambient air conditions for assessing exposure through the inhalation pathway
	Developing methods and providing data on inorganic and organic chemicals on field surfaces, in field dust, and on athlete skin to better understand and estimate both child and adult exposures, particularly for the dermal and ingestion exposure pathways
	Developing, applying, and assessing methods and approaches for personal air sample collection
	As part of a pilot-scale biomonitoring study, collecting and analyzing blood and urine samples for measurement of selected metals and PAH biomarkers before and after the monitored participant sport activities at synthetic turf fields
	Assessing silicone wristbands as potential sampling devices for future use in field air and personal sampling assessments of exposure at synthetic turf fields
	Applying and assessing exposure pathway models to examine differences in exposure levels across pathways, and to identify where lack of data (or lack of robust data) may be limiting accuracy and/or resulting in potentially large uncertainties in exposure estimation for synthetic turf field users (see section 5)
Supplemental Biomonitoring Study	Expanding upon the FRAP's pilot-scale effort by including a larger sample size of synthetic turf with recycled tire crumb rubber infill users and a comparison group of natural grass field users
	Examining potential assocaitions with pre- and post-activity urinary PAH biomarker concerntrations with field type
	Comparing study participants' urinary PAH concentrations to those found in the noninstitutionalized general U.S. population

A pre-pilot test of sample collection and videography standard operating procedures (SOPs) and the overall plan for sample collection at synthetic turf fields was conducted in June 2017. Based on this testing, the SOPs and overall sampling plan were modified prior to initiating the exposure characterization sampling in September 2017; exposure characterization SOPs are provided in Appendix C. Many of the modifications that were made were aimed at reducing sample deployment and collection times at fields because a) the amount of time available at a field before and after the monitored participant activities was likely to be limited in some settings, and b) the time to interact with participants for multiple sample/data collection procedures before and after their monitored activity was likely to be highly constrained. These anticipated time constraints were, in fact, realized during the research study, and the focus on time efficiency in sampling methods and strategies was essential.

Exposure pathway modeling was performed for adult and child athletes using synthetic turf fields with tire crumb rubber infill, first using data available from the literature and then again with data collected in this study. Six chemicals associated with synthetic turf fields and tire crumb rubber were selected for exposure pathway modeling. They were selected to provide a range of physical and chemical properties and because of the availability of previous measurement data. Adult and child pathway-specific exposure estimates were calculated for each of the six chemical substances and were compared to identify the predominant pathway for each chemical substance. Subsequent to the modeling of tire crumb-related exposures using previously existing and newly acquired measurement data, daily intakes of four of the chemicals were also estimated using available dietary and residential "background" concentrations to provide perspective on the relative magnitude of the crumb-related exposure estimates.

3.2 Exposure Measurement Pilot Study Recruiting and Questionnaire Methods

3.2.1 Participant Recruiting

Recruitment for the exposure characterization pilot study was initiated August 28, 2017 and ended on October 4, 2017. Researchers aimed to recruit and obtain consent from 60 participants for the exposure characterization study and 45 participants for the exposure measurements sub-study, including 24 participants to be videotaped during play/athletics. The goal was to have participants from six fields, including at least one field in each of the four U.S. census regions; however, if the researchers were unable to obtain that geographic distribution, no geographic restrictions would be placed on participant recruitment. The target population for the exposure characterization study and exposure measurements sub-study was defined as children and adults (≥ 7 years of age) who played sports on community synthetic turf fields with tire crumb rubber infill in the previous year. There were no restrictions on time of play in the previous year or type of sport (e.g., baseball). Researchers aimed to have a variety of athletes consent to participate in the studies, including: professional athletes, college athletes (≥18), adolescents (ages 13–17), youth (ages 10–12), and children (ages 7–9).

Initially, the research team reached out to synthetic turf fields who participated in the tire crumb characterization study and who consented to allow for recruitment of players at their facilities. Due to scheduling issues and other factors, only three fields in two U.S. census regions were available for participant recruitment during the study time frame, specifically one indoor field and two outdoor fields. The research team received practice schedule information prior to the field visits and reached out to sports organizations scheduled for field use during the planned recruitment and sampling weeks to discuss the project and provide outreach materials.

Recruitment was conducted Monday through Thursday, immediately prior to, during, and after field activities. Prior to practice, research team members endeavored to meet and discuss the project with team coaches; however, this was not always possible. Researchers approached either players (≥18) or their parents/guardians (<18) to determine interest in participating in the study. At the time of initial contact, researchers provided a fact sheet and, if requested, a copy of the consent forms. If parents/guardians or players were interested in participating, an eligibility screening questionnaire was administered. Once eligibility was confirmed, parents/guardians or the participant were given a consent form. If desired, the research team reviewed the consent form with the individual and answered any questions. Participants were given the option to consent to the following study schemes: 1. Field use questionnaire only; 2. Field use questionnaire and exposure measurements sub-study; or 3. Field use questionnaire, exposure measurements sub-study, and videography. For the pilot-scale biomonitoring study, participants were also allowed to decline collection of biological samples. Signed consent was obtained from adult participants and from parents or guardians of participants <18 years of age; participants <18 years of age were required to provide signed assent forms, as well.

3.2.2 Field User Questionnaire Administration

After confirming eligibility to participate in the interview and receiving signed consent/assent forms, exposure study participants were given contact information and an appointment time for the questionnaire to be administered (usually before or after field activities). The questionnaire was administered by a research team member in person at the sampled facility site and lasted approximately 30 minutes. For participants younger than 13 years of age (i.e., youth and children), the questionnaire was administered to a parent or guardian, as outlined in the protocol. Slightly different questionnaire versions were used for administration directly to a participant and administration to a participant parent or guardian; the questionnaires are available in Appendix D. Double data entry occurred, as a hard copy of the questionnaire was used at the facility and later entered into an Epi Info™ 7.2 database (CDC, 2017). After completion of the questionnaire, the participant was given contact information for any further questions, as well as a token of appreciation.

3.3 Exposure Pilot Study Sample Collection Methods

3.3.1 Field Environment Samples

Researchers collected field environment samples that included field and off-field (background) air samples, field surface wipe samples, drag sled samples, and dust samples. Researchers used specified sampling locations for rectangular (soccer and football) synthetic turf fields (Figure 3-2), although air sampling locations varied with wind direction. Standard operating procedures were prepared for each sample collection method; the SOPs are provided in Appendix C. Air samples were collected during the time periods in which participant athletic activities occurred. Field surface wipe, drag sled, and dust sample collections were performed at these fields when there were no athletic activities on the field. Target analytes for metals, VOCs, and SVOCs were the same as those described in Tables 3-1, 3-2, and 3-3 in the Tire Crumb Characterization Report (U.S. EPA & CDC/ATSDR, 2019); however, mercury was not included as a target analyte for field environment samples.

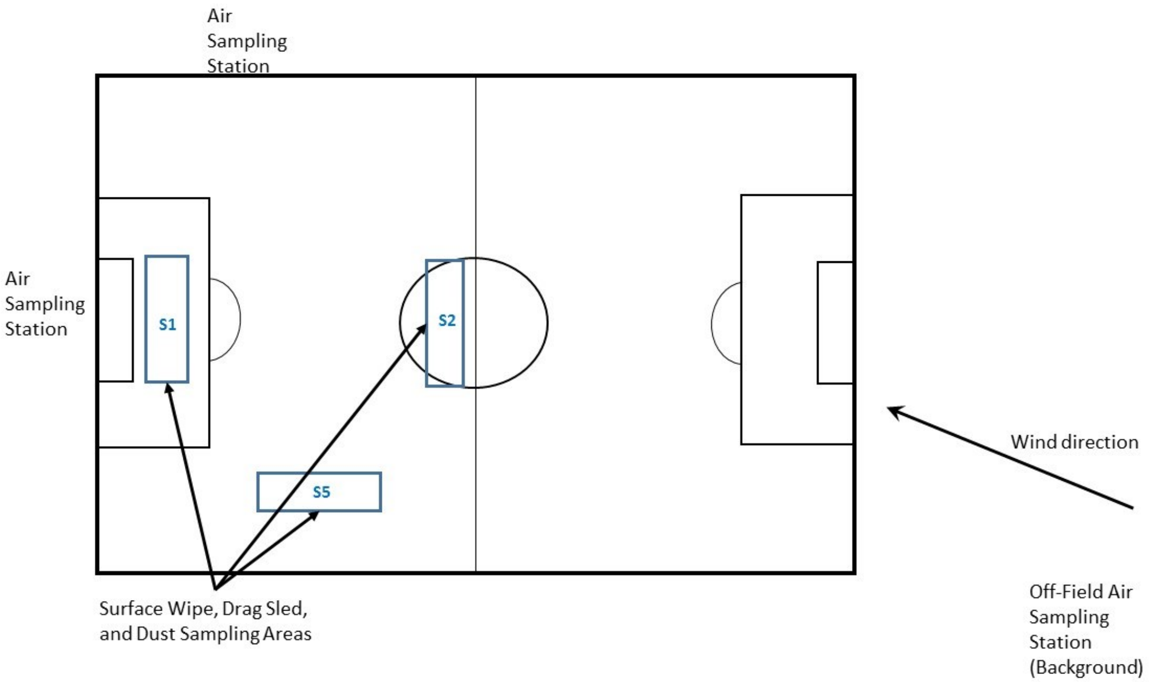


Figure 3-2. Sample collection locations for field air, surface wipe, drag sled, and dust samples. Collection locations for air samplers were dependent on wind direction.

3.3.1.1 Field Air Samples

Field air samples were collected while participants engaged in athletic activities on synthetic turf fields. Samples were collected for particulate, metals, VOC and SVOC analysis. A total of three air samples were collected simultaneously at each synthetic turf field (Figure 3-2). Air samples were collected from two points at each synthetic field, preferably downwind and as close as possible to where activities occurred without posing an obstruction or safety hazard. A third sample was collected upwind and at a sufficient distance from the field to represent background. In the case of indoor fields, the background sample was collected outside of the facility building and in an upwind direction. Air sampler inlets were located 1 meter above the field or ground surface. Figure 3-3 shows the co-located particulate/metals, VOC, and SVOC air samplers deployed at a soccer field. It was anticipated that sample collection durations would be approximately two to three hours in order to represent an exposure period that included participant time spent at the field prior to an athletic activity, during the athletic activity period (ranging up to two hours), and a short time spent at the field following the athletic activity. The actual sampling period reflected the duration of the monitored participants' activity at the synthetic turf field.

Figure 3-3. Typical field air sampling station setup (photo taken during pre-pilot testing), including particulate/metal, semivolatile organic compound (SVOc), active volatile organic compound (VOC), and passive VOC samplers.
This configuration shows duplicate sample collection for each sample type.

Field Air Samples for Particulates and Metals - Air samples were collected for total suspended particulate (TSP) and metals analysis. A typical TSP/metals field air sampling set up is shown in Figure 3-4.

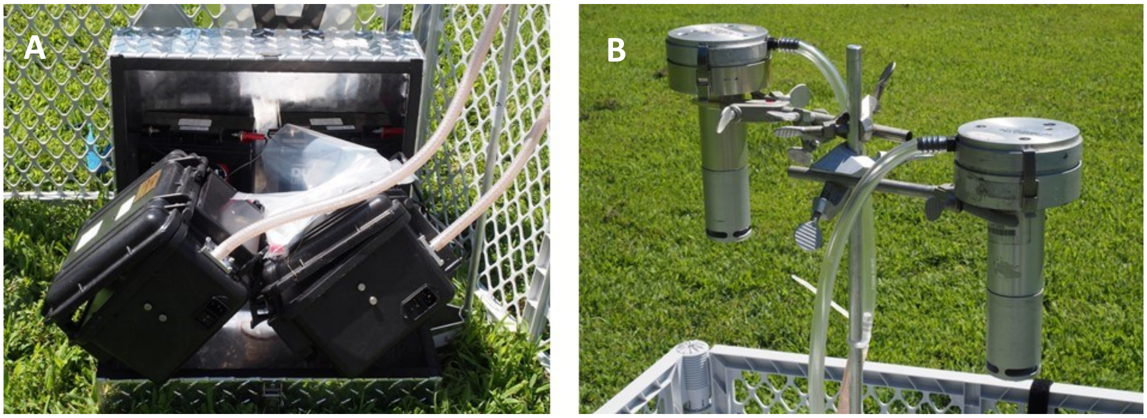


Figure 3-4. Total suspended particulate/metals field air sampling setup, showing deployed A) batteries and pumps and B) filter-containing sampling heads. This configuration shows duplicate sample collection.

Samples for TSP and metals analysis were collected at a nominal flow rate of 20 L/min using metered, direct current-supplied AirChek™ HV30 active samplers (SKC, Inc., Eighty Four, PA, USA), without size-selective impactor inlets, to enable mass loading on pre-weighed 37-mm Pallflex Teflo membrane disk filters (Pall Corporation, Port Washington, NY, USA). Sampler flow rates were measured and recorded, along with the start and stop times at the beginning and completion of the sampling period. At the conclusion of the sampling event, filter samples were recovered and returned to the laboratory under ambient temperatures.

Field Air Samples for VOCs - Two types of VOC air sampling methods were employed at the synthetic turf fields. The first sampling approach employed Radiello^{TM} passive/diffusive samplers containing Carbopack™ X sorbent, (Sigma-Aldrich, Saint Louis, MO, USA). The Radiello^{TM} samplers were selected due to their relatively high effective sampling rates, which was anticipated to provide improved limits of detection for short duration sampling events. The on-field use of the Radiello^{TM} passive samplers was performed to provide comparability to the personal sample collection approach (also using Radiello^{TM} samplers) and to reduce the amount of equipment and set-up time for sample collection. The second sampling approach employed an active pumping system and Carbopack™ X fenceline monitor (FLM) tubes (Sigma-Aldrich, Saint Louis, MO, USA). This active VOC sampler was used to help better understand the performance of the Radiello^{TM} samplers and to provide measurements using a more standard approach. A typical set up for passive and active sampling of field air for VOCs is shown in Figure 3-5.

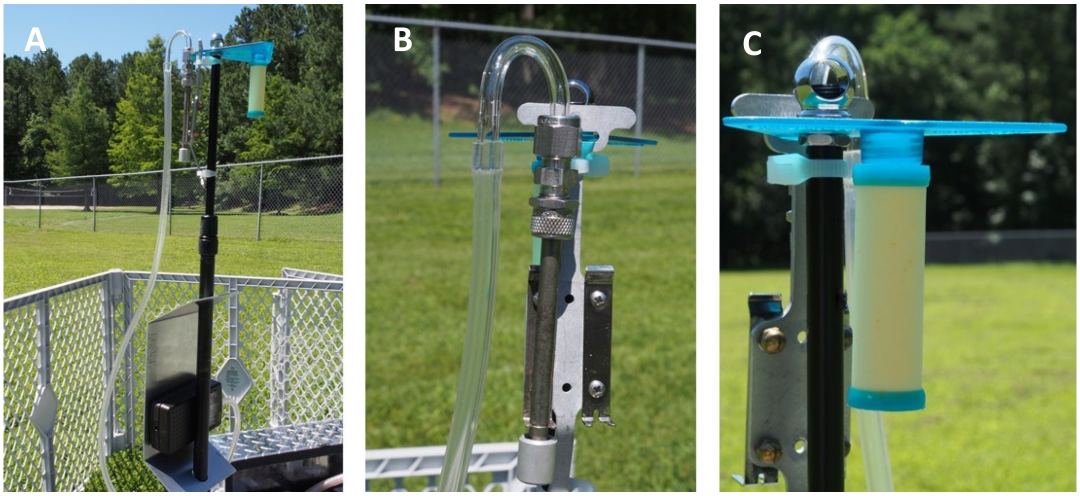


Figure 3-5. Volatile organic compound field air sampling setup, showing A) Pump and passive and active air samplers in deployed configuration, with close-up of B) active Carbopack™ X fenceline monitor sampler and C) passive Radiello™ sampler.

Active sampler flow rates were measured and recorded at the start and completion of the sampling period. Passive samplers were removed from their storage containers to start sampling and returned to the storage containers immediately at the end of the sampling period. All sampling start and stop times were recorded. At the conclusion of the sampling event, filter samples were recovered, stored in sealed transportation containers, and returned to the laboratory. Following receipt at the laboratory, samples were stored at 6 °C until analysis.

Field Air Samples for SVOCs - SVOCs include many chemical analytes, with large ranges of vapor pressures and physical and chemical properties. Some SVOCs with higher vapor pressures are found primarily in the vapor phase in air, while SVOCs with lower vapor pressures are typically found on airborne particles. In this study, air samples were collected for SVOC analysis without a size-selective particle inlet to allow both vapor- and particle-phase SVOCs to be collected simultaneously. Separate particle- and gas-phase air concentrations were not measured. A medium-volume sample collection rate (20 L/min) was selected, instead of a high-volume collection rate, due to the need for portability (i.e., the ability to be deployed around the country), the need to minimize the footprint of equipment next to fields with sports activities, the limited time available for setting up and taking down equipment, and the uncertainty surrounding the availability of electrical power needed for high-volume sampling. Calculations made from previously reported field measurements suggested that approximately 3- to 5-m^3 samples would provide adequate detection limits for important tire crumb constituents, such as pyrene and benzothiazole.

Samples were collected on solvent pre-cleaned open-cell 22-mm × 7.6-cm polyurethane foam (PUF) filters placed in clean 30-mm × 70-mm tubes. The typical equipment used for field air sampling for SVOCs is shown in Figure 3-6.

Samples were collected at a nominal flow rate of 20 L/min using metered, direct-current-supplied AirChek™ HV30 active samplers (SKC, Inc., Eighty Four, PA, USA). Sampler flow rates were measured and recorded, along with the start and stop times at the beginning and completion of the sampling period. At the conclusion of the sampling event, filter samples were recovered, stored in a cooler with ice packs, and returned to the laboratory on frozen ice packs. Following receipt at the laboratory, samples were stored at -20 °C until extraction.

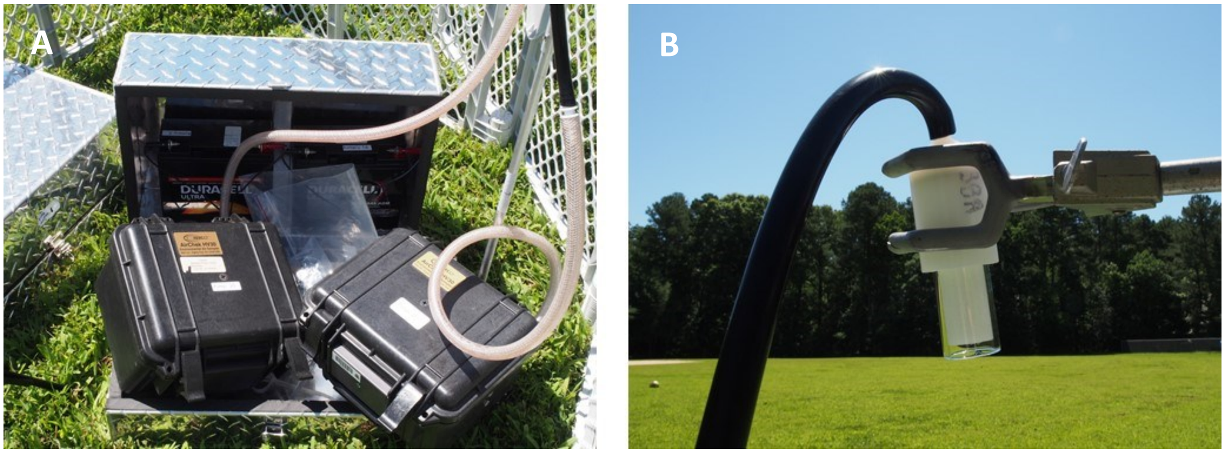


Figure 3-6. Semivolatile organic compound field air sampling setup, with A) batteries and pumps and B) filter-containing sampler. The pump/battery configuration shows duplicate sample collection.

3.3.1.2 Field Surface Samples – Surface Wipe and Drag Sled Samples

Field surface samples were collected for metals analysis using a water-wetted wipe and for SVOC analysis using two methods – an isopropanol-wetted wipe and a drag sled. Samples were collected from the field at times when it was safe to do so without posing an obstruction or safety hazard for any activities occurring on the field. Sample collection time was not critical for these samples; the samples were collected at a convenient time during the overall exposure measurement activities at each field. Field surface wipe samples and drag sled samples were collected at each field (Figure 3-2, locations S1, S2 and S5),

Surface Wipe Samples for Metals - Surface wipe samples for metals analysis were collected at synthetic turf field sites using a GhostWipe wet (water) wipe (Environmental Express, Inc., Catalogue No. SC4210, Charleston, SC, USA) conforming to American Society for Testing and Materials (ASTM) E1792 (ASTM International 2016a) specifications. A total of three surface wipe samples were collected at each field (Figure 3-2, locations S1, S2 and S5). No background (off-field) surface wipe sample were collected.

Samples were collected following ASTM E1728 (ASTM International 2016b), a standard wet-wipe method for collecting dust from indoor floor surfaces using water as the wetting agent. A 30-cm × 30-cm (approximately 1-ft^2) template was placed on the surface of the field. Using clean, powderless nitrile gloves, the field sampling technician removed the wet wipe from the foil packet (Figure 3-7A). Using one side of the wipe, the turf surface was wiped in a S- or Z-shaped pattern within the template area (Figure 3-7B). After folding the wipe in half to get a fresh wipe surface, the area was wiped again in a S- or Z-shaped pattern perpendicular to the first wipe pattern (Figure 3-7C). The wipe was then folded in half again and the edges near the interior portion of the template were wiped. Plastic forceps were used to remove full-size tire crumb rubber infill granules, synthetic grass blades, and other large debris or litter from the wipe (Figure 3-7D). The wipe was then folded and placed in a pre-cleaned 50-mL polyethylene tube (Environmental Express, Inc., Catalogue No. SC475, Charleston, SC, USA) for storage. The tube was tightly capped and transported at ambient temperature or lower to the laboratory.

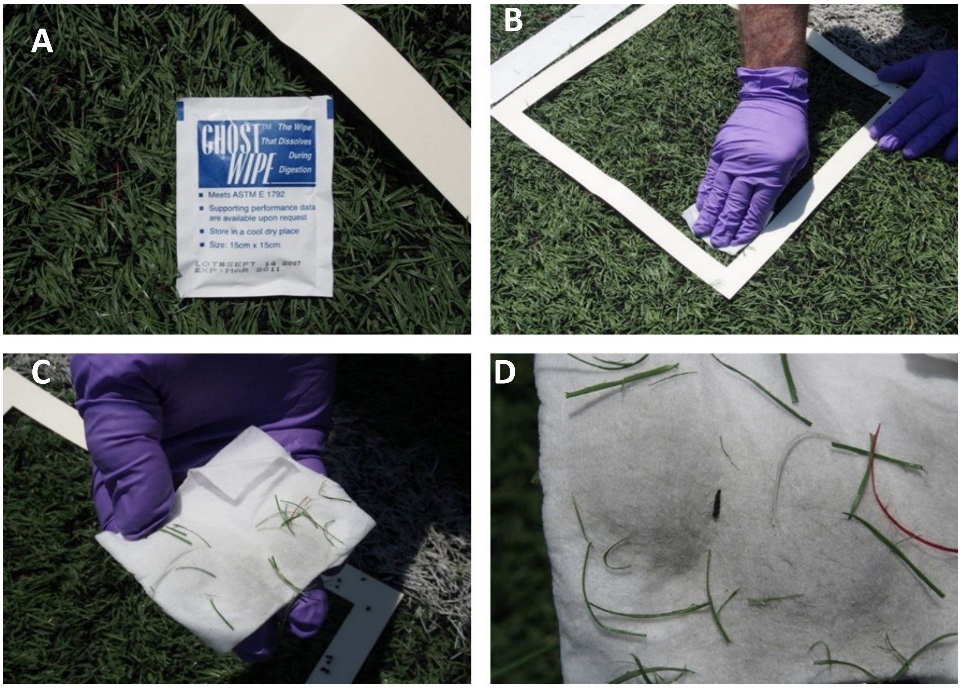


Figure 3-7. Field surface wipe sampling for metals analysis. Blades and debris were removed from samples prior to placing wipes in storage tubes.

Surface Wipe Samples for SVOCs - Wetted surface wipe samples for SVOC analysis were collected at synthetic turf field sites using a 10.2-cm × 10.2-cm Texwipe® TX304 cotton wipe (Texwipe, Kernersville, NC, USA) that was cleaned by pre-extraction, using a series of solvents including acetone and hexane, prior to use. A total of three SVOC surface wipe samples were collected at each field (Figure 3-2, locations S1, S2 and S5). SVOC surface wipe samples were collected from a different area at these locations than that used for metals surface wipe sample collection. No background (off-field) surface wipe samples were collected.

Using clean Silver Shield® gloves (Siebe North, Inc., North Charleston, SC, USA), the field sampling technician removed the cotton wipe, which had been pre-wetted in the laboratory with 3 mL of 1:1 deionized water:isopropanol, from its glass storage jar (Figure 3-8A). (Note: Silver Shield® gloves were used after tests showed potential contamination of wipe material with phthalates, when nitrile gloves were used). A 30-cm × 30-cm (approximately 1-ft^2) template was placed on the surface of the field. Using one side of the wipe, the turf surface was wiped in a S- or Z-shaped pattern within the template area (Figure 3-8B). After folding the wipe in half to get a fresh wipe surface, the area was wiped again in a S- or Z-shaped pattern perpendicular to the first wipe pattern. The wipe was then folded in half again and the edges near the interior portion of the template were wiped. Stainless steel forceps were used to remove full size tire crumb rubber infill granules, synthetic grass blades, and other large debris or litter from the wipe (Figure 3-8C, D). The wipe was then folded and placed in a pre-cleaned 60-mL amber wide-mouth glass jar. The bottle was tightly capped and transported on frozen ice packs to the laboratory, where the samples were placed in a freezer at -20 °C.

Figure 3-8. Field surface wipe sampling for semivolatile organic compound analysis. Blades and debris were removed from samples prior to placing wipes in storage jars. (Note: This figure shows the use of nitrile gloves. Silver Shield® gloves were worn during actual sample collections to reduce phthalate contamination of samples. Also, amber glass jars were used during study.)

Surface Drag Sled Samples for SVOCs - Surface drag sled samples for SVOC analysis were collected at synthetic turf field sites using a dry 30.5 cm × 30.5 cm Texwipe® TX312 cotton wipe (Texwipe, Kernersville, NC, USA) that was cleaned by pre-extraction, using a series of solvents including acetone and hexane, prior to use. The drag sled method provided a standardized approach for collecting dislodgeable residues from field surfaces in a way that might mimic potential transfers to field users' skin or clothing. The drag sled method was also likely to be less susceptible to operator variability with regard to applied pressure. A total of three SVOC drag sled samples were collected at each field (Figure 3-2, locations S1, S2 and S5). Drag sled samples were collected from a different area at these locations than that used for metals and SVOC wipe sample collection. No background (off-field) drag sled samples were collected.

Using clean, Silver Shield® gloves (Siebe North, Inc., North Charleston, SC, USA), the field sampling technician removed the dry cotton wipe from its storage container and clamped it to a custom-built wipe sampling drag sled device. The device had a 10-kg aluminum block, 25.4 cm × 25.4 cm × 5.1 cm in size, with clamps on two sides for securing the wipe, and an attached handle for pushing the device. The wipe was secured so that the 645-cm^2 bottom face of the block was completely covered by the wipe. Using a tape measure, a 5-m × 1-m (5-m^2) area was marked on the synthetic turf field (Figure 3-9A). Starting in one corner, the sled was pushed down and back over the same area. The sled was then moved over one sled width, and the next pass was made to push the sled down and back over the length of the tape measure (Figure 3-9B). This was repeated so that the entire 5-m^2 sampling area was wiped with a down and back pass. Large tire crumb granules were removed with stainless steel forceps from the wipe face that contacted the field, and synthetic grass blades, and other large debris or litter on the sides of the wipe that did not contact the field were removed to the extent possible (Figure 3-9C, D). The wipe was then folded and placed in a clean 500-mL amber wide-mouth glass storage bottle with a Teflon™-lined cap. The bottle was tightly capped and transported on frozen ice packs to the laboratory, where the samples were placed in a freezer at -20 °C.

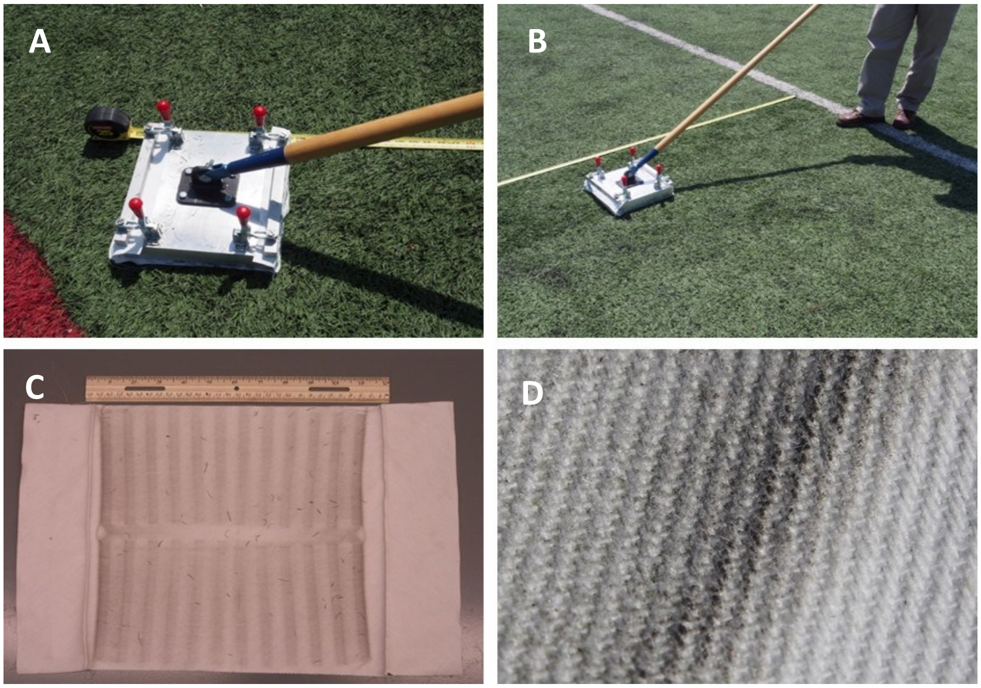


Figure 3-9. Drag sled sampling for semivolatile organic compound analysis.

3.3.1.3 Field Dust Samples

Dermal contact, inhalation, and ingestion of dust at synthetic turf fields may represent important pathways of exposure to chemicals associated with tire crumb rubber, other synthetic field materials, and environmental dust deposited on the field. Although dust may be an important synthetic turf field medium for all three exposure pathways, there are no standard methods for collecting dust from synthetic turf fields with tire crumb rubber infill. Several vacuum methods that have been previously used for dust collection in residential environments were tested. However, problems were encountered with each of these methods, (e.g., entrainment of tire crumb rubber granules, excessive moisture removal, collection of sand material from deep layers, and collection of organic materials and debris), which precluded their use in this study. Based on experience gained during the particle size analyses conducted as part of the tire crumb rubber characterization, a sieving method was tested for obtaining sufficient dust for metals and SVOC analyses. The sieving method was judged to be successful and was applied in the exposure measurement study to collect dust at the study fields.

Dust samples for SVOCs and metals analysis were collected at synthetic turf fields by on-field sieving of bulk dust collected as a composite from three locations on the field, using a 120 mesh (150-µM) stainless steel sieve. Samples were collected at locations S1, S2 and S5 (Figure 3-2) by successive collection and sieving of tire crumb rubber at each location. Plastic spatulas were used to collect tire crumb rubber from the top approximately 3 cm of the field (Figure 3-10A). The sieve was filled approximately half-full at each location (Figure 3-10B); this is approximately 600 mL (or approximately 340 g) of tire crumb rubber. The total amount sieved at each field was approximately 1800 mL (or approximately 1020 g). The sieve lid was placed on the sieve, and vigorous shaking was performed for at least 3 minutes (Figure 3-10C). After sieving at each of the three locations, the combined dust was brushed through a clean funnel and into a pre-cleaned 50-mL polyethylene tube for metals analysis. The amount of dust collected was visually compared to tubes containing 200, 300, and 400 mg of house dust to ensure a sufficient amount was collected for metals analysis. The sample collection and sieving process was then repeated, with the dust deposited into pre-cleaned 40-mL amber glass vials for SVOC analysis. The amount of dust collected was visually compared to tubes containing 200, 300, and 400 mg of house dust to ensure a sufficient amount was collected for SVOC analysis. SVOC dust samples were placed into a cooler with frozen ice packs at the field, stored cold, and shipped to the laboratory on frozen ice packs. SVOC dust samples were stored at -20 °C once at the laboratory. Metals dust samples were stored and shipped along with the SVOC dust samples. No background (off-field) dust samples were collected.

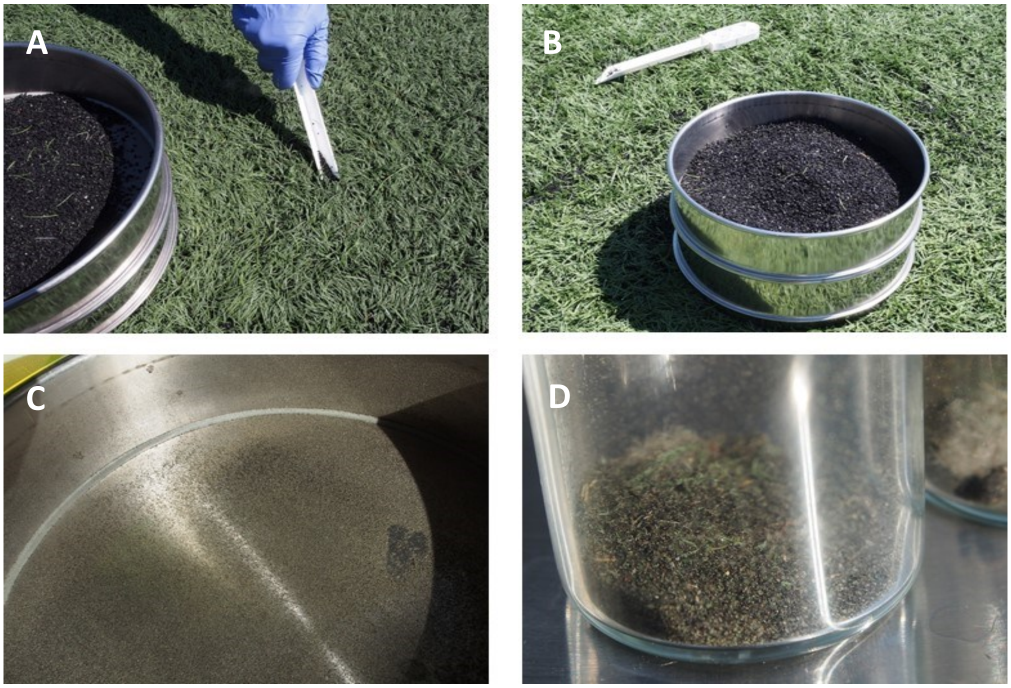


Figure 3-10. Dust sampling for metals and semivolatile organic compound analysis using a sieve method. (Note: This figure shows the use of a glass bottle. Dust was placed in a pre-cleaned 50-mL polyethylene tube for metals analysis and in a pre-cleaned 40-mL amber glass vial for SVOC analysis.)

3.3.2 Personal Samples

Personal sampling included collection of air samples and dermal (skin) wipe samples for exposure characterization study participants.

3.3.2.1 Personal Air Samples

Personal sampling for VOCs was performed using Radiello™ passive/diffusive samplers containing Carbopack™ X sorbent (Sigma-Aldrich, Saint Louis, MO, USA) attached to participants engaged in a sports activity on a synthetic turf field with tire crumb rubber infill. It was anticipated that sample collection durations would be approximately two to three hours in order to represent an exposure period that included participant time spent at the field prior to an athletic activity, during the athletic activity period (ranging up to two hours), and a short time spent at the field following the athletic activity. The actual sampling time reflected the duration of the monitored participant's activity at the synthetic turf field.

Passive samplers were removed from their storage containers to start sampling and were returned to the storage containers as soon as possible after the end of the sampling period. The samplers were attached to the back upper part of a pinnie that participants wore during their activity (Figure 3-11). This position, although not directly in the breathing zone, was selected to minimize interference with participant activities and potential for damage during contact with other athletes or the ground. The sample holder was attached to the pinnie at three points including the top clip and two Velcro fasteners at the bottom corners. All pinnies were laundered prior to initial participant use and between uses. All sampling start and stop times were recorded. At the conclusion of the sampling event, passive samples were recovered, stored in sealed transportation containers, and returned to the laboratory. Following receipt at the laboratory, samples were stored at -20 °C until analysis.

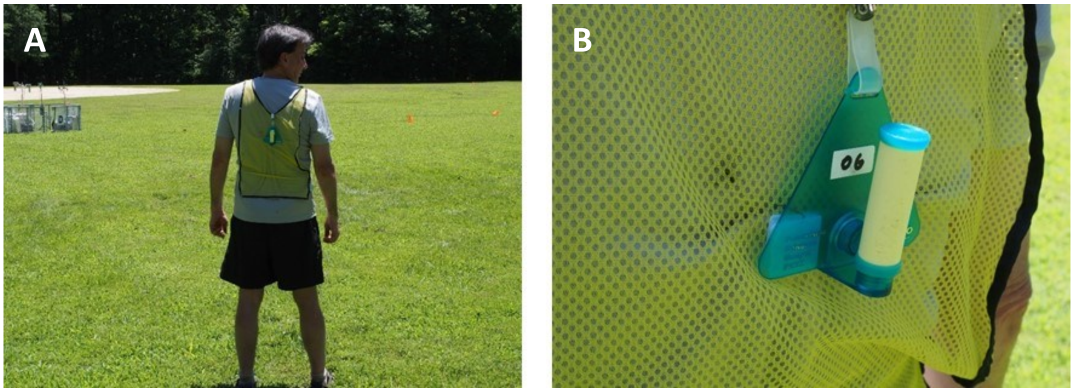


Figure 3-11. Personal air passive sampling for volatile organic compounds, showing A) placement on the participant's pinnie and B) a close-up of the air sampler. (Note: This figure is a demonstration, showing sampler placement on a person that was not a study participant).

3.3.2.2 Dermal Wipe Samples

Dermal Wipe Samples for Metals Analysis - Three dermal wipe samples were collected for metals analysis from each participant in the exposure characterization study, following an on-field sports activity. One wipe sample was collected from the participant's hand, the second wipe sample was collected from a defined area of the forearm, and the third wipe sample was collected from the leg (either calf or thigh depending on which area had more exposed skin area during the sports activity); dermal samples for metals analysis were all collected from the left side of the participant's body. All dermal wipe samples for metal analysis were collected using a GhostWipe wet (water) wipe (Environmental Express, Inc., Catalogue No. SC4210, Charleston, SC, USA) conforming to ASTM E1792 (ASTM International 2016a) specifications. (Note: This is the same wipe material used for collecting field surface wipe samples for metals analysis.) When sampling of the hand, arm, or leg was complete, the wipe was folded with the exposed (contacted) surface on the inside and placed into a pre-cleaned 50-mL polyethylene tube (Environmental Express, Inc., Catalogue No. SC475, Charleston, SC, USA) for storage and shipment to the laboratory.

Using clean, powderless nitrile gloves, the field sampling technician removed a Ghost Wipe wet wipe from the foil packet and unfolded the wipe to its full dimensions. With moderately-firm pressure, the technician wiped the participant's left hand with the wipe, including the back, front, and sides of the hand, fingers, and thumb (Figure 3-12A). The wipe was folded with the exposed (contacted) surface on the inside and placed into a pre-cleaned 50-mL polyethylene tube. The tube was tightly capped and transported at ambient temperature or lower to the laboratory.

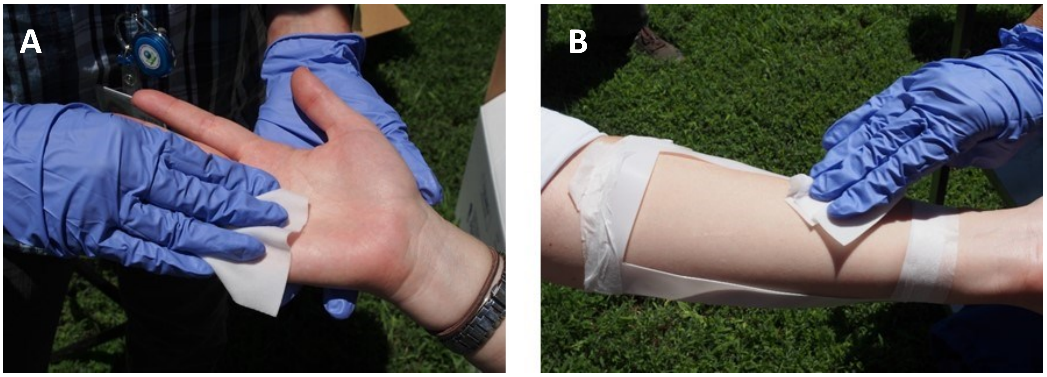


Figure 3-12. Dermal sampling on A) hand and B) arm. Leg sampling not shown. (Note: This figure is a demonstration showing dermal wipe sampling on a person that was not a research study participant. In this study, dermal sampling for metals was performed on the left hand, arm, and leg and dermal sampling for SVOCs was performed on the right hand, arm, and leg; right hand and arm shown in figure.).

Using a fresh pair of clean, powderless nitrile gloves, the field sampling technician removed a Ghost Wipe wet wipe from the foil packet, unfolded the wipe to its full dimensions, and folded it into quarters. With moderately-firm pressure, the field technician wiped the bottom side of the participant's left forearm over a 112-cm^2 area designated using a pre-cleaned rectangular Teflon™ template (Figure 4-12B). The wipe was folded again, with the exposed (contacted) surface now on the inside. The forearm skin was wiped a second time over the same 112-cm^2 area. The wipe was folded with the exposed (contacted) surface on the inside and placed into a pre-cleaned 50-mL polyethylene tube. The tube was tightly capped and transported at ambient temperature or lower to the laboratory.

Using a fresh pair of clean, powderless nitrile gloves, the field sampling technician removed a Ghost Wipe wet wipe from the foil packet, unfolded the wipe to its full dimensions, then folded it into quarters. With moderately-firm pressure, the field technician wiped the outer facing side of the participant's left calf or lower thigh (whichever had more exposed skin) over a 112-cm^2 area designated using a pre-cleaned rectangular Teflon™ template. The wipe was folded again, with the exposed (contacted) surface now on the inside. The leg skin was wiped a second time over the same 112-cm^2 area. The wipe was folded with the exposed (contacted) surface on the inside and placed into a pre-cleaned 50-mL polyethylene tube for storage. The tube was tightly capped and transported at ambient temperature or lower to the laboratory.

Dermal Wipe Samples for SVOC Analysis – Three dermal wipe samples were collected for SVOC analysis from each participant in the exposure characterization study, following an on-field sports activity. One wipe sample was collected from the participant's hand, the second wipe sample was collected from a defined area of the forearm, and the third sample was collected from the leg (either calf or thigh depending on which are had more exposed skin area during the sports activity); dermal samples for SVOC analysis were collected from the right side of the participant's body. All dermal wipe samples for SVOC analysis were collected using a wetted (1:1 water:isopropanol) 10.2-cm ×10.2-cm cotton Twill wipe (Texwipe, Kernersville, NC, USA). (Note: This is the same wipe material that was used for collecting field surface wipe samples for SVOC analysis.) Using clean, Silver Shield® gloves (Siebe North, Inc. North Charleston, SC, USA), the field sampling technician removed the pre-wetted (1:1 water:isopropanol) wipe from its glass storage jar and unfolded it to its full dimensions. With moderately-firm pressure, the field technician wiped the participant's right hand with the wipe, including the back, front, and sides of the hand, fingers, and thumb (Figure 3-12A). The wipe was folded with the exposed (contacted) surface on the inside and placed back into the glass storage jar. The jar was tightly capped and transported on frozen ice packs to the laboratory, where the samples were placed in a freezer at -20 °C.

Using clean, Silver Shield® gloves, the field sampling technician removed the wetted (1:1 water:isopropanol) wipe from its glass storage jar, unfolded it to its full dimensions, then folded it into quarters. With moderately-firm pressure, the field technician wiped the bottom side of the participant's right forearm over a 112-cm^2 area designated using a pre-cleaned rectangular Teflon™ template (Figure 3-12B). The wipe was folded again, with the exposed (contacted) surface now on the inside. The same 112-cm^2 area of the bottom side of the right forearm was wiped a second time. The wipe was then folded with the exposed (contacted) surface on the inside and placed back into the glass storage jar. The jar was tightly capped and transported on frozen ice packs to the laboratory, where the samples were placed in a freezer at -20 °C.

Using clean, Silver Shield® gloves, the field sampling technician removed the wetted (1:1 water: isopropanol) wipe from its glass storage jar, unfolded it to its full dimensions, then folded it into quarters. With moderately-firm pressure, the field technician wiped the outer facing side of the right calf or lower thigh (whichever had more exposed skin) over a 112-cm^2 area designated using a pre-cleaned rectangular Teflon™ template. The wipe was folded again, with the exposed (contacted) surface now on the inside. The outer facing side of the right calf or lower thigh was wiped a second time over the same 112-cm^2 area. The wipe was then folded with the exposed (contacted) surface on the inside and placed back into the glass storage jar. The jar was tightly capped and transported on frozen ice packs to the laboratory, where the samples were placed in a freezer at -20 °C.

3.3.3 Biological Samples – Pilot-Scale Biomonitoring Study

Two types of biological samples were collected in the pilot-scale biomonitoring portion of the exposure characterization study – urine samples and blood samples. Study participants could decline collection of biological samples, if they wished.

3.3.3.1 Urine Samples

Each participant who consented to provide urine samples was provided a sealed, sterile urine collection cup prior to field activity. The participant was informed to (1) not open the container until specimen collection and (2) to not touch the inside of the collection cup. Immediately upon collection, each container was placed in a biohazard bag and placed on dry ice. A second urine sample was collected from the same study participants post-activity, using the same sampling procedure. All specimens were shipped the next morning on dry ice to the National Center for Environmental Health (NCEH) Division of Laboratory Sciences.

3.3.3.2 Blood Samples

Blood Collection Procedure - Blood draws were performed on each consented participant both pre-activity and post-activity. Prior to field activity, each participant was administered a safety questionnaire to confirm it was acceptable to administer the blood draw. A tourniquet was applied to the upper arm and a vein was selected for venipuncture. The area selected for venipuncture was cleaned with an alcohol pad and allowed to air dry. For children and youth, a 23-gauge (23G) butterfly needle was used for blood collection; for adolescents and adults, a 21G butterfly needle was used. After the vein was punctured, blood was collected in a 7-mL blue top tube, followed by a 4-mL ethylenediaminetetraacetic acid (EDTA) purple-top tube for children and youth or a 6-mL EDTA purple-top tube for adolescents and adults. The EDTA purple-top tube was inverted a minimum of eight times prior to placement in a cooler with four freezer packs. After all tubes were filled for a participant, and the last tube had been removed from the needle holder, the needle was removed and pressure was applied with a gauze pad to the venipuncture site. The EDTA purple-top tubes were placed in a cushioned box, which was put into a biohazard bag and set in a cooler with a minimum of four freezer packs. The samples were shipped the next morning to the NCEH Division of Laboratory Sciences.

Serum Processing Procedure - Blue-top tubes filled during blood collection were placed upright and allowed to clot at room temperature for a minimum of 30 minutes and a maximum of 1 hour. After allowing time for the blood to clot, each tube was placed in a Hettich® EBA-20 centrifuge (Hettich Instrument, LP, Beverly, MA, USA) set at 2400 RPM for 15 minutes. After centrifugation, a minimum of 1 mL of serum was transferred from the blue-top tube to a 2-mL Nalgene™ cryovial. The cryovials were immediately placed into a cooler with dry ice. All serum samples were shipped the next morning on dry ice to the NCEH Division of Laboratory Sciences.

3.3.4 Field Meta-Data Collection

Metadata collection was designed to record field and activity information that might be informative for exposure study measurement interpretation, such as:

- ambient and field temperatures, which may be related to emissions of some chemicals from tire crumb rubber;
- overall levels of activity on the field, which may influence the amount of particulate suspended over the field;
- participant activity levels and durations, which may be related to contact with field materials and environmental media; and
- activities or the built environment around the field, which may contribute to non-field related chemicals being collected on air samplers.

Several data collection forms (Appendix E) were designed and filled out for each field and each participant activity to record metadata that might aid in improved understanding of exposure study results. Air temperature, field surface temperature, and wind speed and direction were measured at the beginning, middle, and end of the exposure measurement period at each field and recorded. Air temperatures and wind speeds were measured at a height of 1 meter above the field. Activity and facility information was collected using structured forms to record important information about overall activities at the field, participant-specific activities, and field and field operation conditions during the measurement period.

3.4 Sample Analysis Methods

3.4.1 Gravimetric Particle Size Analysis

Gravimetric particle analysis was performed on the field air samples collected for TSP and metals analysis, following at least 24-hrs equilibration in an environmental weighing chamber operating under EPA's Federal Reference Method (FRM) guidelines (U.S. EPA, 2017) on the EPA-Research Triangle Park (RTP) campus. The 37-mm Pallflex Teflo membrane disk filters were weighed to get the loaded (field-based) mass. This mass was compared to the original (tare) weights of the filters. After correcting for field blank mass change, the resulting mass difference was then used to estimate the mass density ($\mu g/m^3$) of the suspended aerosol. The gravimetric procedure required repeated weighing of each filter sample until the obtained mass was within the required 5 µg reweigh threshold. All reported values reflect gravimetric analyses meeting both the original and final (loaded) weighing requirements.

3.4.2 Extraction and ICP/MS Metals Analysis

3.4.2.1 Field Air Sample and Field Dust Sample Preparation

Metals from particulate matter collected on Teflo membrane disk filters and field dust samples were extracted for high resolution inductively coupled plasma mass spectrometer (HR-ICPMS) analysis. Air filters were carefully placed in acid-cleaned 50-mL polypropylene conical tubes, the surface was covered with 200 µL of ethanol to aid solubility, and then approximately 25 mL of a mixture of 2% nitric acid and 0.5% hydrochloric acid (by volume) was added to ensure the filter was completely submerged. For the dust samples, approximately 20–60 mg of field dust and approximately 25 mL of the 2% nitric acid and 0.5% hydrochloric acid mixture was placed in an acid-cleaned 50-mL polypropylene conical tube. Mass was recorded at each step. Next, the tubes were placed in a 70 °C water bath, sonicated for 30 minutes, and left to sit for 3 hours. After the 3-hr leach step, tubes were removed and left to sit at lab temperature for 10 days. Dust samples were then filtered into acid-cleaned 15-mL polypropylene tubes using 0.2-µm ion chromatography (IC) Millex®-LG 25-mm syringe filters (MilliporeSigma, Burlington, MA, USA).

In order to estimate the metal leaching efficiency of the field dust samples, National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA) Standard Reference Material (SRM®) 1648a, Urban Particulate Matter, was used as a spiked sample surrogate. It is important to note that the collected field dust and the SRM® have many differences, including but not limited to, morphology, particle size, and chemical structure. However, the SRM® is a good indicator of the leaching method precision.

3.4.2.2 Wipe Sample Preparation – Microwave-assisted Extraction

A microwave-assisted extraction procedure was used to prepare wipe samples for elemental analysis. The entire wipe sample was placed into a 100-mL XP-1500 Plus microwave digestion vessel with TFM® liner (CEM Corporation, Matthews, NC, USA), and 9 mL of nitric acid and 3 mL of hydrochloric acid were added to the vessel. The vessel contents were gently swirled and then allowed to rest in a fume hood until the wipe was completely dissolved. The closed microwave digestion vessel was then transferred into a MARS-5^{TM} microwave system fitted with a ESP-1500 Plus pressure sensor and RTP-300 Plus fiber optic temperature sensor (temperature range -40–250 ºC; CEM Corporation, Matthews, NC, USA), where the digestion/extraction was performed at 200 °C.

3.4.2.3 ICP/MS Analysis

Quantitative elemental concentration measurements were carried out using an Element 2™ HR-ICPMS (Thermo Finnigan, Bremen, Germany). The sample introduction system consisted of in-line standardization prior to the PFA micro nebulizer, cyclonic quartz spray chamber, and platinum sampler and skimmer cones. All sample handling and analysis were performed in an Internal Organization for Standardization (ISO) Class 5 Clean Room (ISO 2015). The multi-element instrument method utilized all three resolution modes. Instrument settings and method parameters are the same as those previously shown in Table 3-7 in the Tire Crumb Characterization Report (U.S. EPA & CDC/ATSDR, 2019).

External calibrations were performed with multi-element calibration standards (High-Purity Standards, Charleston, SC, USA). Initial calibration accuracy was performed using a secondary source multi-element standard (SCP Science, Champlain, NY, USA), NIST SRM® 1643f (NIST, Gaithersburg, MD, USA), analysis of the calibration blank, and analysis of the diluent, if necessary. Continuing calibration verification (CCV), continuing blank checks, and re-sampled duplicates were analyzed to verify accuracy and precision during the analytical sequences. Minimum reportable limits (MRL) were determined for each sample matrix based on a statistical representation of the continuing blank checks (10*standard deviation). The reportable limit for selenium was set at the lowest calibration standard, based on observed mass spectral peak shapes at the target isotope ranges.

Sample matrices that were assumed to be high in total dissolved solids (e.g., GhostWipes and field dust) were gravimetrically-diluted by two factors (1:10 and 1:100) prior to analysis. The particulate matter from the field air samples (i.e., the Teflo membrane disk filters) was not diluted. Final acid content in the diluted samples was approximately 2% nitric acid and 0.5% hydrochloric acid (v/v). When a sample was analyzed at each of the dilution factors, the 100-fold (1:100) diluted sample was used for reporting the medium-resolution elements, which were higher in concentration.

3.4.3 TD/GC/TOFMS Analysis of Field Air and Personal Air Samples for VOCs

Carbopack™ X FLM and Radiello™ sorbent tube samples were received from the field and refrigerated at 6 ºC. The samples were removed from the refrigerator and allowed to come to room temperature prior to analysis. Samples were analyzed using a Unity 2™ Ultra 50:50™ thermal desorption (TD) system (Markes International, Inc., Gold River, CA, USA) interfaced to an Agilent 7890B gas chromatograph equipped with an Rxi-ms column (60 m × 0.32mm, 1 µm; Agilent Technologies, Santa Clara, CA, USA) and Markes International BenchTOF™ Select MSD System (Markes International, Inc., Gold River, CA, USA). The instrument was tuned using the AutoOpt function and was calibrated using an internal standard method with concentrations of target compounds in the nominal range of 0–50 ppbv per compound. Internal standards were manually loaded on all tubes analyzed, including calibration tube, QC samples, and field samples. The actual mass loading (in ng/tube) depends on the molecular weight of the individual compound and the loaded volume of gaseous calibration standard. For example, mass loadings in the nominal range of 0 to 160 ng/tube benzene and 0 to 260 ng/tube benzothiazole for the calibration curve. Calibration checks were run using a low-level standard between every 11 samples. The VOC target compounds determined using the TD/GC/TOFMS system are listed in Table 3-2 (with exception of formaldehyde, which was not analyzed in the exposure pilot study), and the TD/GC/TOFMS instrument operating parameters are shown in Table 3-2.

MSD ChemStation Enhanced Data Analysis Software (Version E.02.02.1431, Agilent Technologies, Santa Clara, CA, USA) was used for peak identification/integration and combination of individual files into a database. This database was exported to Microsoft® Excel (Office 365, Microsoft Corporation, Redmond, WA, USA) for final data reduction. Quantitation was performed using quadratic curves generated from the relative response ratios and concentration ratios of internal standards and calibration standards. Inherent artifacts of target compounds found on Carbopack™ X sorbent (e.g., benzene) were addressed through the use of blank corrected calibration curves. Results were reported as ng/tube. In order to determine ng/L or µg/m^3, the total pumped volume for Carbopack™ X FLM actively-collected samples was used. For Carbopack™ X Radiello™ diffusively-collected samples, an effective sampling or uptake rate was used.

Table 3-2. TD/GC/TOFMS Parameters for VOC Field Exposure Sample Analysis[a]

System Component	Parameter	Value
Thermal Desorption System	Trap	TO-15/TO-17 air toxics focusing trap
Thermal Desorption System	Split Flows	Inlet split – none; Outlet split – 25:1
Gas Chromatograph	Column Flow	1.5 mL/min
Gas Chromatograph	Temperature Program	Initial: Set point 30 ºC, hold for 2 min Ramp 1: Rate 3 ºC/min to set point 69 ºC, hold 0 min Ramp 2: Rate 4 ºC/min to set point 141 ºC, hold 0 min Ramp 3: Rate 40 ºC/min to set point 240 ºC, hold 3.52 min
Mass Selective Detector	Mass Range	Mass range: 35-350 mass to charge ratio (m/z)
Mass Selective Detector	Data Rate	3 Hertz (Hz)
Mass Selective Detector	Transfer Line Temperature	250 ºC;
Mass Selective Detector	Ion Source Temperature	280 ºC
Mass Selective Detector	Voltage	Ionization Voltage = 70 electronvolt (eV); Filament voltage = 1.6 volt (V)
Mass Selective Detector	Filament Drops	None

[a] Thermal desorption/liquid chromatography/time-of-flight mass spectrometry (TD/LC/TOFMS) was conducted using a Unity 2™ Ultra 50:50™ Thermal Desorption (TD) system interfaced to an Agilent 7890B gas chromatograph equipped with an Rxi-ms column (60 m × 0.32mm, 1 µm) and Markes International BenchTOF™ Select Mass Selective Detector System.
VOC = Volatile organic compound

3.4.4 Solvent Extraction and SVOC Analysis

3.4.4.1 Air Sample SVOC Extraction

The glass-lined sample cartridges containing the PUF plugs were stored in a freezer at approximately -20 ºC until removed for extraction. For each sample, a 250-mL narrow-mouth glass collection bottle was labelled and fitted with a glass funnel. After the samples had warmed to room temperature, they were removed from the bag and foil and the PUF plug was transferred to an appropriately-labelled, clean 60-mL glass jar using stainless steel forceps. The glass-lined sampling cartridge that contained the PUF plug was rinsed into the corresponding collection bottle with 5 mL of 1:1 acetone:hexane. Internal standard solution (100 µL) was then added to each sample. Each jar was filled with 50 mL of 1:1 acetone:hexane and sealed with a PTFE-lined cap. The jars were placed in an ultrasonic cleaner with water level well below the level of the jar cap. The ultrasonic cleaner was then turned on for 15 minutes. Sample jars were removed from the cleaner and the extracts were transferred through funnels into the corresponding collection bottles. The funnels were rinsed with 1:1 acetone:hexane from a wash bottle after the extracts were added. The solvent addition, extraction and transfer was repeated two more times. The extracts in the bottles were then evaporated to 2–5 mL, using a parallel evaporator. The concentrated extracts were then transferred to a 15-mL graduated glass tube, along with two 2-mL 1:1 acetone:hexane rinses of the collection bottle, prior to concentration to a final volume of 1 mL under nitrogen. The extracts were then transferred to autosampler vials for analysis.

3.4.4.2 Field Surface Wipe Sample SVOC Extraction

The sample jars containing the field surface wipe samples collected for SVOC analysis were stored in a freezer at approximately -20 ºC until removed for extraction. An effort was made to remove all synthetic grass from the wipes before extraction. For each sample, a 250-mL narrow-mouth glass collection bottle was labelled and fitted with a glass funnel. After the samples had warmed to room temperature, internal standard solution (100 µL) was added to each sample. After addition of internal standard, each jar was filled with 50 mL of 1:1 acetone:hexane and sealed with a PTFE-lined cap. The jars were placed in an ultrasonic cleaner with water level well below the level of the jar cap. The ultrasonic cleaner was then turned on for 15 min. Sample jars were removed from the cleaner and the extracts were transferred through funnels into the corresponding collection bottles. The funnels were rinsed with 1:1 acetone:hexane from a wash bottle, after the extracts were added. The solvent addition, extraction and transfer was repeated two more times. The extracts in the bottles were then evaporated to 2–5 mL using a parallel evaporator. The concentrated extracts were transferred to a 15-mL graduated glass tube, along with two 2-mL 1:1 acetone:hexane rinses of the collection bottle, prior to concentration to a final volume of 1 mL under nitrogen. The extracts were then transferred into autosampler vials, through 0.2-µm PTFE syringe filters, in preparation for GC/MS/MS analysis.

3.4.4.3 Drag Sled Sample SVOC Extraction

The sample jars containing the drag sled samples collected for SVOC analysis were stored in a freezer at approximately -20 ºC until removed for extraction. An effort was made to remove all synthetic grass from the wipes before extraction, and the two side sections were left on the wipes. For each sample, a 1-L boiling flask was labelled and fitted with a glass funnel. After the samples had warmed to room temperature, internal standard solution (100 µL) was added to each sample. Then each jar was filled with 300 mL of 1:1 acetone:hexane and sealed with a PTFE-lined cap. The jars were placed in an ultrasonic cleaner with water level well below the level of the jar cap. The ultrasonic cleaner was then turned on for 15 min. Sample jars were removed from the cleaner and the extracts were transferred through funnels into the corresponding boiling flasks. The funnels were rinsed with 1:1 acetone:hexane from a wash bottle, after the extracts were added. The solvent addition, extraction and transfer was repeated two more times. The extracts in the boiling flasks were then evaporated to 2–5 mL using rotary evaporators. The concentrated extracts were transferred to a 15-mL graduated glass tube, along with two 2-mL 1:1 acetone:hexane rinses of the boiling flasks, prior to concentration to a final volume of 1 mL under nitrogen. The extracts were then transferred into autosampler vials, through 0.2-µm PTFE syringe filters, in preparation for GC/MS/MS analysis.

3.4.4.4 Dermal Wipe Sample SVOC Extraction

The sample jars containing the dermal wipe samples collected for SVOC analysis were stored in a freezer at approximately -20 ºC until removed for extraction. For each sample, a 250-mL narrow-mouth glass collection bottle was labelled, fitted with a glass funnel with glass wool, and filled with approximately 10 g of anhydrous sodium sulfate (Na_2SO_4). After the samples had warmed to room temperature, internal standard solution (100 µL) was added to each sample. Then each jar was filled with 50 mL of 1:1 acetone:hexane and sealed with a PTFE-lined cap. The jars were placed in an ultrasonic cleaner with the water level well below the level of the jar cap. The ultrasonic cleaner was then turned on for 15 min. Sample jars were removed from the cleaner and the extracts were transferred through funnels into the corresponding collection bottles through the funnels containing Na_2SO_4 for removal of residual water used along with isopropanol for sampling. The funnels were rinsed with 1:1 acetone:hexane from a wash bottle, after the extracts were added. The solvent addition, extraction and transfer was repeated two more times. The extracts in the bottles were then evaporated to 2-5 mL using a parallel evaporator. The concentrated extracts were transferred to a 15-mL graduated glass tube, along with two 2-mL 1:1 acetone:hexane rinses of the collection bottle, prior to concentration to a final volume of 1 mL under nitrogen. The extracts were then transferred into autosampler vials, through 0.2-µm PTFE syringe filters, in preparation for GC/MS/MS analysis.

3.4.4.5 Field Dust Sample SVOC Extraction

The vials containing the field dust samples for SVOC analysis were stored in a freezer at approximately -20 ºC until removed for extraction. The samples were allowed to warm to room temperature before weighing 100 mg of dust into a 50-mL polypropylene centrifuge tube. Internal standard solution (100 µL) was added to each tube, along with a ceramic homogenizer. A 10-mL volume of 1:1 acetone:hexane was then added to each sample tube. The tubes were capped and vortex-mixed for 1 min, allowed to sit for 2 min, then vortex-mixed for one additional minute. The tubes were then centrifuged at 4,000 RPM for 5 min. The solvent layer was removed and transferred to a 15-mL vial. A 1-mL aliquot of the extract was transferred to an autosampler vial for GC/MS/MS analysis. The extracts were then transferred into autosampler vials, through 0.2-µm PTFE syringe filters, in preparation for GC/MS/MS analysis.

3.4.4.6 GC/MS/MS Analysis for SVOCs

Field air and surface sample extracts were analyzed using an Agilent Model 7890 gas chromatograph equipped with a VF-5ms column (30 m × 0.25 mm, 0.25 µm) and a Model 7010 triple quadrupole mass spectrometer (Agilent Technologies, Santa Clara, CA, USA). The GC/MS/MS parameters previously shown in Table 3-8 in the Tire Crumb Characterization Report (U.S. EPA & CDC/ATSDR, 2019) were used for data acquisition. The instrument was standardized using High Sensitivity Electron Impact (EI) Autotune and was calibrated for target analytes in the range of 0.1 ng/mL to 500 ng/mL. Calibration checks were run using a mid-level standard between every 10 samples. Quantitation was performed using linear regression curves generated from the responses and nominal concentrations of calibration standard solutions. Data were processed using Agilent MassHunter Workstation Quantitative Analysis for QQQ (Version B.07.01, Agilent Technologies, Santa Clara, CA, USA) and were exported to Microsoft® Excel (Office 365, Microsoft Corporation, Redmond, WA, USA) for further data reduction.

3.4.5 Urine, Blood, and Serum Sample Analysis – Pilot-Scale Biomonitoring Study

For blood and serum samples collected as part of the pilot-scale biomonitoring study, venipunctures were performed on-site at a designated area, and blood samples collected by a trained phlebotomist from participants. Sample collection protocols indicate a blood draw of 6 mL for serum metals and 5 mL for blood metals (total of 11 mL); the maximum blood draw per participants did not exceed 25 mL. Serum samples were collected via centrifugation. Per NCEH Division of Laboratory Sciences' sample collection protocols, blood samples were shipped on freezer packs, and serum samples were shipped on dry ice. Blood and serum samples were analyzed for metals via inductively coupled plasma dynamic reaction cell mass spectrometry (ICP-DRC-MS) (Appendix F).

For urine specimens, participants were provided with a sealed sterile urine collection cup to collect the urine samples on-site in facility restrooms. Samples were shipped on dry ice to the NCEH Division of Laboratory Sciences. Urine samples were analyzed for polyaromatic hydrocarbon (PAH) metabolites and creatinine; PAH metabolites were quantified using online solid phase extraction high performance liquid chromatography/tandem mass spectrometry (SPE-HPLC-MS/MS) (Wang et al., 2017). All urinary PAH metabolites were adjusted for creatinine to account for urinary dilution.

3.5 Video Activity Assessments for Synthetic Field Users

In early 2017, a novel videography collection method using online sources was developed to quantify the frequency of select micro-activities (i.e., hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contact) of 60 athletes playing soccer, field hockey, or football on (natural or synthetic turf) fields, as seen on publicly-available videos downloaded from the internet. The adapted video translation part of this method was then slightly modified and used to quantify the frequencies of these four micro-activities for 17 exposure characterization study participant video recordings collected while practicing soccer or football on synthetic turf fields in late 2017 (Freeman et al., 2001; Ferguson et al., 2006; Kwong et al, 2016). In addition, an adapted videography method was developed to quantify the intensity and duration of the activity levels (resting, low activity, or high activity) of the 17 study participants on these same videos.

3.5.1 Online Video Assessment (Phase 1)

This videography (Phase 1) work using online sources was classified as non-human subjects research as defined in the Federal Policy for Protection of Human Research Subjects (the Common Rule) [HHS 45 CFR § 46, Subpart A and EPA 45 CFR § 26, Subpart A]. The research also falls under the fair use of copyrighted materials, as stated in section 107 of the U.S. Copyright Act [Copyright Act of 1976 § 101, 17 U.S.C. § 107 (2012)]. All research activities were conducted in a secure room at the EPA campus in Research Triangle Park, NC.

3.5.1.1 Videos of Selected Athletes from the Internet

Accessing the video-sharing website in the fall of 2016, YouTube (www.youtube.com), three EPA technicians randomly found videos of children and adults playing soccer, field hockey, and football on natural or synthetic turf fields (indoor/outdoor).To be used in the assessment, videos were required to be of high enough quality and resolution to allow a researcher to be able to clearly observe the hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events of selected athletes for a minimum of 15 minutes for soccer/field hockey or 10 minutes for football. Due to the nature of each type of sport, athletes spent varying amounts of time on the turf fields. For example, football teams tended to have more players; therefore, individual players typically had less time of play. These 10-minute and 15-minute time periods were chosen based on the total amount of time that individual athletes were observed playing these three different sports on the videos. Videos were downloaded as MP4 files via a laptop computer onto an encrypted, 256 MB SanDisk Ultra® thumb drive (Western Digital Technologies, Inc., Milpitas, CA, USA). A total of 34 videos (soccer = 12, field hockey = 12, and football = 10) were collected. As these were team sports, up to three different athletes were chosen for assessment per video. Table 3-3 presents the number of children and adults selected by sport from the 34 videos. A technician took a screen shot of each of the 60 selected athletes on video and recorded specific personal characteristics (i.e., child or adult, sex, type/color of clothing, jersey number, and field position [e.g., quarterback, goalie]).

Table 3-3. Number of Subjects Selected for Assessment by Sport from Publicly-available Videos[a]

Sport	Children	Adults	Total
Soccer	10	10	20
Field Hockey	10	10	20
Football	10	10	20
Total	30	30	60

[a] A total of 34 YouTube videos were assessed (12 soccer videos, 12 field hockey videos, and 10 football videos)

3.5.1.2 Training Technicians for Video Translation

After previewing the 34 YouTube videos, the study investigator noticed that athletes playing football generally had much higher occurring frequencies of the targeted micro-activity events than soccer or field hockey athletes. Therefore, it was decided that video translation would be conducted by designated sport (soccer/field hockey or football). The study investigator held two different training sessions (session A for soccer/field hockey and session B for football) to train the three EPA technicians to translate the hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contact of athletes playing soccer, field hockey or football. A fourth technician was trained later to assist in football video translations.

Training Session A - The study investigator made two training videos that included 15 minutes of play of two different athletes participating in soccer or field hockey from the actual study videos. The two training videos were developed at two levels of difficulty (easy and difficult), based on the number of targeted micro-activity events of the selected athletes observed on video; the easy level had a total of 8 micro-activity events, and the difficult level had a total of 38 micro-activity events. The study investigator and three technicians previewed each training video as a group to agree on the type and number of targeted micro-activity events that occurred by each selected athlete. Each training video was translated twice by each technician. To pass the training videos, individual technicians were required to have a total percent error rate of less than 5% for the easy level and 10% for the difficult level. After translating the training videos, the EPA technicians had a total percent error rate of 0% for the easy level and less than 9% for the difficult level.

Training Session B - The study investigator made one 10-minute training video, from the actual study videos, of an athlete playing football. This training video had a total of 69 different micro-activity events occurring over the 10 minutes of play and was deemed "difficult" based on the high number of observed targeted micro-activity events made by the football player. The study investigator and four technicians reviewed this training video together several times to agree on the type and number of targeted micro-activities made by this athlete.

3.5.1.3 Translation of Targeted Micro-activities of Athletes in Publicly-available Videos

The selected micro-activities of individual athletes were translated from the 34 YouTube videos by trained EPA technicians. The technicians completed training session A over a two-day period and then translated the targeted micro-activities of the 20 soccer players and 20 field hockey players in the videos for 15 minutes per selected player (Table 3-3). Approximately six weeks later, these same technicians completed training session B over one day and then translated the targeted micro-activities of the 20 selected football players in the videos for 10 minutes per player. Hand-to-mouth events were contacts made by either an ungloved or gloved hand to the lips or inside the mouth. Object-to-mouth events were contacts made by an object (i.e., shirt, mouthguard, or water bottle) to the lips or inside the mouth. Hand-to-turf events were contacts made by either an ungloved or gloved hand to the field. Body-to-turf events were contacts made by any part of the body (excluding hands and feet) to the field.

The EPA technicians viewed the MP4 files of the study videos using Windows Media Player (Version 12.0, Microsoft® Corporation, Redmond, WA, USA) on a 28-inch computer monitor (ViewSonic® Corporation, Walnut, CA, USA). The procedures used to translate the targeted micro-activities of the athletes were specific to the designated sport (soccer/field hockey videos or football videos).

Soccer and Field Hockey Videos - An EPA technician previewed each selected soccer or field hockey player on video for a total of 15 minutes. During the second viewing of the video, the technician manually tallied the athlete's observed frequency of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contacts on a paper template (Figure 3-13). The athlete's use of specific sporting items, such as mouthguards and gloves, was also recorded on this paper template. In addition, the technician re-wound sections of the video, as needed, to more accurately quantify the athlete's micro-activity contacts. In cases where an athlete was observed having less than 9 total micro-activity events over the

15 minutes, the video was translated again by the same technician.

Hand-to-mouth	Object-to-mouth	Hand-to-turf	Body-to-turf

Figure 3-13. Paper template for tallying the selected micro-activity events of an athlete.

Football Videos - A group of three or four EPA technicians concurrently viewed each selected football player on video for a total of 10 minutes. One of the technicians manually tallied, on notebook paper, each hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contact by the athlete. Sections of each video were re-wound, as needed, to more accurately quantify the athlete's micro-activity events. All technicians had to agree that a targeted micro-activity event occurred by the athlete before the event was recorded. Then, a second technician transcribed the athlete's individual micro-activity events from the notebook paper to a paper template (Figure 3-13). The athlete's use of specific sporting items, such as mouthguards and gloves, was also recorded on this paper template.

3.5.1.4 Quality Control Measures

In addition to training the technicians responsible for translating the videos, several additional quality control measures were taken during video translation.

Soccer and Field Hockey Videos - In cases where a selected soccer or field hockey athlete was observed having less than 9 total micro-activity events over the 15-minute translation period, the video was translated again by the same technician. This is because the potential error rate for a technician is much higher when an athlete has a lower number of micro-activity events compared to a higher number of events. For example, if a technician records 2 out of 3 actual micro-activity events, the error rate would be 33%, but if a technician only records 10 out of 11 micro-activity events, the error rate would be 9%.

Football Videos - To ensure high quality data was obtained from the football videos, the micro-activities of each selected football player were concurrently translated by a minimum of three EPA technicians. This was done because of the significantly higher frequency of targeted micro-activity events in football.

3.5.1.5 Statistical Analysis

For individual videos that were translated twice (i.e., videos with < 9 micro-activity events by an athlete), the data were averaged by each type of micro-activity event per person. The frequency of micro-activity contacts by category (events/hour) were normalized to one hour for each athlete. This approach assumed that the targeted micro-activity rates of an athlete occurred for the entire one-hour period. Descriptive statistics (e.g., arithmetic mean and standard deviation, percentiles [25th, 50th, 75th, and 95th], and range) were presented as frequency of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events/hour for children and adult athletes by sport. Welch's *t*-tests and one-way ANOVAs were used to analyze differences between frequencies of micro-activity events by field type, gender, age, equipment and sport type. All statistical analyses were performed using RStudio (RStudio, Inc., Boston, MA, USA) with R (Version 3.1.2, R Core Team 2014).

3.5.2 Exposure Pilot Study Participant Video Assessment (Phase 2)

EPA contractor technicians videotaped a select number of exposure study participants, for up to two hours each, while practicing soccer or football on synthetic turf fields at facilities in the fall of 2017. A total of 17 athletes (14 children and 3 adults) were videotaped during the study.

3.5.2.1 Videography of Study Participants

An HXR-NX100 Full HD NXCAM camcorder (Sony Corporation, Minato, Tokyo, Japan) attached to a Manfrotto™ XPRO monopod (Lino Manfrotto + Co. Spa, Cassola, Italy) was used to record a selected participant athlete's activities while playing on the synthetic turf field simultaneously on two different Sony 32GB High Speed UHS-I SDHC U3 Memory Cards (Sony Corporation, Minato, Tokyo, Japan). Only one participant athlete was videotaped by the technician at a time. To be used in assessment, videos were required to be of high quality and resolution to allow a researcher to be able to clearly observe the hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contacts, as well as the intensity and duration of activity levels (i.e., resting, low activity, and high activity), of the athletes playing on the synthetic turf fields for a minimum of 30 minutes. Table 3-4 presents the number of children and adult study participants recorded by sport. Ancillary information about each athlete (i.e., sex, child or adult, sport, and type of field [indoor or outdoor]) was also recorded.

Table 3-4. Number of Exposure Study Participant Athletes Videotaped by Sport

Sport	Children	Adults	Total
Soccer	9	3	12
Football	5	0	5
Total	14	3	17

3.5.2.2 Training Technicians for Video Translation

In October 2017, the EPA study investigator held two different training sessions (session A for micro-activity events and session B for activity level intensity and duration) to train two EPA contractor technicians to quantitatively translate the frequencies of the targeted micro-activity events and the intensity and duration (in seconds) of the selected activity levels of individual athletes on video.

Training Session A - The study investigator used a study video of a child football player to train to the two technicians to accurately translate the athlete's micro-activity contacts on a paper template (Figure 3-13). This 1-hour video was chosen based on the total number of micro-activity events (> 50) for the athlete observed on video. As a group, the study investigator and the two technicians concurrently viewed the video to agree on the actual type and number of micro-activity contacts that occurred by this athlete. Then, the two technicians separately translated this 1-hour video twice. The acceptable intra-person and inter-person error rate was < 10% and < 15%, respectively. Results for the same technician translating the video twice yielded a total percent error rate of 0% for technician 1 and 2% for technician 2. The total percent error rate between the two technicians was less than 3%.

Training Session B - The study investigator used a study video of an adult soccer player to train the same two technicians to accurately translate the intensity and duration of the selected participant's activity levels. This 1-hour video was chosen based on the intensity and duration of activity levels of the participant observed on video. The study investigator and the two technicians reviewed the video together to agree on the actual intensity and duration of the activity levels of the athlete. Then, each technician translated this 1-hour video twice. The acceptable intra-person and inter-person error rate was < 5% and < 10%, respectively. Results for the same technician translating the video twice, yielded a total percent error rate of <1% for technician 1 and 1% for technician 2. The total percent error rate between the two technicians for this video was less than 2%.

3.5.2.3 Translation of Targeted Micro-activities of Study Participant Athletes

Fourteen of the study participants had their activities recorded for at least 1 hour on video, while practicing soccer or football on the synthetic turf fields. The remaining three participants (child soccer players) were videotaped practicing on the synthetic turf fields for less than 1 hour (i.e., 37–48 minutes).

The selected micro-activities of individual athletes were translated from the videos by trained EPA contractor technicians. The technicians completed training session A over one day and then translated the targeted micro-activity events of the 17 participants on video for up to one continuous hour. Approximately two weeks later, the same two technicians completed training session B over one day and then translated the intensity and duration of the targeted activity levels of the 17 participants on video for up to one continuous hour.

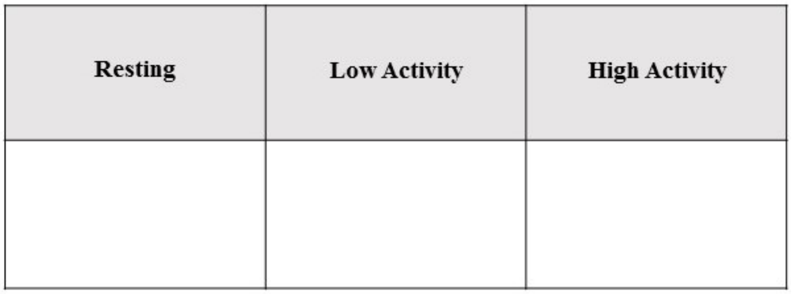
3.5.2.4 Quantification of the Frequency of Micro-activity Events for Study Participants

In October 2017, a trained EPA contractor technician translated the targeted micro-activity events of the individual study participants on video for one continuous hour, except for the three child soccer players who practiced less than one hour. For these three children, the technician translated the total time they were recorded on video (i.e., 37, 45, and 48 minutes). Each video was viewed on the SD card using Windows Media Player (Version 12.0, Microsoft® Corporation, Redmond, WA, USA) on a 27-inch VX2757-MHD computer monitor (ViewSonic® Corporation, Walnut, CA, USA). The technician first previewed the athlete for the entire length of the video. During the second viewing of the video, the technician manually tallied the participant's observed frequencies of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contact on a paper template (Figure 3-13). Sections of the video were re-wound, as necessary, to more accurately quantify the athlete's micro-activity events. The athlete's use of specific sporting items, such as mouthguards and gloves, was also recorded on this paper template.

3.5.2.5 Quantification of the Intensity and Duration of Activity Levels of Study Participants

The CDC (1999) method was modified to classify the selected intensity levels (resting, low activity, or high activity) of the 17 study participant athletes observed on the videos. For this study, resting was when a person was observed standing, sitting, or kneeling. Low activity was when a person was observed walking, stretching, or when stationary (e.g., catching, throwing, or kicking a ball). High activity was when a person was observed jogging, running, tackling, or had a similar level of intensity (e.g., jumping jacks, pushups, and grapevines).

From late October to early December 2017, a trained EPA contractor technician translated the intensity and duration of the selected activity levels of individual study participants on video for one continuous hour, except for the three child soccer players, which were translated for the total time they were recorded (i.e., 37, 45, and 48 minutes). Each video was viewed on the SD card using Windows Media Player (Version 12.0, Microsoft® Corporation, Redmond, WA, USA) on a 27-inch VX2757-MHD computer monitor (ViewSonic®, Corporation, Walnut, CA, USA). The technician first previewed the participant for the entire length of the video. During the second viewing of the video, the technician manually tallied the intensity and duration (in seconds) of the athlete's observed activity levels on a paper template (Figure 3-14). The technician re-wound sections of the video, as needed.



Resting	Low Activity	High Activity

Figure 3-14. Paper template for tallying the intensity and duration of selected activity levels of an athlete.

3.5.2.6 Quality Control Measures

In addition to training the technicians responsible for translating the videos, several additional quality control measures were taken during video translation.

To maintain high intra- and inter-person accuracy of coding the targeted micro-activity events on the videos over time, the two trained technicians translated two additional participants' videos -- after completing 50% and 95% of the total videos (*n* = 17). A 1-hour video of a youth football player was translated at 50% completion and a 37-minute video of a child soccer player was translated at 95% completion; both videos had greater than 40 observed micro-activity events. The translation conducted at 50% completion, yielded a total percent error rate of 7% for technician 1 and 9% for technician 2; however, the total percent error rate between the two technicians was slightly above the maximum allowable error rate (i.e., 15%). Therefore, each technician translated this video a third time, and the total percent error decreased to less than 10% between these two technicians. The translation conducted at 95% completion, yielded a total percent error rate of 0% for technician 1 and 4% for technician 2. The total percent error rate between the two technicians was also less than 5% for this video.

To maintain high intra- and inter-person accuracy of coding the intensity and duration of activity levels for athletes on the videos, the two technicians translated two additional participants' videos -- after completing 50% and 95% of the total videos (n = 17). These videos (1 hour each) consisted of two different child soccer players. The translation conducted at 50% completion, yielded a total percent error rate of < 2% for each technician translating the same video twice; the total percent error rate between the two technicians was less than 7%. The translation conducted at 95% completion, yielded a total percent error rate of 2% for technician 1 and 1% for technician 2 after translating the same video twice; the total percent error rate between the two technicians was less than 5%.

3.5.2.7 Statistical Analysis

For the three child athletes (videotaped < 1 hour), their frequency of micro-activity contacts by category (events/hour) and the intensity and duration of activity levels (seconds/hour) were normalized to 1 hour. This approach assumed that the selected activity contacts/durations levels of an athlete occurred for an entire 1-hour period. Descriptive statistics (e.g., arithmetic mean and standard deviation, percentiles [25th, 50th, 75th, and 95th], and range) were presented as frequency of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contacts (events/hour) for the children and adult athletes by sport. Descriptive statistics were also provided as duration of resting, low activity, or high activity levels (seconds/hour) for the children and adult athletes by sport. Welch's *t*-tests and one-way ANOVAs were used to analyze differences between the frequencies of micro-activity events and duration of activity levels by field type, gender, age group, equipment, and sport type. All statistical analyses were performed using RStudio (RStudio, Inc., Boston, MA, USA) with R (Version 3.1.2, R Core Team 2014).

3.6 Data Processing and Analysis

3.6.1 Data Processing

Chemical analysis data and field sampling data sets produced by the researchers were subjected to a secondary review by an independent expert. Following secondary review, the field sampling, VOC, SVOC, metals, and air particulate data sets were submitted to the project's data manager. The data manager uploaded data sets using SAS/STAT® 13.1 (SAS Institute Inc., Cary, NC, USA) and performed a series of organizational, review, cleaning, and output steps. Following initial intake and organization, the data manager provided data reports to the analyst and project manager to review for potential data issues or labeling problems and to determine whether any additional cleaning or organization was required. Following resolution, final draft data files were created for further data processing operations. The analysts and data manager then consulted with the project manager to interpret the quality control results (shown in Appendix B), make decisions on required adjustments, if any, and calculation requirements to bring measurement data into the correct final result.

Field blank corrections were performed for all exposure pilot study measurement data. The amount of chemical measured on a field blank deployed to a specific field was subtracted from the measurement results for all samples of that type collected from that specific field. Two field blanks were deployed for most media at the first field, the field blank results were averaged prior to subtraction from the sample results. The chemical recoveries in the spiked field controls were examined, but no recovery corrections were performed to any exposure pilot measurement data. In some cases, decisions were made not to report results for specific chemicals due to poor recoveries from spiked field control samples.

3.6.2 Data Analysis

Air sampling field data were combined with chemical and particulate analysis data to calculate sample volumes and concentrations of each analyte in air. Field wipe and drag sled data were combined with field sampling data to allow calculation of surface loadings based on amount of chemical measured per square centimeter of the field surface. Dust concentrations were calculated by dividing the amount of chemical measured by the amount of dust that was digested or extracted. Dermal wipe measurement data were combined with field sample collection data to first organize the results by age and sport, and then to calculate the amount of chemical measured per square centimeter of skin that was wiped. For hand wipe samples, the entire hand was wiped, so the surface area used was based on the age-specific value for hand surface area from the EPA Exposure Factors Handbook (U.S. EPA, 2011b).

Field metadata were processed separately by transferring information from field data collection forms to spreadsheet tables, where they were organized among and within groups and categories.

Chemical concentration measurement values and their mean or median statistics and ranges were presented in tables generated using SAS/STAT® 13.1 (SAS Institute Inc., Cary, NC, USA) with data reported at two significant figures. Due to small sample sizes, no within- or between-group statistical analyses were performed for exposure pilot study personal and field sample measurement results.

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4.0 Exposure Characterization Results

The exposure characterization study was a pilot-scale effort aimed at collecting information and data to characterize how users of synthetic turf fields with tire crumb rubber infill might be exposed to the chemical constituents present in tire crumb rubber. We enrolled youth and adults taking part in athletic activities on synthetic turf fields in several locations to participate in questionnaire, exposure measurement and videographic study elements. In addition, we used publicly available video to further assess exposure-related activities for people engaged in athletic activities at sports fields. The exposure characterization activity and measurement results are reported in this section, and the results of further exposure modeling for a subset of chemicals of interest – lead (Pb), methyl isobutyl ketone (MIBK), benzothiazole, pyrene, benzo(a)pyrene and zinc – are reported in section 5.

4.1 Exposure Pilot Study Recruitment

Due to scheduling and availability issues, the number of fields and participants available for recruitment during the field study implementation window was reduced. The target sample size of six fields and 60 participants was not reached during the study period. Overall, the research team recruited 32 participants at three field locations in the study. Final participant numbers for the different study components are presented in Table 4-1.

Table 4-1. Exposure Pilot Study Participant Recruitment and Participation Types

Study Participant Activity Types	Outdoor Field 1	Outdoor Field 2	Indoor Field	Total
Exposure characterization study – total	15	15	2	32
Exposure characterization – questionnaire only	4	3	0	7
Exposure measurement – personal air monitoring and dermal wipe sampling	11	12	2	25
Exposure measurement – blood biomonitoring	10	3	0	13
Exposure measurement – urine biomonitoring	10	4	0	14
Videography	8	8	1	17

4.2 Exposure Pilot Study Field User Questionnaires

4.2.1 Demographics

A total of 32 questionnaires were administered in the field for participants ranging in age from 7 to 51. For variables with large enough sample sizes, we categorized participants into three age groups for comparison. The youngest age group (i.e., children between 7 and 10 years of age) and the oldest age group (i.e., adults 18 years and older), each comprised 22% of the recruited questionnaire participants (Table 4-2). The largest age group (i.e., 56% of questionnaire participants) included participants that ranged in age from 11 to 17 years of age. Slightly more than half of the participants were male (i.e., 53%; Table 4-2). The questionnaire results presented in Tables 4-3 through 4-15 reflect the answers of all 32 participants; results are presented by age group in the text, where possible.

Table 4-2. Age and Gender of Questionnaire Participants

Study Participant	Number of (%) Questionnaire Participants Age 7 to 10	Number of (%) Questionnaire Participants Age 11 to 17	Number of (%) Questionnaire Participants Age 18 and older	Number of (%) Female Questionnaire Participants	Number of (%) Male Questionnaire Participants
Questionnaire participant	7 (22%)	18 (56%)	7 (22%)	15 (47%)	17 (53%)

4.2.2 Field Contact Frequency and Duration Questions

Most questionnaire participants reported playing at the facility between 3 and 4 years (31%), followed by 1 to 2 years (28%; Table 4-3). More than half (57%) of children younger than 11 years of age were more likely to report using the facility for 1 to 2 years, while 50% of participants ages 11 to 17 reported using the facility for 3 to 4 years. Approximately 43% of adult questionnaire participants reported using the facility for less than a year.

For all age groups combined, summer and fall had the highest reported frequency of use (i.e., two or more days per week; Table 4-4). Younger children tended to minimally use the field year-round, typically 1 day or less per week. Children ages 11 to 17 years had more diverse uses throughout the season, with the highest seasonal use reported in the summer (i.e., 4 to 5 days per week) and less frequent use in the winter (i.e., 0 to 1 day per week). Adults also reported less turf field use in the spring and winter and higher use in summer and fall (i.e., 4 to 5 days per week).

Table 4-3. How Long Questionnaire Participants Have Been Coming to the Facility for All Combined Age Groups

Years Coming to Facility	Number of (%) Questionnaire Participants
< 1	6 (19%)
1–2	9 (28%)
3–4	10 (31%)
5+	7 (22%)

Table 4-4. Number of Days per Week Questionnaire Participants Typically Spent on the Synthetic Turf Fields at this Facility, by Season

Days per Week	Number of (%) Questionnaire Participants - Spring	Number of (%) Questionnaire Participants - Summer	Number of (%) Questionnaire Participants - Fall	Number of (%) Questionnaire Participants - Winter
0 – 1	18 (56%)	11 (34%)	7 (22%)	24 (75%)
2+	14 (44%)	21 (66%)	25 (78%)	8 (25%)

For all questionnaire participants, a majority spent an hour and a half or less per day on synthetic turf fields in the spring, summer, and winter, though 44% of participants in the summer spent two or more hours (Table 4-5). Most participants (59%) reported using synthetic turf fields for two or more hours per day in the fall. Participants under 18 did not report more than 2 hours per day year-round, while some adults reported three or more hours on synthetic turf fields per day. The majority of all participants (56%) reported the longest period of time spent on synthetic turf fields in a single day was between 0 to 2 hours (Table 4-6). Adult participants commonly reported a maximum time of 3 to 5 hours per day (71%), while 0 to 2 hours per day was commonly reported for age groups 7 to 10 years of age (86%) and 11 to 17 years of age (67%).

Table 4-5. Number of Hours per Day Questionnaire Participants Typically Spent on the Synthetic Turf Fields at this Facility, by Season

Hours per Day[a]	Number of (%) Questionnaire Participants in Spring	Number of (%) Questionnaire Participants in Summer	Number of (%) Questionnaire Participants in Fall	Number of (%) Questionnaire Participants in Winter
0 – 1.5	27 (84%)	18 (56%)	13 (41%)	27 (84%)
2+	5 (16%)	14 (44%)	19 (59%)	5 (16%)

[a] Data is presented in these categories due to the distribution of the data and small cell sizes

Table 4-6. Longest Period of Time Questionnaire Participants Spent on Synthetic Turf Fields in a Single Day

Hours per Day	Number of (%) Questionnaire Participants
0 – 2	18 (56%)
3+	14 (44%)

Table 4-7 shows how often all questionnaire participants played on synthetic turf fields, grass fields, or playgrounds with rubber or synthetic turf in the past year and the past five years. A majority of participants have played on synthetic turf fields at least once a week in the past year (63%) and past five years (56%). Additionally, a majority have played on grass fields at least once a week in either the past year (59%) or past five years (56%). Though not shown due to small cell sizes, playing on playgrounds with rubber or turf in the past year or five years was less common. Few participants reported playing on these playgrounds 1 to 3 times a month in the past year (25%) and in the past 5 years (28%).

Concerning age groups, children less than 11 years generally reported playing at least once a week on synthetic turf fields in the past year or 5 years (57%). Additionally, these participants more often reported playing on natural grass fields at least once a week in the past year (86%) or 5 years (100%), frequently reported as 2 to 3 times a week. For the second age group (11 to less than 18 years), a majority reported playing on synthetic turf fields at least once a week in the past year (56%) as well as past 5 years (50%). However, this age group less frequently reported playing on grass fields once a week in the past year or 5 years (44%). Adults commonly reported playing on synthetic turf fields at least once a week in the past year (86%) and past 5 years (71%), most commonly 2 to 3 times a week (57%) in the past year and 4 or more times a week (57%) in past 5 years. Adults also reported using natural grass fields in the past year (57%) and past 5 years (43%).

Table 4-7. How Often Questionnaire Participants Played on Synthetic Turf Fields and Grass Fields in the Past Year and Past Five Years

Field Use	Number of (%) Questionnaire Participants Who Used Field 1 to 3 Times per Month	Number of (%) Questionnaire Participants Who Used Field At Least Once a Week
Any synthetic turf field in past year	11 (34%)	20 (63%)
Any synthetic turf field in past 5 years	11 (34%)	18 (56%)
Any natural grass in past year	7 (22%)	19 (59%)
Any natural grass in past 5 years	9 (28%)	18 (56%)

4.2.3 Contact Types and Scenarios per Field Use

For all questionnaire participants, diving, falling, sitting, and drinking on synthetic turf fields was more commonly reported in summer than spring; eating on turf fields was not commonly reported for any season (Table 4-8). Over 50% of children ages 7 to less than 11 reported falling and/or sitting on synthetic turf often/sometimes in the spring, summer, and fall. All age groups reported drinking on the field often/sometimes for all seasons except winter, mostly due to the lack of activities during wintertime. Participants 11 years and older most commonly reported diving onto turf often/sometimes in the summer and fall.

Table 4-8. Types and Frequency of Questionnaire Participant Contact with Synthetic Turf Fields in Spring and Summer [a]

Contact Type/ Scenario	Spring Contact Frequency- Number of (%) Questionnaire Participants Who Made Contact Rarely/Never or No Response	Spring Contact Frequency- Number of (%) Questionnaire Participants Who Made Contact Often/Sometimes	Summer Contact Frequency - Number of (%) Questionnaire Participants Who Made Contact Rarely/Never or No Response	Summer Contact Frequency - Number of (%) Questionnaire Participants Who Made Contact Often/Sometimes
Dive	21 (66%)	11 (34%)	13 (41%)	19 (59%)
Fall	17 (53%)	15 (47%)	9 (28%)	23 (72%)
Sit	17 (53%)	15 (47%)	12 (38%)	20 (63%)
Eat	27 (84%)	5 (16%)	25 (78%)	7 (22%)
Drink	16 (50%)	16 (50%)	9 (28%)	23 (72%)

[a] Possible questionnaire responses included Often (>50% of the time), Sometimes (<50% of the time), and Rarely/Never. Due to small cell sizes, Often and Sometimes responses are reported together.

4.2.4 Activity Intensity

For all questionnaire participants, 28% reported high/moderate activity less than 25% of the time when using synthetic turf fields (Table 4-9). Additionally, more participants (38%) reported high/moderate activity between 25% and less than half of the time, while 20% of participants reported higher intensity between 50% and less than 75% and only 14% reported 75% or greater. A large majority of participants (81%) categorized low activity or resting for less than 25% of time when using synthetic turf fields while 19% of participants categorized this as between 25% and less than 50% of the time. There were not any visible patterns of differences between age groups and activity intensity. Resting and low activity was commonly reported as 0 to less than 25% of time for all age groups. All age groups most frequently categorized high activity as between 50 to less than 90% of time when using synthetic turf fields and moderate activity between 10 to less than 50%.

Table 4-9. Intensity of Activity Engaged in by Questionnaire Participants When Using Synthetic Turf Fields

Percentage of Time (%)	Number of (%) Questionnaire Participants Engaged in High/Moderate Activity	Number of (%) Questionnaire Participants Engaged in Low Activity/Resting
0 – <25	18 (28%)	52 (81%)
25 – <50	24 (38%)	12 (19%)
50 – <75	13 (20%)	0
75+	9 (14%)	0

4.2.5 Dermal and Non-dietary Ingestion Exposure

Commonly reported activities occurring on synthetic turf fields every time or often included drinking (81%), hands touching the turf (78%), and body parts (other than hands) touching the turf (75%; Table 4-10). Activities like chewing gum, eating, and using hand wipes did not have large enough cell sizes to present (i.e., they were not commonly reported). Getting cuts or abrasions from contact with the turf and touching one's mouth while on the field were also not commonly reported to occur every time/often (19% and 28%, respectively). Adults were more likely to report playing in the rain often (71%), and children ages 7 to less than 11 were more likely to report sitting with bare skin on the field every time (57%) (data not shown).

Shorts and short sleeve shirts were most commonly worn in the spring, summer, and fall for all questionnaire participants (Table 4-11). Gloves were not commonly worn, but had the highest frequency of use in the fall (41%). Pads were most commonly worn in summer (53%) and fall (75%). Long sleeve shirts and long pants did not have large enough cell sizes to be presented, but were most commonly reported as worn in fall and winter. Little variation was present among age groups.

Table 4-10. Frequency of Different Activities Performed by Questionnaire Participants on Synthetic Turf Fields

Activity	Number of (%) Questionnaire Participants Engaged in Activity Every Time/Often	Number of (%) Questionnaire Participants Engaged in Activity Sometimes/Never
Drink	26 (81%)	6 (19%)
Play in rain	14 (44%)	18 (56%)
Hand touches turf	25 (78%)	7 (22%)
Body part (other than hand) touches turf	24 (75%)	8 (25%)
Sit with bare skin	16 (50%)	16 (50%)
Play with turf material/ rubber granules	6 (19%)	26 (81%)
Touch mouth with hands or fingers	9 (28%)	23 (72%)
Put non-food objects in mouth	18 (56%)	14 (44%)
Cuts/abrasions from contact with turf	6 (19%)	26 (81%)

Table 4-11. Clothing Worn by Questionnaire Participants, by Season

Clothing	Number of (%) Questionnaire Participants Who Wore Clothing in Spring	Number of (%) Questionnaire Participants Who Wore Clothing in Summer	Number of (%) Questionnaire Participants Who Wore Clothing in Fall	Number of (%) Questionnaire Participants Who Wore Clothing in Winter
Shorts	16 (50%)	26 (81%)	30 (94%)	6 (19%)
Short Sleeve Shirts	16 (50%)	26 (81%)	30 (94%)	7 (22%)
Gloves	6 (19%)	10 (31%)	13 (41%)	9 (28%)
Socks	17 (53%)	26 (81%)	32 (100%)	12 (38%)
Helmet	0	6 (19%)	8 (25%)	0
Pads	12 (38%)	17 (53%)	24 (75%)	8 (25%)

4.2.6 Tire Crumb, Dirt and Debris in Other Areas

For all participants, a majority noticed tire crumb rubber, dirt or debris every time or often on their body (66%), in their car (75%), or at home (59%) after using a synthetic turf facility (Table 4-12). Adults frequently reported finding tire crumb rubber, dirt or debris on their body often (57% often), as did youth age 11 to less than 18 years (44% every time; 28% often); however, this was not common for the youngest participants (29% every time; 14% often; data not shown).

Table 4-12. Frequency of Questionnaire Participants Noticing Tire Crumb Rubber, Dirt or Debris After Using Facility

Location Tire Crumb, Dirt and Debris Found	Number of (%) Questionnaire Participants Who Noticed Every Time/Often	Number of (%) Questionnaire Participants Who Noticed Sometimes or Rarely/Never
Body	21 (66%)	11 (34%)
Car	24 (75%)	8 (25%)
Home	19 (59%)	13 (41%)
Laundry room/mudroom	15 (47%)	17 (53%)
Living room	13 (41%)	19 (59%)
Bedroom	12 (38%)	20 (63%)
Bathroom	12 (38%)	20 (63%)

4.2.7 Hygiene Practices Post-Field Use

Concerning post-field hygiene, 47% of participants reported showering or changing clothes immediately after facility use, while 53% reported sometimes or rarely/never showering immediately after field use (Table 4-13). Approximately half of participants (53%) reported removing shoes or equipment every time or often before entering their homes. A majority of participants age 7 to less than 11 years (71%) reported rarely or never showering or changing clothes immediately after using the synthetic turf facility. In contrast, 57% of adult participants reported showering or changing clothes immediately after facility use every time. Younger children also infrequently reported removing shoes or equipment before entering a home, while adults and older children (11 to less than 18 years of age) more frequently reported (every time or often) performing these tasks.

Table 4-13. Frequency of Hygiene Practices by Questionnaire Participants, Post-field Use

Hygiene Practice	Number of (%) Questionnaire Participants Engaged in Practice Every time/Often	Number of (%) Questionnaire Participants Engaged in Practice Sometimes or Rarely/Never
Shower/change clothes immediately	15 (47%)	17 (53%)
Shoes/equipment wiped or removed before entering home	17 (53%)	15 (47%)

4.2.8 General Hygiene Practices

Most participants (69%) reported washing their hands in general four or more times a day (Table 4-14), with little variation between age groups. Half of all participants reported bathing or showering between 6 and 10 times a week (Table 4-15; most commonly 7 times per week), but frequency varied with age. Younger children most commonly reported showering between 5 and 7 times per week, while answers were more variable for teen participants, ranging from 5 times to more than 10 times a week. The majority of adults reported showering 10 or more times per week.

Table 4-14. How Many Times per Day Questionnaire Participants Generally Wash Their Hands

Number of Times Hands Washed per Day	Number of (%) Questionnaire Participants
1-3	10 (31%)
4+	22 (69%)

Table 4-15. How Often Questionnaire Participants Generally Shower or Bathe per Week

Number of Times Bathe/Shower per Week*	Number of (%) Questionnaire Participants
0 - 5	9 (28%)
6 - 10	16 (50%)
11+	7 (22%)

*Data is presented in these categories due to the distribution of the data and small cell sizes

4.3 Video Activity Assessments for Field Users

4.3.1 Publicly-Available Video Assessment (Phase 1)

Publicly-available videos of adult and youth engaged in soccer, football, and field hockey were used to assess specific exposure-related activity frequencies. These included hand-to-turf, body-to-turf, hand-to-mouth, and object-to-mouth activities. These activities are likely to be important components of skin (dermal) and ingestion exposures for youth and adults playing sports on synthetic turf fields. (Most of the videos viewed in Phase 1 included actual game play; activities may be different for sports practice sessions).

4.3.1.1 General Descriptive Statistics of Athletes and Fields Observed in Publicly-Available Videos

Table 4-16 presents the general characteristics of the 60 athletes (20 per sport – soccer, football, and field hockey) and the fields that they were observed playing on in the 34 publicly-available YouTube videos. Fifty percent of the athletes were adults and 50% were children; of those, 63% were males (n = 38) and 37% were females (n = 22). Gloves were worn by 37% of the players, although a portion of those athletes wore only one glove. Mouthguards were worn by the majority of the players (53%), but were not commonly observed being worn by soccer players. Of the players wearing mouthguards, only 6% were soccer players. The 60 athletes were observed in the videos playing on both outdoor fields (n = 41, 68%) and indoor fields (n = 19, 32%); the majority of the videos (n = 28; 82%) were for athletes playing on fields with synthetic turf.

Table 4-16. General Characteristics of the Athletes and Fields They Were Observed Playing on in Publicly-available Videos (Phase 1)

Characteristic	Number of (%) Athletes
Child Athlete	30 (50%)
Adult Athlete	30 (50%)
Male Athlete[a]	38 (63%)
Female Athlete	22 (37%)
Mouthguard Worn - Yes	32 (53%)
Mouthguard Worn - No	28 (47%)

Table 4-16. Continued

Characteristic	Number of (%) Athletes
Glove(s) Worn - Yes	22 (37%)[b]
Glove(s) Worn - No	38 (63%)
Indoor Field	19 (32%)
Outdoor Field	41 (68%)

[a] Males were the only sex observed playing football on the selected videos.

[b] 18% of the athletes (n = 4) wore only one glove.

4.3.1.2 Descriptive Statistics of Micro-activity Events Observed in Publicly-available Videos

Descriptive statistics for the frequencies of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events per hour for the children and adults observed playing soccer, field hockey, and football in the publicly-available videos are provided in Figure 4-1 and in Appendix G. The box-and-whisker plots in Figure 4-1 present the frequencies of the selected micro-activity contacts (events/hour) by age group (child or adult) and sport type.

Children - For all sports combined, the total mean frequencies of children's hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events per hour on the publicly-available videos were 29 ± 47, 7.0 ± 11, 33 ± 48 and 21 ± 28 events/hr, respectively. These micro-activity events were consistently higher for children playing football compared to children playing soccer or field hockey. The mean hand-to-mouth events per hour were about four times higher for football players (58 ± 75 events/hr) compared to soccer players (14 ± 9.9 events/hr) and field hockey players (15 ± 13 events/hr; Figure 4-1 and Appendix G). The mean object-to-mouth events per hour were much greater for football players (17 ± 13 events/hr) than for field hockey players (3.6 ± 5.1 events/hr) and soccer players (0.0 ± 0.0 events/hr), respectively. The mean hand-to-turf events per hour were also much greater when playing football (83 ± 51 events/hr) compared to soccer (12 ± 26 events/hr) and field hockey (5.8 ± 7.5 events/hr). And the mean body-to-turf events were between 8 and 18 times higher for football (52 ± 25 events/hr) players than for both soccer (6.4 ± 12 events/hr) and field hockey (2.8 ± 5.0 events/hr) players, respectively.

Adults - For all sports combined, the total mean frequencies of adults' hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events observed on the publicly-available videos were 30 ± 65, 10 ± 22, 42 ± 99 and 21 ± 37 events/hr, respectively (Figure 4-1 and Appendix G). Like with the children, these select micro-activity events were consistently higher for adults playing football compared to adults playing soccer or field hockey. The mean hand-to-mouth events per hour were roughly 7 to 18 times higher for football players (74 ± 99 events/hr) compared to field hockey players (11 ± 14 events/hr) and soccer players (4.2 ± 6.5 events/hr). The mean object-to-mouth events per hour were about 5 times greater for football players (25 ± 33 events/hr) than for soccer players (4.0 ± 1.3 events/hr) or field hockey players (5.2 ± 9.1 events/hr). For hand-to-turf events per hour, the mean was much greater when playing football (110 ± 150 events/hr) compared to playing soccer (14 ± 17 events/hr) or field hockey (2.4 ± 6.3 events/hr), respectively. Mean body-to-turf events per hour were as much as 49 times higher for football players (49 ± 54 events/hr) compared to soccer players (11 ± 11 events/hr) and field hockey players (1.2 ± 3.8 events/hr).

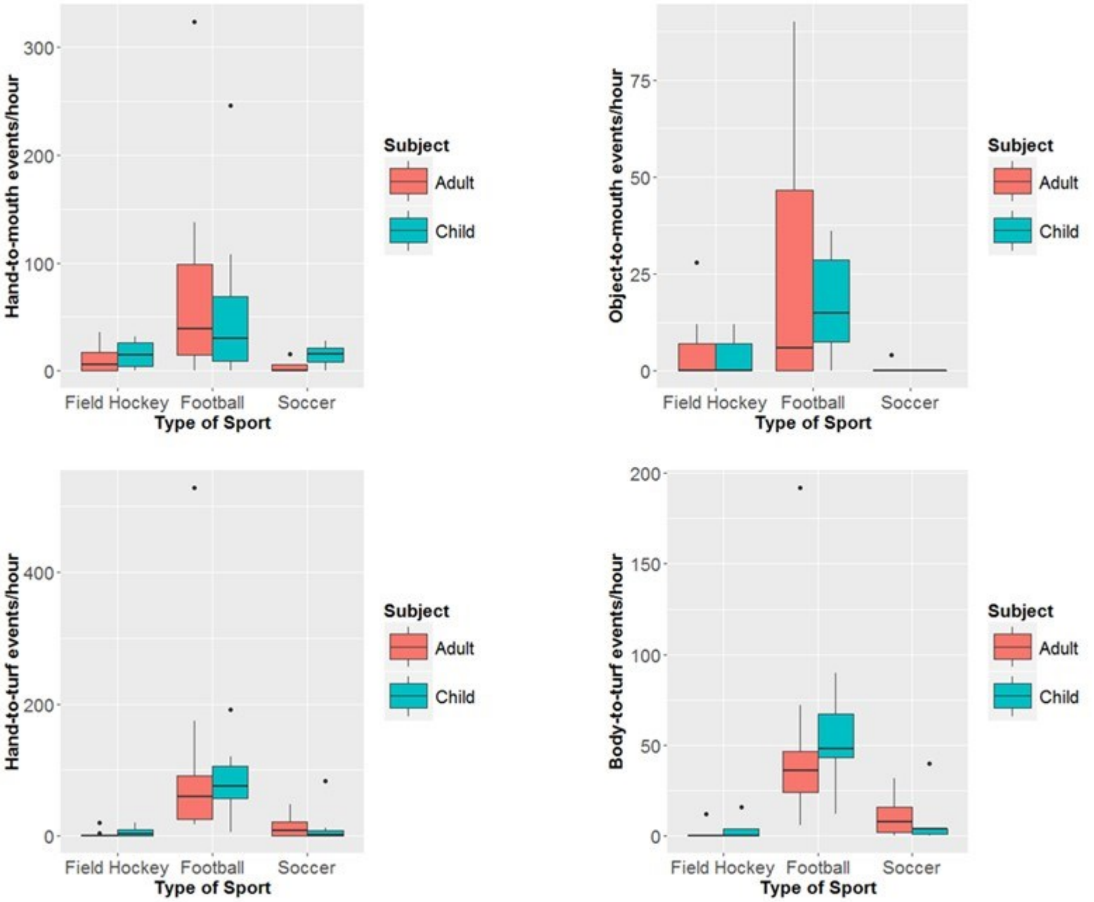

Figure 4-1. Box-and-whisker plots of athlete micro-activity events per hour observed on publicly-available video (Phase 1), by age group and sport.

Turf Type - Welch's t-tests were performed to determine if there were differences in the number of athlete (children and adults combined) individual micro-activity (hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf) events or total micro-activity events occurring per hour when playing on natural fields. The results showed that there were no significant differences in the mean number of individual micro-activity events per hour or total micro-activity events per hour observed in publicly-available videos for athletes by turf type (data not shown).

Age Group - Welch's t-tests were run to determine if there were differences in individual micro-activity (hand-to-mouth, object-to-mouth, hand-to-turf, body-to-turf) events or total micro-activity events occurring per hour between child and adult athletes while playing on turf fields (natural and synthetic). The results showed that there were not any significant differences in the mean number of individual micro-activity events per hour or total micro-activity events per hour of athletes by age group in the publicly-available videos (data not shown).

Type of Sport - In Table 4-17, a one-way ANOVA was performed to determine if there were differences in the number of individual micro-activity events or total micro-activity events per hour of all athletes (children and adults) observed in the publicly-available video, by type of sport (field hockey, football, or soccer). The results showed that there were significant differences in the number of individual and total micro-activity events per hour of these athletes by sport type. The total mean micro-activity events per hour were significantly higher ($p<0.001$) for football players (230 ± 61 events/hr) compared to field hockey players (23 ± 18 events/hr) or soccer players (31 ± 7.0 events/hr; Table 4-17 and Figure 4-2). In addition, football players had significantly ($p < 0.001$) higher hand-to-mouth, object-to-mouth, hand-to-turf, and body-turf events than either field hockey players or soccer players. Field hockey and soccer players, however, did not significantly differ from each other by each type of micro-activity (Table 4-17).

Table 4-17. One-way ANOVA Results for Select Micro-activity Events Performed per Hour by Athletes (Children and Adults) Observed on Publicly-available Video (Phase 1), by Sport[a]

Micro-activity	Field Hockey - Events per Hour (mean ± standard deviation)	Football - Events per Hour (mean ± standard deviation)	Soccer - Events per Hour (mean ± standard deviation)[a]	F-statistic	*p*-value[b]
Hand-to-mouth	13 ± 13	66 ± 86	9.2 ± 9.6	$F(2,57) = 7.93$	$p < 0.001$
Object-to-mouth	4.4 ± 7.2	21 ± 25	0.20 ± 0.89	$F(2,57) = 11.32$	$p < 0.001$
Hand-to-turf	4.1 ± 6.9	96 ± 110	13 ± 1.3	$F(2,57) = 11.70$	$p < 0.001$
Body-to-turf	2.0 ± 4.4	51 ± 41	8.8 ± 11	$F(2,57) = 23.25$	$p < 0.001$
Total events	23 ± 18	230 ± 61	31 ± 7.0	$F(2,57) = 31.11$	$p < 0.001$

[a] Number of athletes in each sport (n=20)

[b] p = significance level

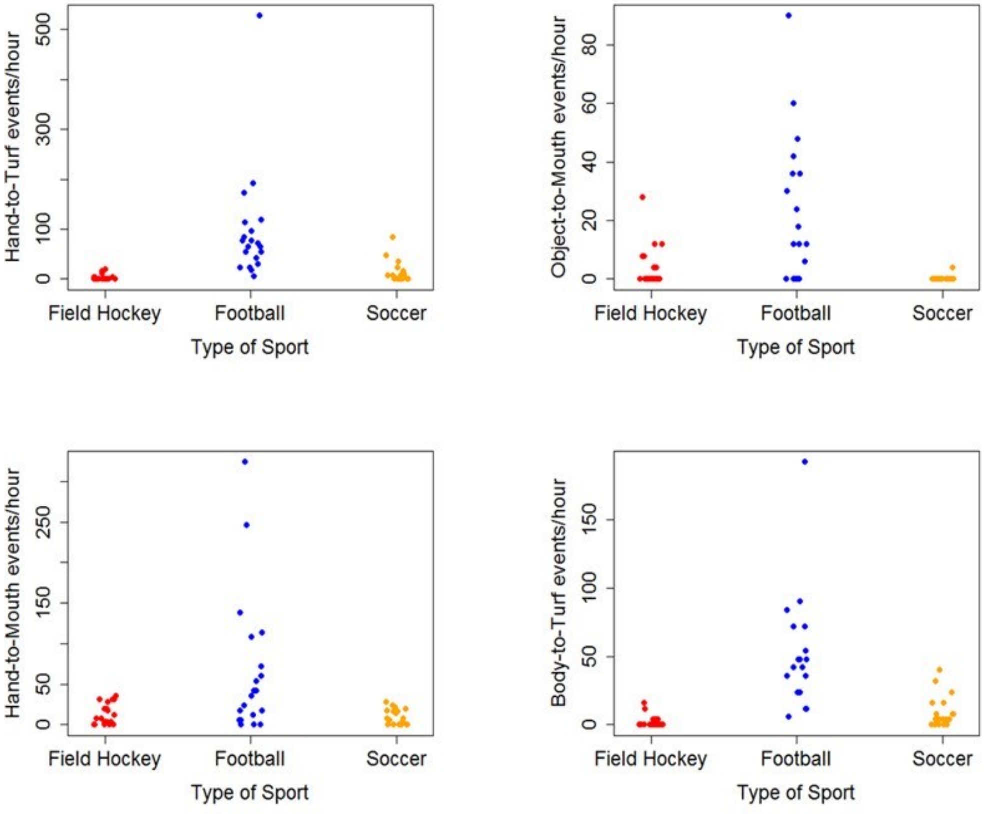

Figure 4-2. Micro-activity events per hour for all athletes (children and adults) observed on publicly-available video (Phase 1), by sport.

Type of Sport by Age Group: Adults - Five one-way between-subject ANOVAs were run to determine if type of sport played (field hockey, football, or soccer) influenced the number of micro-activity events per hour of adult athletes observed on publicly-available video (Table 4-18 and Figure 4-3). The results showed that there was a significant difference in the total mean number of micro-activity events per hour of adults by sport type [F(2,27) = 12.34, p < 0.001]. The total mean number of micro-activity events per hour for football players (260 ± 6.8 events/hr) were significantly higher than the total mean number of micro-activity events per hour for field hockey players (20 ± 21 events/hr) or soccer players (30 ± 9.7 events/hr).

Table 4-18. ANOVA Results for Select Micro-activity Events per Hour for Adults Observed on Publicly-available Video (Phase 1), by Type of Sport[a]

Micro-activity	Field Hockey - Events per Hour (mean ± standard deviation)	Football - Events per Hour (mean ± standard deviation)	Soccer - Events per Hour (mean ± standard deviation)\	F-statistic	*p*-value [b]
Hand-to-mouth	11 ± 14	74 ± 99	4.2 ± 6.6	$F(2,27) = 4.49$	$p = 0.021$
Object-to-mouth	5.2 ± 9.1	25 ± 33	0.40 ± 1.2	$F(2,27) = 4.53$	$p = 0.020$
Hand-to-turf	2.4 ± 6.3	110 ± 54	14 ± 7.0	$F(2,27) = 4.26$	$p = 0.024$
Body-to-turf	1.2 ± 3.8	49 ± 53	11 ± 0.80	$F(2,27) = 6.41$	$p = 0.005$
Total events	20 ± 21	260 ± 6.8	30 ± 9.7	$F(2,27) = 12.34$	$p < 0.001$

[a] Number of athletes in each sport (n=10)

[b] *p* = significance level

Table 4-18 shows that ANOVAs run by type of micro-activity indicated that differences by sport were significant for mean hand-to-mouth [F(2,27) = 4.49, p = 0.021]; object-to-mouth [F(2,27) = 4.53, p = 0.020]; hand-to-turf [F(2,27) = 4.26, p = 0.024] and body-to-turf [F(2,27) = 6.41, p = 0.005] events per hour. Post-hoc analysis revealed that the number of mean hand-to-mouth events per hour were significantly different between soccer players and football players (p = 0.029), but were not significantly different between field hockey and football players or field hockey and soccer players. For mean object-to-mouth events per hour, Tukey post-hoc analysis revealed a similar pattern of significant differences occurring between soccer and football players (p = 0.022) and no significant differences between field hockey and football players or field hockey and soccer players. Post-hoc analysis of hand-to-turf events showed that the mean number of hand-to-turf events per hour were significantly different for field hockey and football players (p = 0.033); however, hand-to-turf events per hour by soccer players were not significantly different from those of football players or field hockey players. In addition, mean body-to-turf events per hour were found to be significantly different between football and soccer players (p < 0.001) and football and field hockey players (p < 0.001), but not between soccer and field hockey players.

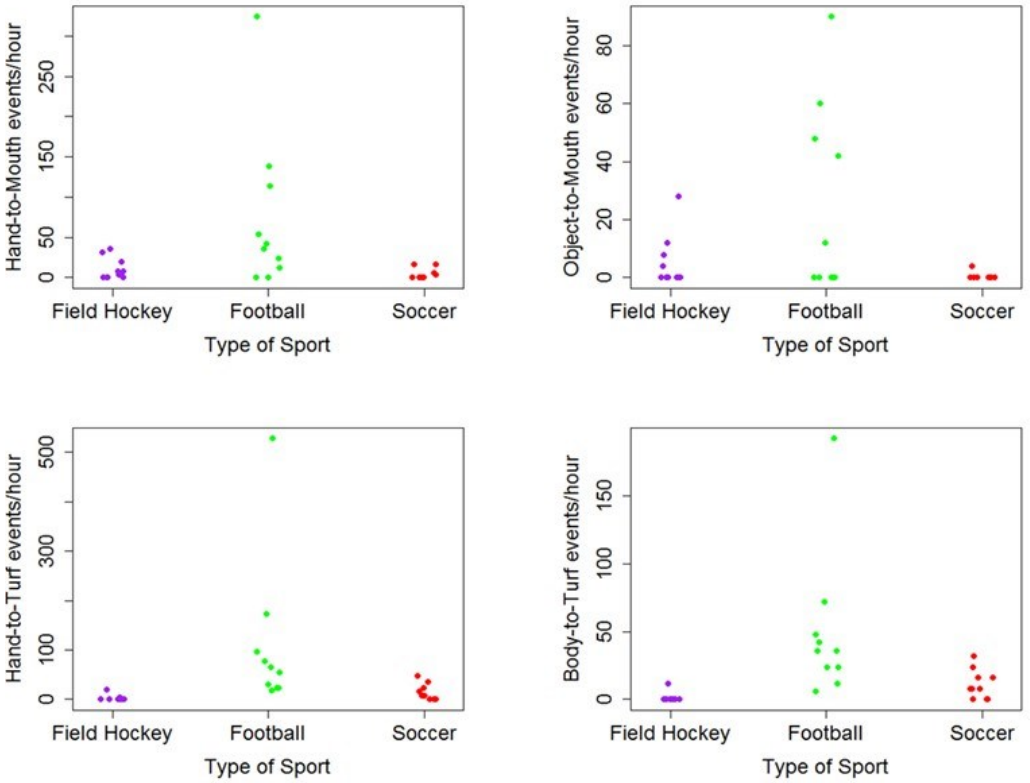

Figure 4-3. Micro-activity events per hour for adults observed on publicly-available video (Phase 1), by sport.

Type of Sport by Age Group: Children - Five one-way between-subject ANOVAs were run to determine if type of sport played (field hockey, football, or soccer) influenced the mean number of micro-activity events per hour of child athletes observed on publicly-available video (Table 4-19 and Figure 4-4). The results showed that there was a significant difference (p < 0.001) in the total mean number of micro-activity events per hour of children by type of sport. These results showed that football players had a significantly higher total mean number of micro-activity events per hour (210 ± 100 events/hr) than field hockey players (27 ± 13 events/hr) or soccer players (6.4 ± 12 events/hr).

Table 4-19. ANOVA Results for Select Micro-activity Events per Hour for Children Observed on Publicly-available Video (Phase 1), by Sport[a]

Micro-activity	Field Hockey - Events per Hour (mean ± standard deviation)	Football - Events per Hour (mean ± standard deviation)	Soccer - Events per Hour (mean ± standard deviation)	F-statistic	*p*-value [b]
Hand-to-mouth	15 ± 13	58 ± 75	14 ± 9.9	$F(2,27) = 3.16$	$p = 0.058$
Object-to-mouth	3.6 ± 5.2	17 ± 14	0.0 ± 0.0	$F(2,27) = 11.82$	$p < 0.001$
Hand-to-turf	46 ± 7.5	83 ± 51	13 ± 21	$F(2,27) = 16.77$	$p < 0.001$
Body-to-turf	2.8 ± 5.0	52 ± 25	12 ± 26	$F(2,27) = 29.61$	$p < 0.001$
Total events	27 ± 13	210 ± 100	6.4 ± 12	$F(2,27) = 25.77$	$p < 0.001$

[a] Number of athletes in each sport = 10

[b] p = significance level

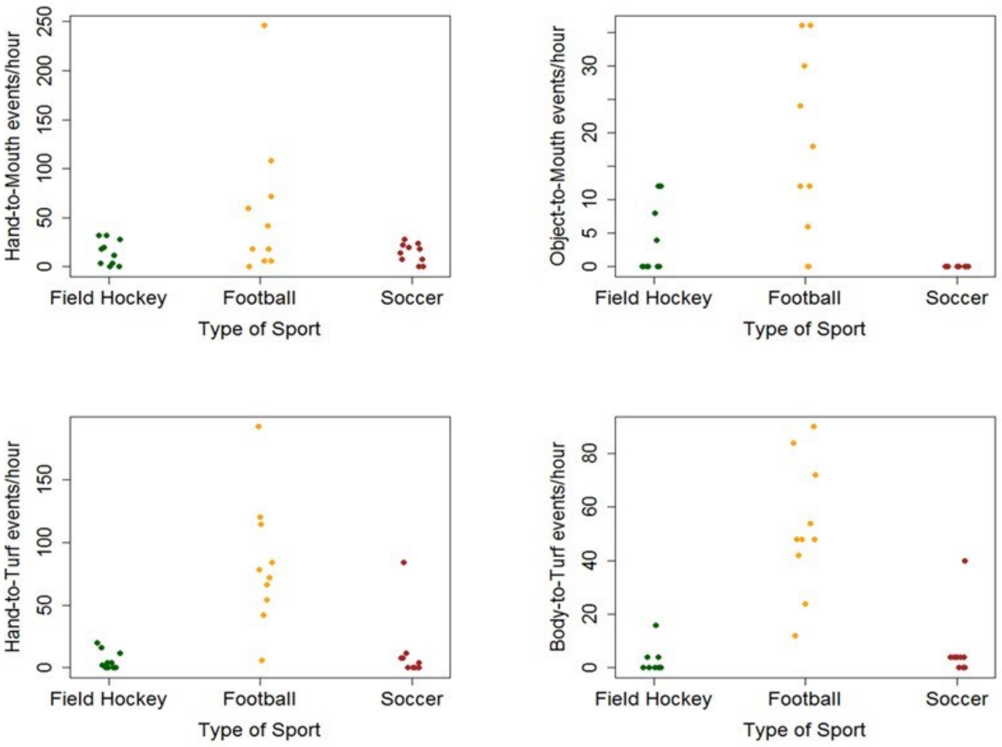

Figure 4-4. Micro-activity events per hour for children observed on publicly-available video (Phase 1), by sport.

Table 4-19 also shows that there were not any significant differences in the children's mean hand-to-mouth events per hour [F(2,27) = 3.16, p = 0.058] among the three different types of sports. However, there were significant differences in the mean number of micro-activity events per hour for object-to-mouth events [F(2,27) = 11.82, p < 0.001]; hand-to-turf events [F(2,27) = 16.77, p < 0.001]; and body-to-turf events [F(2,27) = 29.61, p < 0.001] for child athletes among the three different sports (Table 4-19 and Figure 4-4). Tukey post-hoc analysis showed that each micro-activity specific ANOVA analyzing differences in mean hand-to-mouth, object-to-mouth, hand-to-turf, or body-to-turf contact between sports, indicated that football players had a significantly greater number of micro-activity events per hour for each category than both field hockey and soccer players. However, the number of micro-activity events per hour in each category did not significantly differ between soccer players and field hockey players.

Glove Use - Welch's t-tests were performed to determine if wearing at least one glove had a substantial impact on hand-to-mouth or hand-to-turf events per hour for adults and children combined. Athletes wearing gloves (n = 22, 10 ± 17 events/hr) had significantly fewer hand-to-mouth events per hour than those not wearing gloves [n = 38, 40 ± 67 events/hr); t(44.40) = 2.60, p = 0.012; Figure 4-5]. However, there was no significant difference in the mean number of hand-to-turf events per hour between athletes wearing gloves (n = 22, 59 ± 120 events/hr) and athletes not wearing gloves [n = 38, 25 ± 34 hr; t(23.04) = 1.33, p = 0.195]. For football players, player position (i.e., center or quarterback) appeared to have a large influence on the observed hand-to-turf events per hour (data not shown).

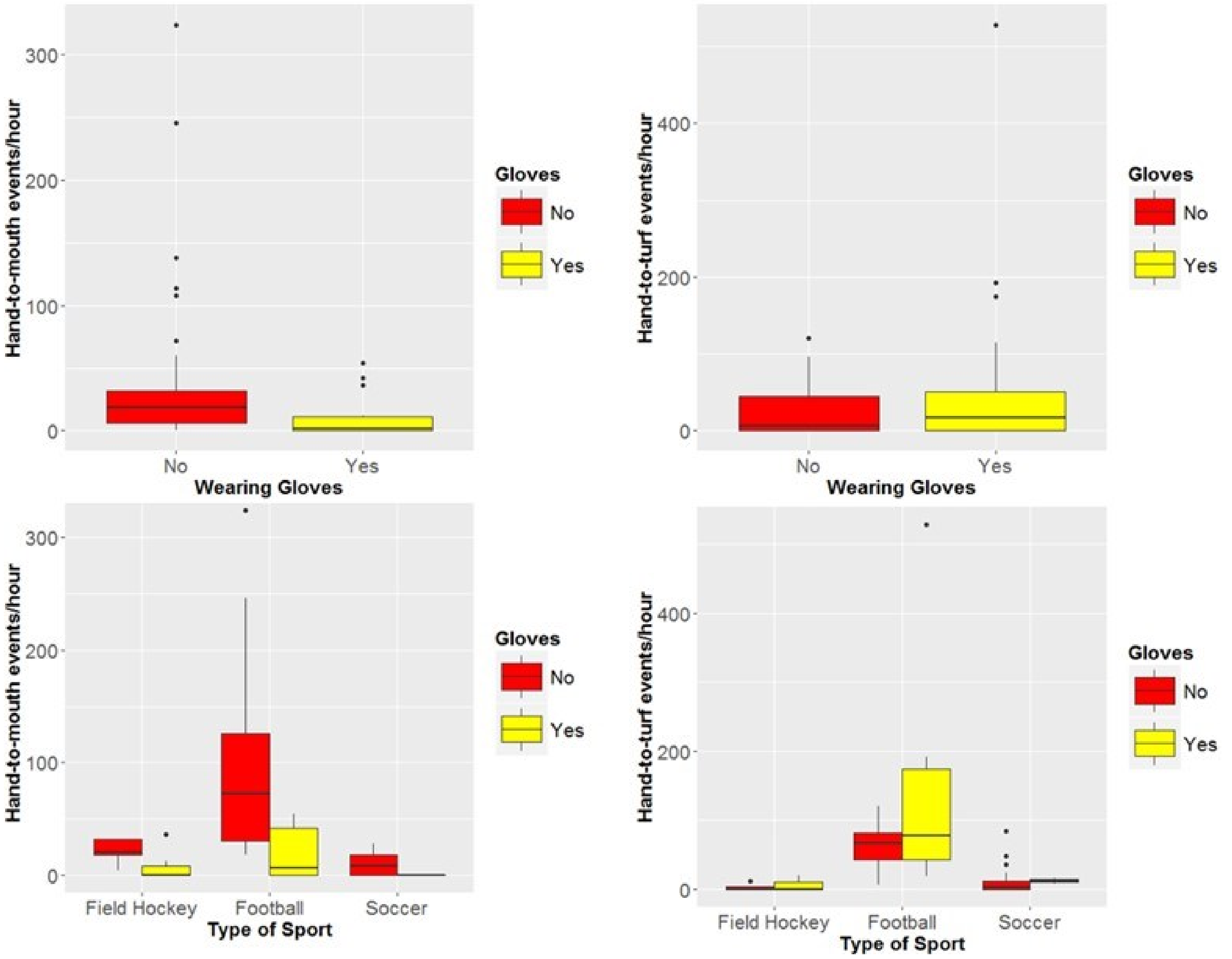

Figure 4-5. Hand-to-mouth and hand-to-turf events per hour for athletes observed on publicly-available video (Phase 1), by glove use and by glove use and sport.

Mouthguard Use - For children and adults combined, Welch's t-test results showed a significantly higher mean number of hand-to-mouth events per hour for players wearing mouthguards ($n = 32$, 50 ± 71 events/hr) compared to players not wearing mouthguards [$n = 28$, 5.6 ± 7.7 events/hr; $t(31.85) = 3.54$, $p = 0.001$; Figure 4-6]. Welch's t-test results also showed a significantly greater mean number of object-to-mouth events per hour for athletes wearing mouthguards (16 ± 21 events/hr) compared to athletes not wearing mouthguards [0.14, ± 0.76 events/hr; $t(31.09) = 4.27$, $p < 0.001$].

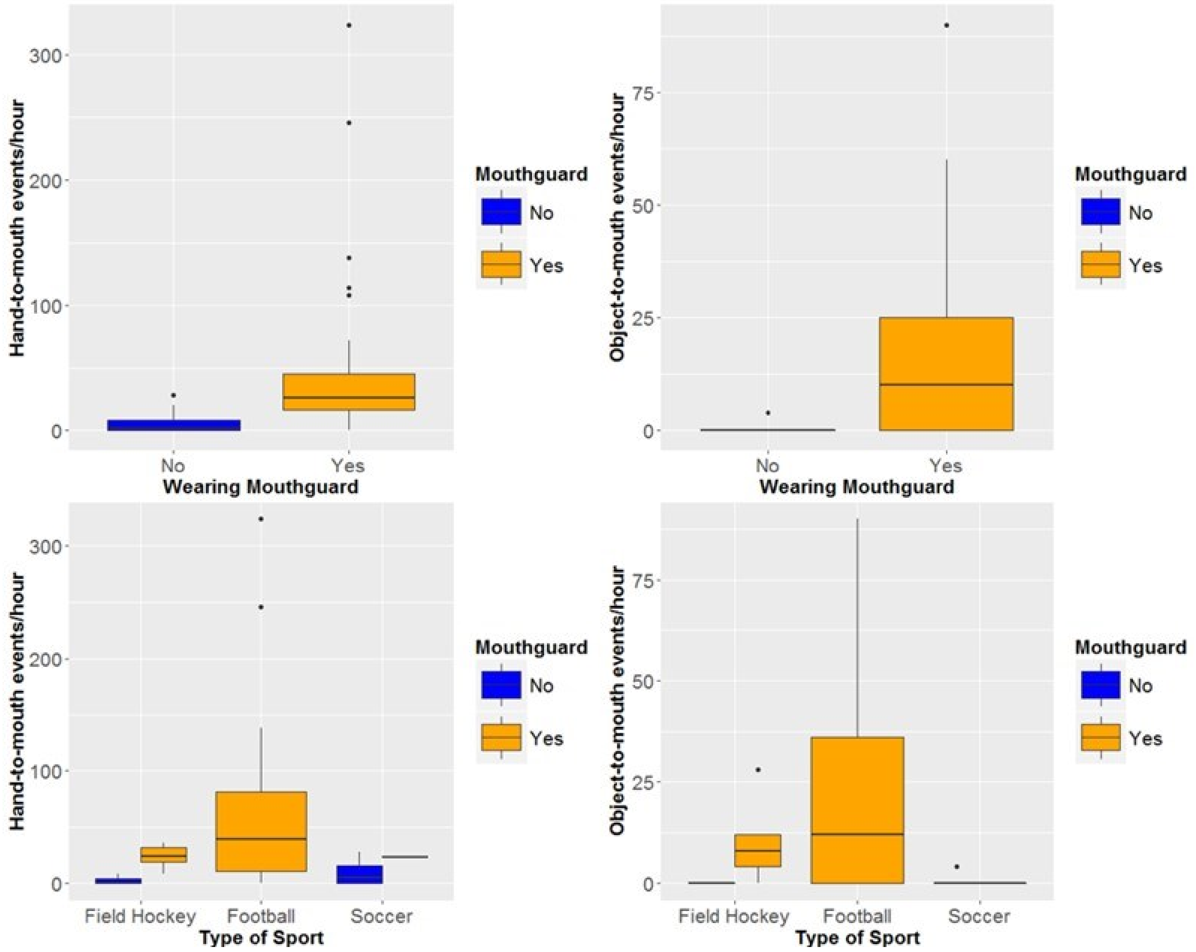

Figure 4-6. Hand-to-mouth and object-to-mouth events per hour of athletes observed on publicly-available video (Phase 1), by mouthguard use and by mouthguard use and sport.

4.3.2 Exposure Pilot Study Participant Video Assessment (Phase 2)

4.3.2.1 General Descriptive Statistics of Athletes Videoed in the Exposure Pilot Study

Table 4-20 presents the general characteristics of the seventeen exposure pilot study participants who consented to being videographed playing soccer (n = 12) and football (n = 5) on synthetic turf fields. Results showed that 18% (n = 3) of the athletes were adults over the age of 18 (all of which played soccer), and 82% (n = 14) were children ages 7 to 14 (nine of which played soccer and five of which played football). Of these athletes, 53% (n = 9) were males, and 47% (n = 8) were females. Gloves were worn (on both hands) by 24% (n = 4) of the athletes, and mouthguards were also worn by 23% of athletes (all football players). Sixteen of the seventeen recruited athletes played on outdoor fields (94%); only one athlete was able to be recruited and videoed on an indoor field. (It should be noted that these observations were made during sports practice activities; different levels of activity may be associated with games).

Table 4-20. General Characteristics of the Athletes Observed Playing Soccer and Football in Exposure Pilot Study Videos (Phase 2) [a]

Characteristics	Number of (%) Athletes
Child Athlete	14 (82%)
Adult Athlete	3 (18%)
Male Athlete[a]	9 (53%)
Female Athlete	8 (47%)
Mouthguard Worn - Yes	4 (23%)
Mouthguard Worn - No	13 (77%)
Gloves Worn - Yes	4 (23%)
Gloves Worn - No	13 (77%)

[a] Only males were videographed playing football on synthetic turf fields

4.3.2.2 Descriptive Statistics of Micro-Activity Events by Athletes Videoed in the Exposure Pilot Study

Descriptive statistics for the frequencies of the select micro-activity events per hour for the children and adults videographed playing soccer or football in the Phase 2 video assessment are provided in Figure 4-7 and in Appendix G. The box-and-whisker plots in Figure 4-7 present the frequencies of hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf contacts (events per hour) by age group (child or adult) and sport type (soccer or football).

Children (ages 7 to 14) - For both sports combined, the total mean frequencies of the children's hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events per hour were 16 ± 12, 10 ± 13, 18 ± 23, and 4.7 ± 4.9, respectively. Results showed that football players had about 6 times higher mean object-to-mouth events per hour (22 ± 17 events/hr) than soccer players (3.8 ± 3.6 events/hr; Figure 4-7 and Appendix G). Mean body-to-turf events per hour were about two times higher for football players (6.8 ± 2.6 events/hr) than for soccer players (3.6 ± 5.7 events/hr).

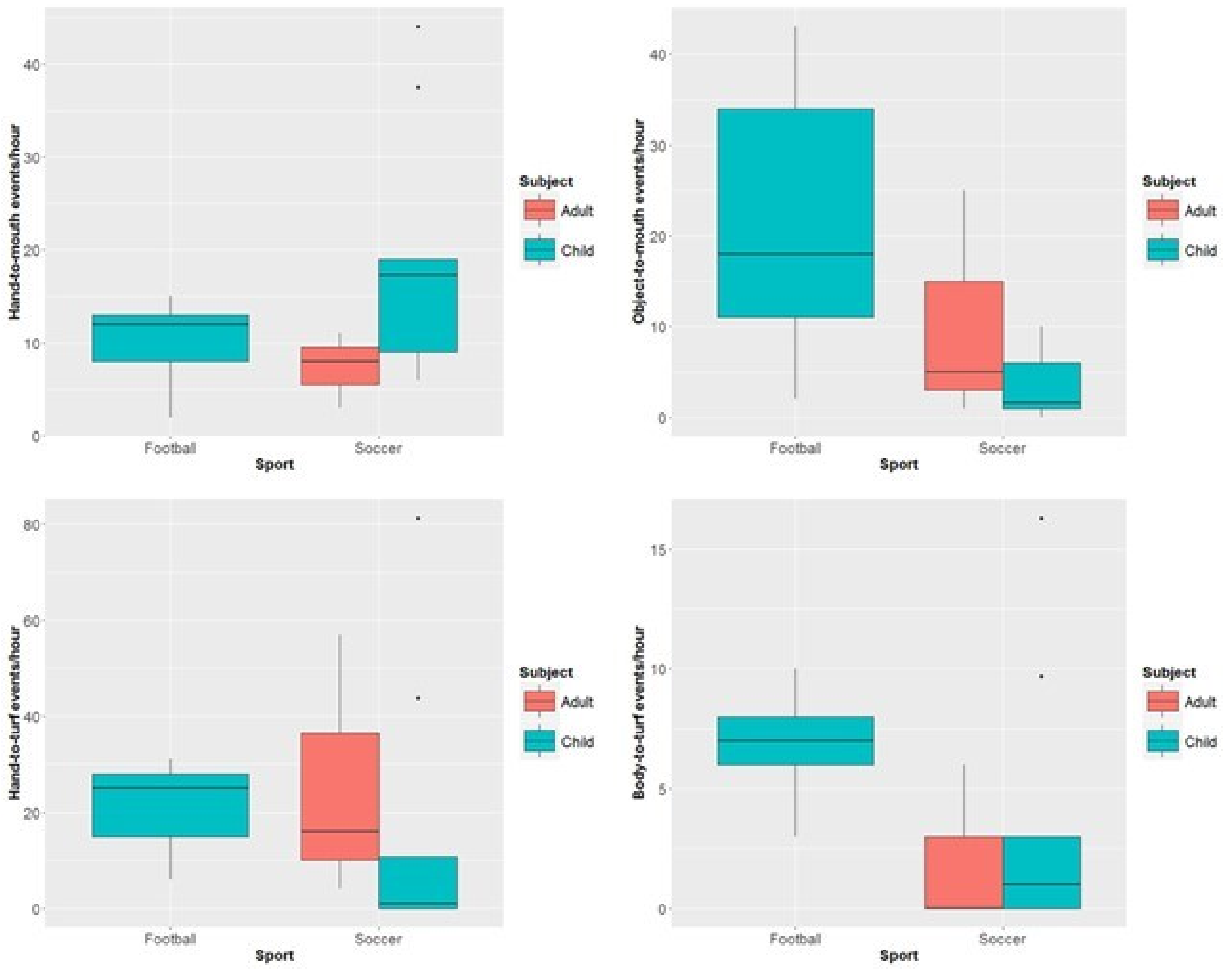

Figure 4-7. Box-and-whisker plots of the micro-activity events per hour by athletes in Exposure Pilot Study videos (Phase 2), by age group and sport type.

Adults (over 18 years of age) - For all adults (3 soccer players only), the total mean hand-to-mouth, object-to-mouth, hand-to-turf, and body-to-turf events per hour were 7.3 ± 4.0, 10 ± 13, 26 ± 28, and 2.0 ± 3.5, respectively. Results showed that the hand-to-turf contact of adult soccer players (26 ± 28 events/hr) were about 3 times higher compared to hand-to-mouth and object-to-mouth contact and 13 times higher than body-to-turf contacts (Figure 4-7 and Appendix G). However, these results are based on a small number of participants.

Inferential Results for Athlete Micro-Activity Events - Due to the small sample size of participants (n = 17), Welch's t-tests were used to determine if there were significant differences in the mean number of micro-activity events between all athletes (children and adults) playing soccer (n = 12) and all athletes (children only) playing football (n = 5). Results showed that there were no significant differences in the mean number of individual micro-activity events (hand-to-mouth, object-to-mouth, hand-to-turf, or body-to turf contacts) per hour by sport (Table 4-21). However, the reader is cautioned that these results may be due to the small sample size. There were also no significant differences in the mean number of micro-activity events per hour by category for child soccer players (n = 9) compared to child football players (n = 5; data not shown).

Table 4-21. Welch's t-test Results for Micro-activity Events Per Hour by Athletes in Exposure Pilot Study Videos (Phase 2), by Sport[a]

Micro-activity	Soccer Players - Events per Hour (mean ± standard deviation)	Football Players - Events per Hour (mean ± standard deviation)	*t*-statistic	*p*-value[b]
Hand-to-mouth	16 ± 13	10 ± 5.2	$t(15.0) = 1.40$	$p = 0.181$
Object-to-mouth	5.4 ± 7.0	22 ± 17	$t(4.59) = 2.09$	$p = 0.096$
Hand-to-turf	19 ± 27	21 ± 10	$t(15.0) = .268$	$p = 0.793$
Body-to-turf	3.2 ± 5.1	6.8 ± 2.6	$t(14.0) = 1.93$	$p = 0.075$
Total events	43 ± 40	59 ± 12	$t(14.4) = 1.28$	$p = 0.220$

[a] Number of athletes, Soccer (n = 12) and Football (n = 5)

[b] p = significance level

Welch's t-tests were also performed to determine if there were significant differences in the mean number of hand-to-mouth or hand-to-turf events per hour for players wearing gloves (n = 4, all children) compared to players not wearing gloves (n = 13). Results showed that there were no significant differences in the number of hand-to-mouth or hand-to-turf events per hour between athletes wearing gloves and athletes not wearing gloves (Table 4-22); however, the reader is cautioned that these results may be due to the small sample size of participants.

Table 4-22. Welch's t-test Results for Hand-to-mouth and Hand-to-turf Events per Hour by Athletes in Exposure Pilot Study Videos (Phase 2), by Glove Use[a]

Micro-activity	Athletes Wearing Gloves - Events per Hour (mean ± standard deviation)	Athletes Not Wearing Gloves - Events per Hour (mean ± standard deviation)	*t*-statistic	*p*-value[b]
Hand-to-mouth	11 ± 7.1	15 ± 12	$t(9.0) = .953$	$p = 0.366$
Hand-to-turf	22 ± 16	18 ± 25	$t(8.1) = .386$	$p = 0.709$

[a] Number of athletes wearing gloves (n = 4), not wearing gloves (n = 13)

[b] p = significance level

In addition, Welch's t-tests were run to determine if there were significant differences in the mean number of hand-to-mouth or object-to-mouth events per hour for players wearing mouthguards (n = 4, all child football players) compared to players not wearing mouthguards (n = 13). Results showed that there were no significant differences for hand-to-mouth events per hour between athletes wearing mouthguards and athletes not wearing mouthguards (Table 4-23). However, for object-to-mouth events per hour, there were marginally significant differences (p = 0.057) between players wearing mouthguards compared to players not wearing mouthguards.

Table 4-23. Welch's t-test Results for Hand-to-mouth and Object-to-mouth Events per Hour by Athletes in Exposure Pilot Study Videos (Phase 2), by Mouthguard Usage

[a] Micro-activity	Athletes Wearing Mouthguard - Events per Hour (mean ± standard deviation)	Athletes Not Wearing Mouthguard - Events per Hour (mean ± standard deviation)	*t*-statistic	*p*-value[b]
Hand-to-mouth	11 ± 5.8	15 ± 12	$t(11.5) = 1.10$	$p = 0.293$
Object-to-mouth	27 ± 15	5.1 ± 6.7	$t(3.4) = 2.83$	$p = 0.057$

[a] Number of athletes wearing mouthguard (n = 4), not wearing mouthguard (n = 13)

[b] *p* = significance level

4.3.2.3 Descriptive Statistics of Activity Intensity and Duration by Athletes Videoed in the Exposure Pilot Study

Descriptive statistics for the number of seconds per hour the videographed football and soccer players spent in the three different activity levels (resting, low activity, or high activity) while playing on synthetic turf fields are presented in Appendix G for children and adults. These activity levels were defined for the video reviewers in section 3.5.2.5 and summarized as follows. Resting included rest and break periods or periods of extended coaching discussion. Low activity levels included stationary activities or conducting drills over intervals with instruction or waiting turns in between. High activity levels included constant or near constant running or, for football, continual 'plays'.

Activity Levels: Children (ages 7 – 14) - The results showed that both child soccer players and football players spent the least amount of time (seconds per hour) engaged in high-level activity while playing on the synthetic turf fields (710 ± 410 sec/hr and 500 ± 120 sec/hr, respectively; Appendix G). Child football players spent the greatest amount of time resting (1800 ± 370 sec/hr), followed by low-level activity (1300 ± 320 sec/hr). In contrast, child soccer players spent the most amount of time engaged in low-level activity (1900 ± 600 sec/hr) followed by resting (1000 ± 610 sec/hr; Appendix G). (It should be noted that these observations were made during sports practice activities; different levels of activity may be associated with games).

Activity Levels: Adults (over 18 years of age) - For the three adult soccer players, they spent the greatest amount of time engaged in low-level activity (1400 ± 37 sec/hr) followed by resting (1200 ± 320 sec/hr), while practicing on the synthetic turf field (Appendix G). (It should be noted that these observations were made during sports practice activities; different levels of activity may be associated with games).

Inferential Results for Athlete Activity Levels - Due to the small sample size and the consistent dispersion pattern, adults and children were combined (n = 17), and an ANOVA was run to determine if there were significant differences in the amount of time (in seconds) that the athletes spent engaged in the three different activity levels while playing soccer and football on the synthetic turf fields. The results showed that there was a significant difference in the amount of time spent (seconds/hour) among the three activity levels for the athletes playing both sports combined ($F(2,47) = 14.03$, $p < 0.001$; Figure 4-8). Tukey post-hoc analysis indicated that these athletes spent significantly less time in high-level activity (700 ± 370 sec/hr) compared to resting (1300 ± 590 sec/hr) and low-level activity (1600 ± 530 sec/hr; data not shown). However, there was no significant difference in the amount of time athletes spent resting and at low activity levels (Figure 4-8).

Using Welch's t-tests, the results showed, however, that there was a significant difference [$t(11.3) = 3.04$, $p = 0.011$] in the amount of time spent resting between soccer players (1100 ± 550 sec/hr) and football players (1800 ± 370 sec/hr). There were also significant differences [t(14.3) = 2.25, p = 0.040] in the amount of time engaged at the high activity level between soccer players (790 ± 400 sec/hr) and football players (500 ± 120 sec/hr; Table 4-24 and Figure 4-9). It is important to note that all of the participants were videoed while engaged in sports practice sessions. Activity levels and their durations may be different for game situations. These results are also based primarily on youth sports, with only a small number of adults.

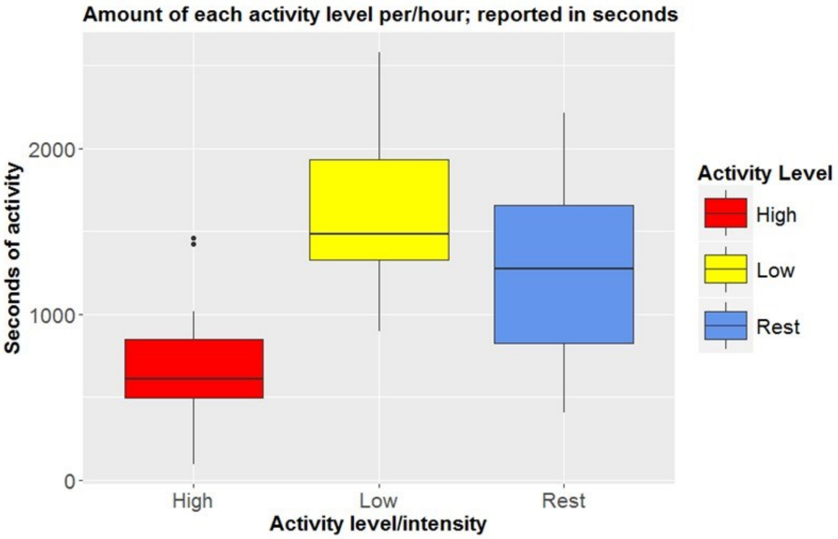

Figure 4-8. Box-and-whisker plots of the mean amount of time all athletes spent (seconds/hour) at the three different activity levels in Exposure Pilot Study videos (Phase 2).

Table 4-24. Welch's t-test Results for the Mean Amount of Time Athletes in Exposure Pilot Study Videos (Phase 2) Spent (Seconds/hour) in the Three Different Activity Levels, by Sport[a]

Activity Level	**Soccer Players - Seconds per Hour Spent at Activity Level (mean ± standard deviation)**	**Football Players - Seconds per Hour Spent at Activity Level (mean ± standard deviation)**	***t*-statistic**	***p*-value [b]**
Resting	1100 ± 550	1800 ± 370	*t*(11.3) = 3.04	*p* = 0.011
Low activity	1700 ± 560	1300 ± 320	*t*(13.0) = 1.86	*p* = 0.086
High activity	790 ± 400	500 ± 120	*t*(14.3) = 2.25	*p* = 0.040

[a] Number of athletes, Soccer (n = 12), Football (n = 5)

[b] p = significance level

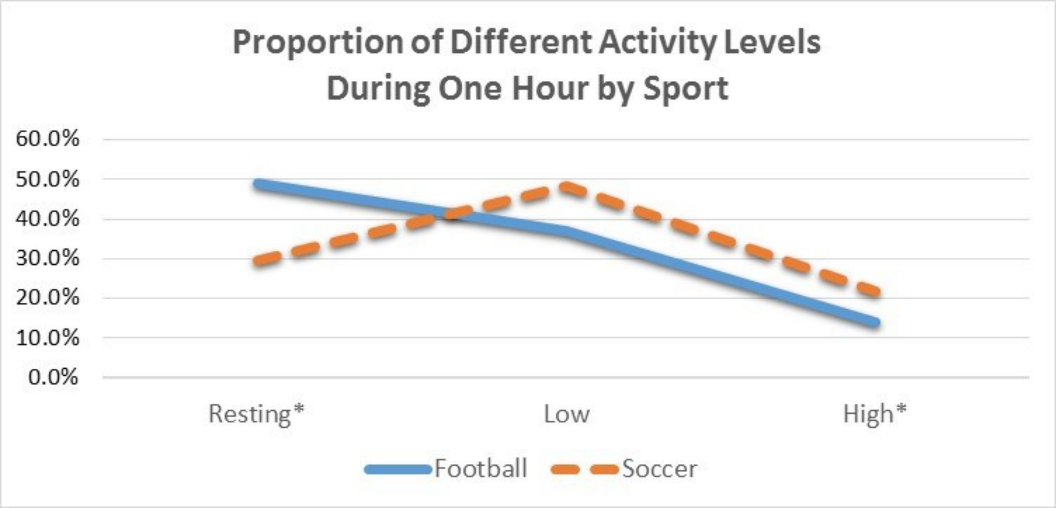

Figure 4-9. The proportion of time athletes in Exposure Pilot Study videos (Phase 2) spent participating at the three different activity levels in one hour, by sport. (*significant difference between sports, p<0.05)

Welch's t-tests were also performed to determine if there were differences in the three different activity levels by gender (8 females and 9 males). The results showed that there were not any significant differences in the amount of time for any activity level (resting, low activity, or high activity) between female athletes and male athletes (Table 4-25 and Figure 4-10).

Table 4-25. Welch's t-test Results for the Mean Amount of Time Athletes in Exposure Pilot Study Videos (Phase 2) Spent (Seconds/hour) at the Three Different Activity Levels, by Gender[a]

Activity Level	Female Players - Seconds per Hour Spent at Activity Level (mean ± standard deviation)	Male Players - Seconds per Hour Spent at Activity Level (mean ± standard deviation)	*t*-statistic	*p*-value [b]
Resting	1100 ± 620	1400 ± 540	*t*(14.1) = 1.24	*p* = 0.237
Low Activity	1800 ± 580	1500 ± 470	*t*(13.6) = 1.17	*p* = 0.264
High Activity	730 ± 430	680 ± 320	*t*(12.9) = .278	*p* = 0.786

[a] Number of athletes, Female (n = 8), Male (n = 9)

[b] p = significance level

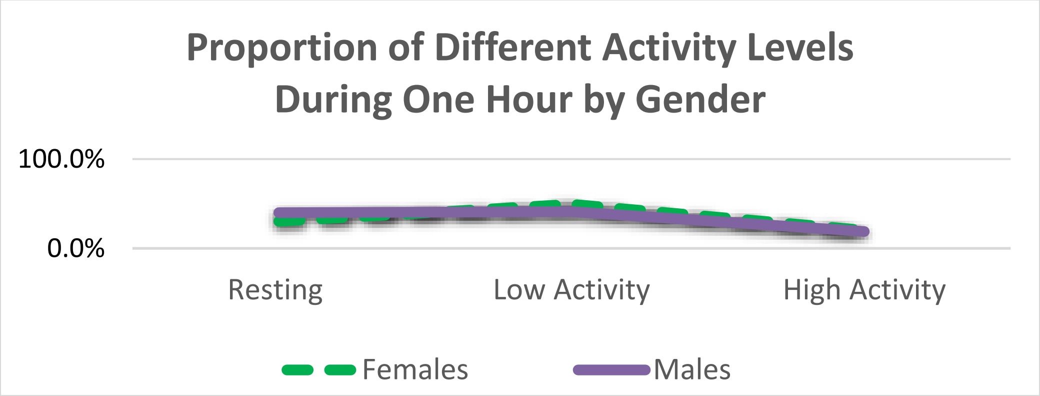

Figure 4-10. The proportion of time athletes in Exposure Pilot Study videos (Phase 2) spent participating at the three different activity levels, by gender.

4.4 Exposure Measurement Pilot Study Meta-Data Summaries

For the exposure pilot study, meta-data were collected around and during the field and participant measurements to provide information about conditions and activities that might affect or explain field and personal exposure measurement results. Meta-data types included weather conditions, field and surrounding area conditions, sport types, participant activities and clothing, and the overall activity levels at the study field and surrounding fields.

Table 4-26 provides an overview of the exposure measurement pilot study activities performed across two or more days at the three fields. At Outdoor Field 1, exposure pilot study participants were recruited from both soccer and football teams that used the field at different times of day. Air sampling at this field was performed during a soccer practice with study participants on one day and during a football practice with study participants on a second day. Air samples were also collected during youth soccer practice activities at another outdoor field (Outdoor Field 2) and at an indoor field (Indoor Field 1). In some cases, there was more than one practice group on the study field at a time; in these cases, the team or group with study participants typically used one half of the study field. Personal sampling, including personal air sampling and dermal wipe sampling, was performed with 25 of the athletes participating in the exposure pilot study. Field surface wipe, drag sled, and dust sample collections were performed at these fields when there were no athletic activities on the field.

Table 4-26. Exposure Pilot Study Field Measurement Overview

Pilot Study Activity	Outdoor Field 1 – Day 1	Outdoor Field 1 – Day 2	Outdoor Field 1 – Day 3	Outdoor Field 2 – Day 1	Outdoor Field 2 – Day 2	Outdoor Field 2 – Day 3	Outdoor Field 2 – Day 4	Outdoor Field 2 – Day 5	Indoor Field – Day 1	Indoor Field – Day 2
Field Air Sampling	Yes	Yes	No	Yes	No	No	No	No	No	Yes
Field Surface Wipe, Drag Sled and Dust Sampling	No	Yes	No	No	Yes	No	No	No	Yes	No
Participant Sport	Soccer	Football	Football	Soccer	N/A	Soccer	Soccer	Soccer	N/A	Soccer
Number of Practice Groups	1	2	2	1	0	2	2	2	0	1
Personal Sampling (Number of Athletes Sampled)	3	4	4	1	0	3	4	4	0	2

Emissions of some organic chemicals associated with tire crumb rubber infill are affected by temperature, with higher emissions at warmer temperatures, so attempts were made to perform field and personal exposure measurements during warm to hot and dry conditions. Wind speed affects the concentration of emitted chemicals above fields by affecting the rate at which the air above the field is replaced by air that has not been impacted by emissions from field materials. The amount of tire crumb rubber infill and field dust particles that athletes were exposed to could depend, in part, on the amount and types of activities occurring on the field; higher-level, more intense activities may lead to suspension of more particulates in the air around athletes.

This exposure pilot study was successful at obtaining measurements under conditions that likely represent the potential for higher inhalation exposures at each field – on days with warm to hot temperatures, dry conditions, and on most days, relatively low wind, with high-level activity occurring on the fields. Table 4-27 provides more detailed weather, field, and activity information for each day on which participant exposure measurement activities occurred. Air temperature, field surface temperature, and wind speed and direction were measured at the beginning, middle, and end of the exposure measurement period at each field and recorded. Maximum air temperatures 1 meter above the fields ranged from 23 to 35 °C. It was sunny or partly cloudy on each sampling day, and maximum field surface temperatures ranged from 28 to 42 °C. With exception of the first day, practices were conducted after school in the late afternoon and early evening, so the temperatures decreased rapidly after sundown. Wind speeds (1-minute average) ranged from 1.7 to 6.7 km/h for practices at the outdoor fields, with no wind present at the indoor field. Many athletes, coaches, and bystanders were present on or at the study fields during most study measurement periods. Most study periods also had moderate to high numbers of people using an adjacent synthetic turf field and, on some days, adjacent grass fields as well.

Table 4-27. Field Conditions and Overall Activities During Time Periods When Personal Exposure Measurement Sample Collection Activities Were Performed at Synthetic Turf Fields

Condition or Activity	Outdoor Field 1 – Day 1 –	Outdoor Field 1 – Day 2	Outdoor Field 1 – Day 3	Outdoor Field 2 – Day 1	Outdoor Field 2 – Day 3	Outdoor Field 2 – Day 4	Outdoor Field 2 – Day 5	Indoor Field – Day 2
Participant Sport on Study Field	Soccer	Football	Football	Soccer	Soccer	Soccer	Soccer	Soccer
Activity on Study Field	Practice	Practice	Practice	Practice	Practice	Practice	Practice	Practice
Field Air Sampling Performed	Yes	Yes	No	Yes	No	No	No	Yes
Average Field Air Temperature (°C at 1-m height)	32	24	22	30	20	22	25	27
Maximum Field Air Temperature (°C at 1-m height)	33	29	23	35	25	26	30	28
Minimum Field Air Temperature (°C at 1-m height)	32	21	21	24	14	15	21	26
Average Field Surface Temperature (°C)	36	25	24	31	20	25	26	28
Maximum Field Surface Temperature (°C)	39	33	28	42	29	34	34	29
Minimum Field Surface Temperature (°C)	32	20	20	23	14	14	20	27
Average 1-minute Average Wind Speed (km/h at 1-meter height)	5.7	3.1	6.7	1.7	1.9	3.4	3.8	0
Maximum 1-minute Wind Speed (km/h at 1-meter height)	14.1	6.5	12	1.8	3.7	5.6	3.8	0
Conditions[a]	D,S	D,S,C	D,P	D,S,C	D,S,C	D,S,C	D,S,P,C	D,S,C
Number of Athletes at Study Synthetic Turf Field	16 - 22	18 - 38	28 – 36	43 – 55	13 - 65	23 – 36	38 - 58	9 - 11
Number of Coaches and Bystanders at Study Synthetic Turf Field	3 - 18	9 - 13	14 – 22	5 – 24	9 - 19	5 – 35	20 - 32	14 - 16
Number of People at Adjacent Synthetic Turf Field(s)	0 - 26	0 - 28	18 – 32	63 – 72	7 - 45	25 – 30	32 - 48	0
Number of People at Adjacent Grass Field(s)	0	0 - 80	30 - 60	0 - 18	0 - 10	0 - 10	0 - 14	0

[a] D = dry field; S = sunny; C = clear after sundown; P = partly cloudy

Athlete exposures to chemicals associated with tire crumb rubber infill at synthetic turf fields may be influenced by the activity duration, activity types, frequency of contact with field materials, and the clothing and equipment the athletes wear. Higher activity levels may lead to higher inhalation of airborne chemicals and particles through increased rates of respiration. Higher activity levels can also lead to increased sweat production that may lead to increased adherence of field dust to the skin. Increased contact with field materials may lead to increased skin (dermal) exposures, as could higher amounts of exposed skin. Likewise, higher hand-to-field, hand-to-mouth, and object-to-mouth frequencies may lead to higher ingestion exposures.

Information on each of these metrics was collected for each participant during their study measurement period. With exception of athlete clothing and equipment, this information was collected and recorded at the start and end of the practice and at intervals of approximately 30 minutes during practice; this resulted in three to six observations over the duration of their on-field activities. Athlete clothing and equipment was observed and recorded once for each participant during the practice. Results for these metrics were summarized across the three sports and age groups and are shown in Tables 4-28 and 4-29.

Because these were practice sessions during summer conditions, all participants wore short-sleeved shirts and short pants, leaving exposed arm and skin surfaces (Table 4-28). A few soccer players wore goalie gloves for relatively short periods during practice. Although attempts were made to recruit full-time soccer goalies, none volunteered to participate in the study; this means that the study did not include the soccer position likely to experience the greatest field contact frequency. Football players were required to wear protective pads, helmets, and mouthguards during practice; several football players also wore gloves. With the use of mouthguards, football players had higher rates of object-to-mouth events (although these frequencies were only counted in the video data analysis).

Table 4-28. Summaries of Observed Participant Clothing and Safety Equipment in Exposure Pilot Study

Clothing/Safety Equipment Worn	% Soccer Players Age 11 – 21 (n = 11)	% Soccer Players Age 7 – 10 (n = 6)	% Football Players Age 13 – 14 (n = 8)
Short-sleeved shirt	100	100	100
Short pants	100	100	100
Socks – high	64	100	0
Socks – medium	36	0	63
Socks – low	0	0	37
Gloves	18	0	50
Helmet	0	0	100
Pads	0	0	100
Mouthguard	0	0	100

Practice durations ranged from approximately one hour for the youngest soccer player group to approximately 1.5 to 2 hours for other soccer and football groups (data not shown). The total time spent at/on the field ranged from 1 to 2.5 hours, when the times immediately before and after practices were included. Information on the type of activities, physical activity levels, and athlete contact with the surface of the synthetic turf field was collected for each athlete regularly throughout the duration of the practice (Table 4-29).

Table 4-29. Summaries of Observed Participant Activities in Exposure Pilot Study

Participants	Types of Participant Activities[a]	Number of Activity Observations per Person[b]	Total Number of Activity Observations	Estimated Activity Levels[c] (Average % of Total Activity Observations Across Participants)			Contact with Synthetic Turf Field Surface (Average % of Total Activity Observations Across Participants)							Estimated Frequency of Contact with Field Surface		
				High	**Medium**	**Low**	**Yes**	**No**	**Hand**	**Arm**	**Leg**	**Body**	**Face/Head**	**≥ 1/min**	**≥ 1/5min**	**< 1/5min**
Soccer Players Age 11 – 21 (n=11)	S,W,R,D,M	5 – 6	51	37	59	4	20	80	5	10	20	6	4	7	10	2
Soccer Players Age 7 – 10 (n=6)	D,M	3 – 5	23	35	56	9	7	93	7	0	7	0	0	3	0	3
Football Players Age 13 – 14 (n=8)	W,R,D,M	5 – 6	43	15	75	10	59	31	63	21	25	21	3	25	38	0

[a] S = stretching, on field; W = warmup activities; R = running, not as part of drills or scrimmage; D = practice drills; M = practice scrimmage

[b] Participant activities observed and recorded at start, end, and approximately every 30 minutes during sampling period; observation periods were approximately 5 minutes

[c] High activity level included constant movement (running or drills or for football, continual "plays"); medium activity level included intermittent movement (running or drills over intervals with instruction or waiting in between); low activity level included watching teammates, periods of extended coaching instruction or discussion, and rest or break periods

Participant activities during their sports practices included stretching; warm-up activities; running (not as part of drills or scrimmages); practice drills including ball-kicking exercises; sport skills drills and offensive and defensive team drills; and within-team practice scrimmages. Note that in this phase of the research project, activity levels were categorized as low, medium and high, rather than resting, low and high, as was done in the video assessments because the at-field observations typically did not include rest periods and water break times. On average, soccer players had longer durations of high-level physical activity compared to football players, although football players had higher frequencies of hand and body contact with the field than the soccer players (Table 4-29).

4.5 Exposure Pilot Study Measurement Results

In the exposure pilot study, several types of samples were collected – field environment samples, personal samples, and biological samples. Field environment samples included field and off-field (background) air samples, field surface wipe samples, drag sled samples, and dust samples collected from each field. Researchers used specified sampling locations (Figure 4-11), although air sampling locations varied with wind direction. Field air samples were analyzed for total suspended particulates, metals, VOCs and SVOCs; field surface wipe samples and dust samples were analyzed for metals and SVOCs, and drag sled samples were analyzed for SVOCs. Personal samples included personal air samples collected during the activity for VOC analysis and dermal wipe samples collected from the hand, arm and leg of each participant immediately after the sport practice and analyzed for metals and SVOCs. Urine and blood samples were collected before and after practices for a subset of participants. Urine samples were analyzed for select PAH metabolites, and blood samples were analyzed for select metals. The numbers and types of field environment, personal, biological, and quality control samples that were collected are shown in Table 4-30, and results of these analyses are presented in the following report sub-sections.

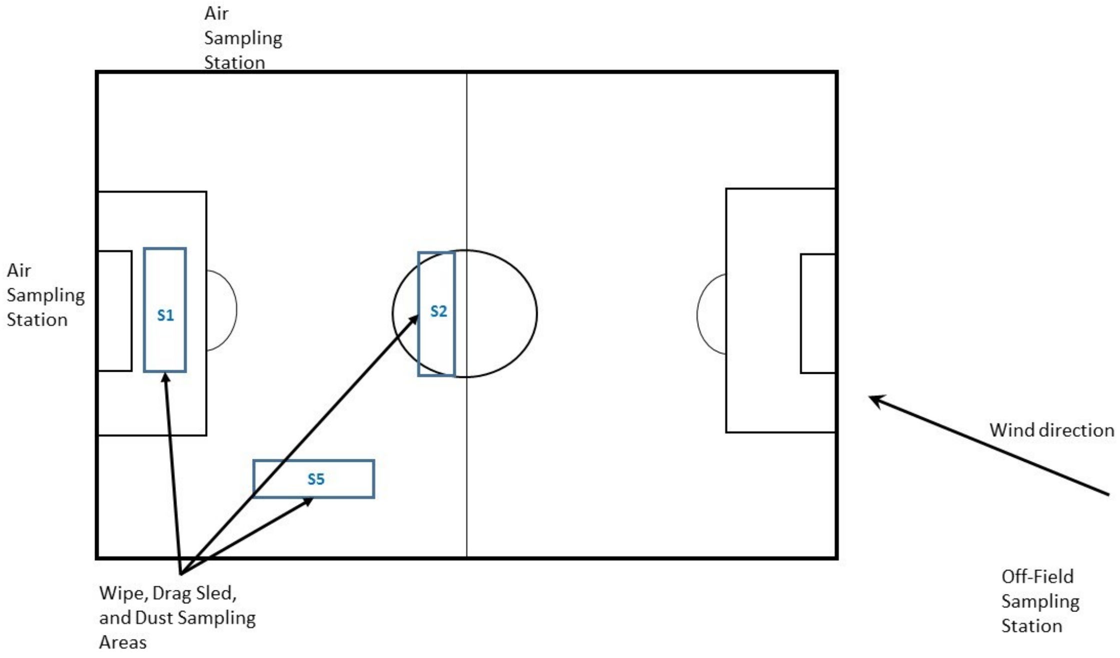

Figure 4-11. Sample collection locations of field air, field wipe, drag sled, and dust samples. Collection locations for air samplers was dependent on wind direction.

Table 4-30. Types and Numbers of Samples and Quality Control Samples for the Exposure Pilot Study

Sample Type	Analyte[a]	Number Samples	Number Duplicate Samples[b]	Number Field Blanks[b]	Number Field Controls[b]	Number Lab Blanks[b]	Number Lab Controls[b]
Field Air	PM	12	4	5	0	5	0
Field Air	Metals	12	4	5	0	5	0
Field Air	VOCs (active)	12	4	5	5	5	5
Field Air	VOCs (passive)	12	4	5	5	5	5
Field Air	SVOCs	12	4	5	5	5	5
Field Surface Wipe	Metals	9	3	4	4	4	4
Field Surface Wipe	SVOCs	9	3	4	4	4	4
Field Drag Sled	SVOCs	9	3	4	4	4	4
Field Dust	Metals	3	0	4	4	4	4
Field Dust	SVOCs	3	0	4	4	4	4
Personal	Air VOCs	24	0	0	0	0	0
Personal	Dermal Metals	75	0	5	5	5	5
Personal	Dermal SVOCs	75	0	5	5	5	5
Biological	Urine Pre-Activity	14	0	0	0	0	0
Biological	Urine Post-Activity	14	0	0	0	0	0
Biological	Blood Pre-Activity	13	0	0	0	0	0
Biological	Blood Post-Activity	11	0	0	0	0	0
	Totals	**319**	**29**	**55**	**45**	**55**	**45**

[a] PM = particulate matter; VOC = volatile organic compound; SVOC = semivolatile organic compound

[b] Quality control samples

4.5.1 Field Environment Sample Measurements

4.5.1.1 Field Air Samples

Air samples were collected to assess the potential for inhalation exposures for athletes during sports activities at synthetic turf fields. Field air samples were collected during four sport practices conducted at three synthetic turf fields. Air temperatures were warm to hot during the air sample collection on all four field air sample collection days. As noted in section 4.2.4, samples were collected on two different days at Outdoor Field 1 during soccer and football practices and on one day at Outdoor Field 2 and an indoor field, both during soccer practices. Field air samples were collected at two locations that were next to the field, in downwind positions (for the outdoor fields), and at another (off-field) location that was upwind and further away from the field for samples representative of the background, or ambient, air that was entering the field area.

At Outdoor Field 1, there were no obvious large pollutant sources in the immediate upwind vicinity of the fields. On the first day of air sampling (i.e., during the soccer practice), the wind came from a direction that brought it across both an adjacent synthetic turf field, as well as the field where study activities were performed. On the second day (i.e., during the football practice), the wind was coming from a direction that did not come over the adjacent field.

At Outdoor Field 2, there was a six-lane road with very heavy traffic upwind of the facility. The facility had two synthetic turf fields and participants spent time on both fields during the practice session. On the air sampling day, the wind brought air across the road, across one synthetic turf field, and then across the second synthetic turf field. The background samples were collected at a position downwind from the road and upwind from the synthetic turf fields. One set of field samples was collected downwind from the first synthetic turf field and upwind from the second synthetic turf field. The second field sample set was collected on the downwind side of the second field, at a location receiving air that had come across both synthetic turf fields at the facility.

At the indoor field, the background samples were collected at a position outside of the field facility. This background position may have been affected by road dust from a nearby gravel driveway. The field samples were collected inside the facility and immediately next to the field, on opposite sides of the field. A large gable mounted fan and open doors provided some ventilation in the facility during the soccer practice session.

Particulate Matter - The Teflo membrane disk filters from the two field air samplers and one upwind (off-field) background air sampler at each field were analyzed for total suspended particulate (TSP). Air TSP measurement results are shown in Table 4-31. Typically, the TSP concentrations for samples collected at the fields were not higher than the concentrations measured in the (off-field) background samples. The background sample collected outside of the indoor facility was not included in the average, however, because it was apparently impacted by dust from a nearby gravel drive.

Table 4-31. Exposure Pilot Study Field Air Sampling Total Suspended Particulate (TSP) Measurements [a]

Field Air Sample Location	Number Samples	TSP Median (μg/m^3)	TSP Mean (μg/m^3)	TSP Std. Dev. (μg/m^3)	TSP Maximum (μg/m^3)
Field – Location 1	4	28	39	30	83
Field – Location 2	4	26	29	16	50
Off-field/Background[b]	3[b]	32	30	19	49

[a] Average results for samples collected at three exposure pilot study synthetic turf fields. At each field, two air samples were collected at the field and one air sample was collected at an upwind (off-field) location to represent background air. Samples were collected on two different days at one field, resulting in a total of four sets of air samples.

[b] The background sample measurement from the indoor field was not included, because it was contaminated by road dust.

Metals - The Teflo membrane disk filters from the two field air samplers and one upwind (off-field) background air sampler at each field were also analyzed for metals. Air metals measurement results are shown in Table 4-32. Beryllium and selenium were not measured above the minimum reporting limit in any sample. Except for arsenic, cadmium, cobalt and rubidium, all metals were measured above the minimum reporting limits (MRL) in 100% of the samples. For most metals, the median concentrations in the samples collected at the two field locations were not substantially different than concentrations measured in the background samples. However, maximum concentrations were substantially higher than background levels for many metals. Air concentrations of many metal analytes associated with tire crumb rubber were higher in the indoor field facility compared to the outdoor field and background levels.

Table 4-32. Exposure Pilot Study Field Air Sampling Metals Measurements[a]

Metal	> Minimum Reporting Limit (%)	Background Air Sample Median (ng/m^3)	Field Air Sample Location 1 Median (ng/m^3)	Field Air Sample Location 2 Median (ng/m^3)	Field Air Sample Max (ng/m^3)
Arsenic	50	0.44	0.46	0.36	0.76
Cadmium	75	0.054	0.017	0.066	0.25
Chromium	100	3.5	3.8	3.4	6.7
Cobalt[b]	33	0.69	0.21	0.19	2.5
Lead	100	1.8	2.0	2.2	3.9
Zinc	100	30	100	19	640
Aluminum	100	420	330	180	1000
Antimony	100	0.74	0.61	0.95	7.0
Barium	100	12	13	7.5	62
Copper	100	20	7.0	10	51
Iron	100	750	490	340	870
Magnesium	100	160	110	100	510
Manganese	100	27	13	9.8	27
Molybdenum	100	0.16	0.17	0.17	0.89
Nickel	100	0.58	1.5	1.1	15
Rubidium[b]	25	0.57	0.27	0.23	1.8
Strontium	100	3.5	2.7	2.2	6
Tin	100	0.64	0.84	0.97	4.9
Vanadium	100	1.3	0.88	0.70	1.5

[a] Median and maximum results for samples collected at the three exposure pilot study synthetic turf fields. At each field, two air samples were collected at the field and one air sample was collected at an upwind (off-field) location to represent background air. Samples were collected on two different days at one field, resulting in a total of four sets of air samples. Median results were calculated using all measurements from the outdoor fields and indoor field.

[b] Although cobalt and rubidium had < 50% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the MRLs, were used in the calculation of median values.

Air concentration results are shown for cobalt, lead, and zinc in Figure 4-12. The background results for Field 3 are not shown due to likely contamination with road dust. The background zinc concentration at Field 2 was slightly below zero after field blank subtraction. The figure illustrates the higher levels measured at the indoor field compared to the outdoor fields for cobalt and zinc. The concentrations of lead in air at Field 2 may have been impacted by the proximity to heavy traffic that was present upwind of the field during the sampling period.

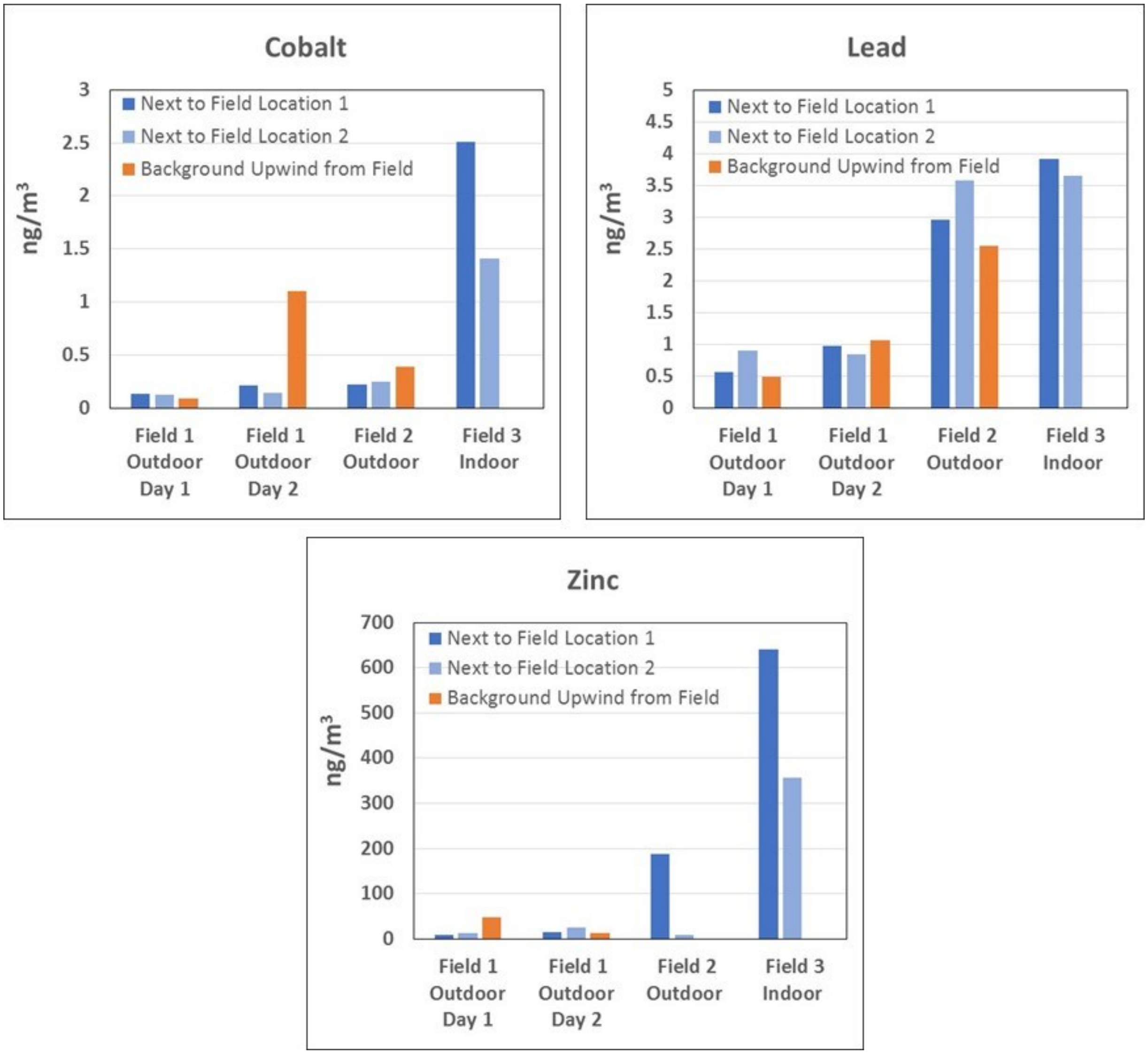

Figure 4-12. Concentrations of cobalt, lead, and zinc in air samples collected next to fields and at upwind background sample collection locations.

SVOCs - The polyurethane foam (PUF) filters from the two field air samplers and one upwind (off-field) background air sampler at each field were analyzed for SVOCs. Air SVOC measurement results are shown in Table 4-37. Seventeen (17) of the 35 SVOC analytes reported in Table 4-33 were measured above the minimum quantifiable limits (MQL) in 100% of the samples. Measurement results below the MQL were included in calculation of median results. Some negative values are reported as a result of field blank subtractions. Several analytes are not included in Table 4-33 due to low recoveries in field control samples, including aniline, naphthalene, n-butylbenzene, 2-bromomethylnaphthalene, and bis(2,2,6,6-tetramethyl-4-piperidyl) sebacate.

Several PAHs, benzothiazole, 4-tert-octylphenol, and bis(2-ethylhexyl) phthalate had median concentrations in field samples that were higher than concentrations measured in background samples. Concentrations of the 5- and 6-ring PAHs that are only present in air as part of air particulates (benzo[a]pyrene, benzo[ghi]perylene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, dibenz[a,h]anthracene, and indeno(1,2,3-cd)pyrene) were very low to not measurable (Table 4-33). For many SVOCs, maximum concentrations were substantially higher than background levels. Air concentrations of most SVOC analytes were higher in the indoor field facility compared to the outdoor fields and background levels (data not shown); this was a factor in median field concentrations being higher than median background concentrations.

Table 4-33. Exposure Pilot Study Field Air Sampling SVOC Measurements[a,b,c]

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Background Air Sample Median (ng/m^3)	Field Air Sample Location 1 Median (ng/m^3)	Field Air Sample Location 2 Median (ng/m^3)	Field Air Sample Max (ng/m^3)
Phenanthrene	100	2.0	4.5	5.7	35
Fluoranthene	100	0.37	0.90	1.3	9.9
Pyrene	17	0.15	0.54	0.89	15
Benzo[a]pyrene	0	0	0	0	0.030
Benzo[ghi]perylene	33	0.013	0	0	0.23
Sum15PAH[d]	N/A[e]	3.2	8.4	10	70
Benzothiazole	100	-3.9	6.5	15	214
Dibutyl phthalate	100	12	7.4	19	102
Bis(2-ethylhexyl) phthalate	100	7.5	15	11	77
4-tert-octylphenol	100	1.7	5.4	11	68
n-Hexadecane	100	-0.13	-14	-5.5	14
1-Methylnaphthalene	100	-0.16	-0.0965	-0.11	0.70
2-Methylnaphthalene	100	-0.46	-0.25	-0.34	0.58
Acenaphthylene	58	-0.013	0.19	0.16	0.46
Fluorene	100	0.98	2.1	1.9	4.6
Anthracene	17	0.059	0.053	0.30	4.7
1-Methylphenanthrene	92	0.12	0.45	0.57	6.8
2-Methylphenanthrene	25	0.16	0.64	0.74	7.0
3-Methylphenanthrene	83	0.21	0.81	0.94	8.9
Benz[a]anthracene	0	0.022	0.013	0.015	0.18
Chrysene	17	0.013	0.034	0.047	0.26
Benzo(b)fluoranthene	0	0	0	0	0.29
Benzo(k)fluoranthene	0	0	0	0	0
Benzo(e)pyrene	0	0.022	0	0.015	0.21
DBA + ICDP	0	0	0	0	0
Coronene	0	0	0	0	0.26
Dibenzothiophene	100	0.26	0.44	0.52	6.1
Dimethyl phthalate	100	0.43	0.40	0.32	1.4
Diethyl phthalate	100	-11	-3.2	3.0	38
Benzyl butyl phthalate	100	6.4	4.8	11	75
Di-n-octyl phthalate	42	0.46	-0.58	-0.41	7.9
2,6-Di-tert-butyl-p-cresol	100	0.93	0.31	-0.003	10
Cyclohexylisothiocyanate	0	0	0	0	0

[a] Median and maximum results for samples collected at the three exposure pilot study synthetic turf fields. At each field, two air samples were collected at the field and one air sample was collected at an upwind (off-field) location to represent background air. Samples were collected on two different days at one field, resulting in a total of four sets of air samples. Median results were calculated using all measurements from the outdoor fields and indoor field.

[b] Although several chemicals had < 50% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of

median values.

[c] Several results are reported as negative values. This is a result of the subtraction of field blank values from the sample measurement results. Although this does not represent a physical reality, the negative results are retained as part of the distribution of corrected results.

[d] Sum15PAH = Sum of 15 of the 16 EPA 'priority' PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

[e] N/A = not applicable

[f] DBA + ICDP = Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene

Air concentration results are shown for several SVOCs in Figure 4-13. Values that appear to be missing are near or slightly below zero after field blank subtraction. The figure illustrates the higher levels measured at the indoor fields compared to the outdoor fields for these SVOC analytes. Except for dibutyl phthalate, the concentrations next to the outdoor fields were slightly higher than those measured at the upwind background location for these analytes. The concentrations of several analytes at Field 2 may have been impacted by the proximity to heavy traffic that was present upwind of the field during the sampling period.

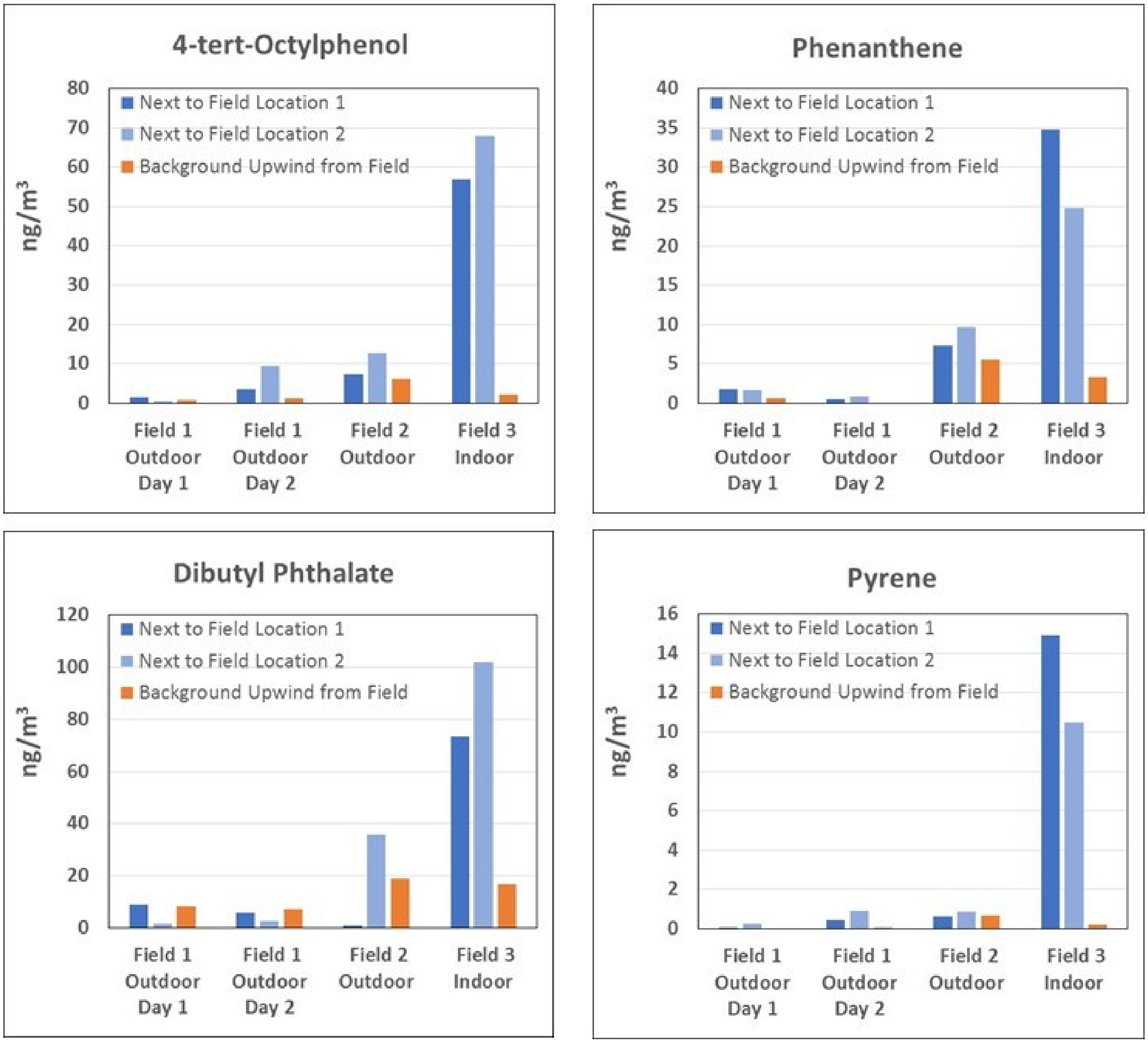

Figure 4-13. Concentrations of several SVOCs in air samples collected next to fields and at

upwind background sample collection locations.

VOCs - The Carbopack™ X FLM sorbent tube samples from the two field air samplers and one upwind (off-field) background air sampler at each field were analyzed for VOCs. Air VOC measurement results are shown in Table 4-34. For seventeen (17) of the 29 SVOC analytes reported in Table 4-34, 100% of the measurements had results above the method detection limits. Measurement results below the method limit of detection were included in calculation of median and maximum results. Some negative values are reported as a result of field blank subtractions. Methyl isobutyl ketone and benzothiazole, found to be associated with tire crumb rubber in the chamber emission experiments, had median concentrations in next-to-field samples that were consistently higher than concentrations measured in background samples. Air concentrations of methyl isobutyl ketone and benzothiazole were higher in the indoor field facility compared to outdoor field and background levels. Several VOCs, including the BTEX compounds and styrene, had their highest levels at the outdoor field that was potentially impacted by traffic pollutants.

Table 4-34. Exposure Pilot Study Field Air Sampling VOC Measurements[a,b]

Volatile Organic Compound (VOC)	> Method Detection Limit (%)	Background Air Sample Median (ng/m^3)	Field Air Sample Location 1 Median (ng/m^3)	Field Air Sample Location 2 Median (ng/m^3)	Field Air Sample Max (ng/m^3)
Methyl isobutyl ketone	83	160	430	820	1900
Benzothiazole	17	41	69	96	1600
1,3-Butadiene	100	24	28	13	50
Styrene	100	92	92	200	670
Benzene	100	500	400	360	590
Toluene	100	2100	1400	1300	5300
Ethylbenzene	100	200	160	170	740
m/p-Xylene	100	650	500	510	2400
o-Xylene	100	150	140	190	520
SumBTEX[c]	N/A[d]	3700	2700	2500	9500
trans-2-Butene	100	14	17	9.8	31
cis-2-Butene	100	12	15	10	33
4-Ethyltoluene	75	42	42	40	52
1,3,5-Trimethylbenzene	83	24	22	25	45
1,1-Dichloroethene	0	0.72	13	6.7	17
1,1-Dichloroethane	58	9.8	11	20	23
cis-1,2-Dichloroethene	0	0	0	0	0
1,2-Dichloroethane	67	26	55	60	95
1,1,1-Trichloroethane	50	43	43	42	59
Carbon tetrachloride	100	720	760	730	1200
1,2-Dichloropropane	0	0	0	0	0
Trichloroethylene	0	12	13	12	41
Tetrachloroethylene	100	53	52	64	150
Chlorobenzene	100	20	22	22	37
m-Dichlorobenzene	75	10	23	11	30
p-Dichlorobenzene	100	30	32	31	34
o-Dichlorobenzene	100	1.8	5.0	2.3	23

Table 4-34. Continued

Volatile Organic Compound (VOC)	> Method Detection Limit (%)	Background Air Sample Median (ng/m^3)	Field Air Sample Location 1 Median (ng/m^3)	Field Air Sample Location 2 Median (ng/m^3)	Field Air Sample Max (ng/m^3)
Trichlorofluoromethane (Freon™ 11)	100	1300	1300	1300	1400
Dichlorodifluoromethane (Freon™ 12)	100	330	340	370	520
1,1,2-Trichlorotrifluoroethane (Freon™ 113)	100	570	560	540	620

[a] Median and maximum results for samples collected at the three exposure pilot study synthetic turf fields. At each field, two air samples were collected at the field and one air sample was collected at an upwind (off-field) location to represent background air. Samples were collected on two different days at one field, resulting in a total of four sets of air samples. Median results were calculated using all measurements from the outdoor fields and indoor field.

[b] Although several chemicals had ≤50% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of median values.

[c] SumBTEX = Sum of benzene, toluene, ethylbenzene, m/p-xylene, and o-xylene

[d] N/A = not applicable

Air concentration results are shown for methyl isobutyl ketone, benzothiazole, benzene, and styrene in Figure 4-14. The background value that appears to be missing for methyl isobutyl ketone at Field 1 is near zero. The figure illustrates the higher levels measured at the indoor fields compared to the outdoor fields for methyl isobutyl ketone and benzothiazole, two analytes associated with tire crumb rubber. Levels of these two chemicals were higher at the next to field locations as compared to the background locations at all fields. Benzene illustrates that for the BTEX chemicals the levels at the indoor and outdoor fields are not different and appear to be related to the concentrations in ambient air. The concentrations of several analytes at Field 2 may have been impacted by the proximity to heavy traffic that was present upwind of the field during the sampling period.

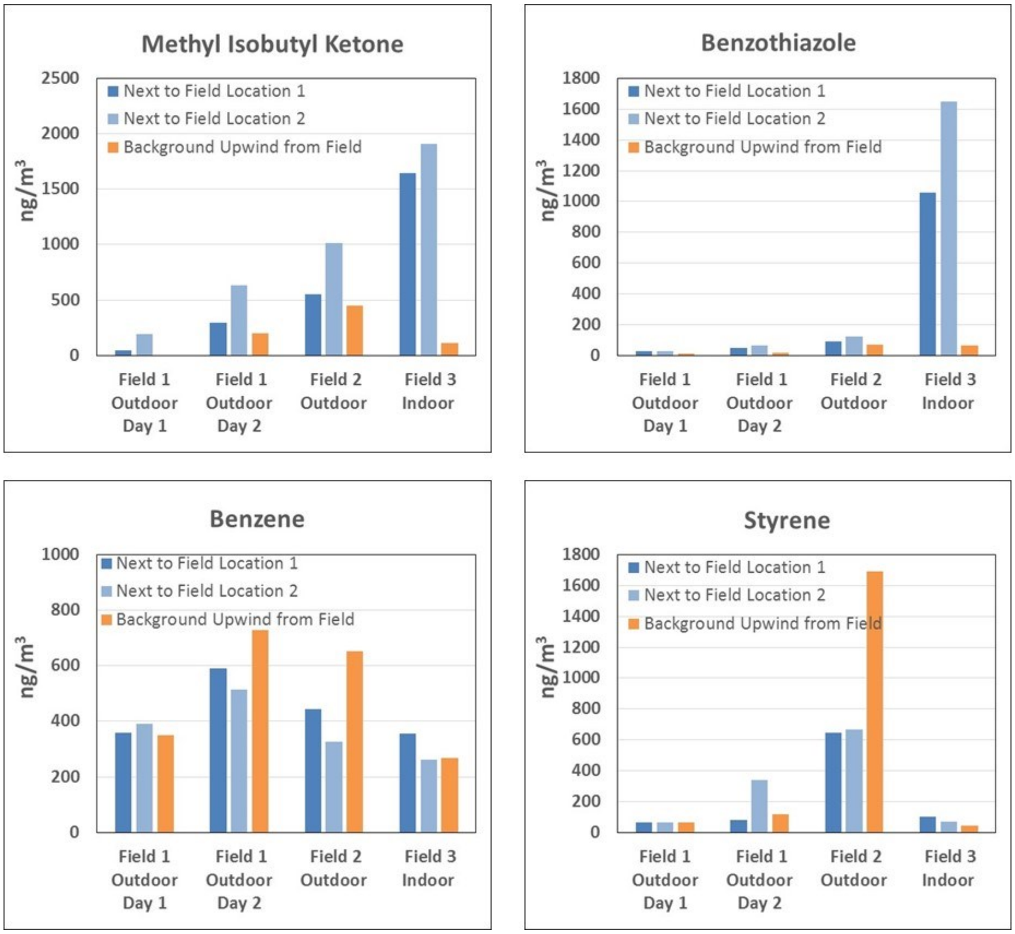

Figure 4-14. Concentrations of methyl isobutyl ketone, benzothiazole, benzene, and styrene in air samples collected next to fields and at upwind background sample collection locations.

4.5.1.2 Field Surface Wipe, Drag Sled and Dust Samples

Field surface wipe and drag sled samples were collected to measure chemicals that may be transferrable from synthetic turf field surfaces to athletes' skin during sport activities. Field dust was collected to provide information about a medium that may be important for inhalation, dermal, and ingestion exposures. Samples were collected at the three synthetic turf fields when it was safe to do so without posing an obstruction or safety hazard for any activities occurring on the field. Separate surface wipe, drag sled, and dust samples were collected at three locations on the field (Figure 4-11). Dust samples were collected from the three locations at each field and were composited at the field to provide sufficient mass for metal and SVOC analyses.

Metals in Field Dust Samples - The composited dust samples from each field were analyzed for metals. Field dust metals measurement results are shown in Table 4-35. It should be noted that because the dust samples were collected with stainless-steel sieves, contributions of stainless steel metal components to the measured sample concentrations cannot be ruled out. Selenium was not measured above the minimum reporting limit in any sample. Except for tin and vanadium, the remaining metals were measured above their minimum reporting limits in at least two of the three field dust samples. Average concentrations for zinc and cobalt, two tire material constituents based on previous tire crumb rubber characterization, were measured at 9400 mg/kg and 45 mg/kg, respectively. Average lead and chromium concentrations were 38 mg/kg and 13 mg/kg, respectively. Cadmium and arsenic were measured at average concentrations that were ≤ 0.5 mg/kg. Other metals commonly found in crustal particles (i.e., soil and other matter from Earth's crust), including aluminum, iron, and magnesium, were measured at average levels ≥ 1700 mg/kg.

Table 4-35. Exposure Pilot Study Field Dust Sampling Metals Measurements[a,b]

Metal	> Minimum Reporting Limit (%)	Field Dust Sample Mean (mg/kg)	Field Dust Sample Standard Deviation (mg/kg)	Field Dust Sample Maximum (mg/kg)
Arsenic	67	0.50	0.95	1.1
Cadmium	67	0.044	0.61	0.42
Chromium[c]	67	13	3.7	15
Cobalt	100	45	2.3	48
Lead	67	38	11	50
Zinc	100	9400	2900	11000
Aluminum	100	4700	400	5100
Antimony	67	1.9	0.58	2.3
Barium	67	93	14	108
Beryllium	67	0.14	0.056	0.20
Copper	100	140	87	210
Iron[c]	100	7700	3400	12000
Magnesium	100	1700	580	2300
Manganese[c]	100	170	30	200
Molybdenum[c]	67	0.99	0.25	1.3
Nickel[c]	100	8.9	2.9	11
Rubidium	100	10	5.2	13
Strontium	100	26	8.5	33
Tin	33	1.8	1.5	3.5
Vanadium	33	7.4	2.9	11

[a] Results from samples collected across the three exposure pilot study synthetic turf fields. At each field, dust was collected from three on-field locations (Figure 4-24, locations S1, S2 and S5) and combined to create a single composite sample for the field.

[b] Although two chemicals had <67% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of mean values.

[c] These metals may be components of stainless steel 316; a stainless-steel sieve was used for sample collection.

Metals in Field Surface Wipe Samples - Field surface wipe samples collected using Ghost wipe sample media pre-wetted with water were analyzed for metals. Metals measurement results from field surface wipe samples are shown in Table 4-36. Selenium was not measured above the minimum reporting limit in any sample. The remaining metals were measured at concentrations above the minimum reporting limit in 100% of the samples. Average surface loading values for zinc and cobalt ranged from 93 to 170 ng/cm^2 and from 0.4 to 1.4 ng/cm^2, respectively. Ranges of average lead and chromium concentrations were 0.3 to 3.4 ng/cm^2 and 0.25 to 1.1 ng/cm^2, respectively. Cadmium and arsenic were measured at average surface loadings that were ≤ 0.021 ng/cm^2. Other metals commonly found in crustal particles, including aluminum, iron, and magnesium, were found at average surface loading levels that were > 20 ng/cm^2.

Table 4-36. Exposure Pilot Study Field Surface Wipe Sampling Metals Measurements[a]

Metal	> Minimum Reporting Limit (%)	Field Surface Wipe Sample – Location S1 Mean (ng/cm^2)	Field Surface Wipe Sample – Location S2 Mean (ng/cm^2)	Field Surface Wipe Sample – Location S5 Mean (ng/cm^2)	Field Surface Wipe Sample Maximum (ng/cm^2)
Arsenic	100	0.012	0.015	0.021	0.033
Cadmium	100	0.0044	0.0068	0.0070	0.015
Chromium	100	0.25	0.50	1.1	2.6
Cobalt	100	0.64	1.4	0.40	2.2
Lead	100	0.31	1.4	3.4	9.5
Zinc	100	93	130	170	360
Aluminum	100	130	110	120	190
Antimony	100	0.051	0.098	0.19	0.42
Barium	100	1.5	1.3	1.4	1.8
Beryllium	100	0.00051	0.0005	-0.00007	0.0023
Copper	100	0.92	0.78	1.1	2.1
Iron	100	150	130	190	270
Magnesium	100	24	22	25	37
Manganese	100	2.2	1.8	2.0	3.5
Molybdenum	100	0.027	0.029	0.038	0.069
Nickel	100	0.12	0.13	0.17	0.27
Rubidium	100	0.17	0.15	0.15	0.24
Strontium	100	0.40	0.35	0.40	0.63
Tin	100	0.58	0.34	0.072	1.7
Vanadium	100	0.37	0.29	0.26	0.71

[a] Average results from samples collected across the three exposure pilot study synthetic turf fields. Each set of field measurements had wipe samples collected at three on-field locations (Figure 4-24, locations S1, S2 and S5).

SVOCs in Field Dust Samples - The composited dust samples from each field were analyzed for SVOCs. Field dust SVOC measurement results are shown in Table 4-37. Of the 35 target SVOC analytes reported in Table 4-37, 29 were measured above the minimum quantifiable limit in 100% of the samples. 2-methlnaphthylene was not measured above the method detection limit in any samples. Aniline, napthalene, n-butylbenzene, cyclohexylisothiocyanate, 2-bromomethylnaphthalene, bis(2-ethylhexyl) adipate, and bis(2,2,6,6-tetramethyl-4piperidyl) sebacate measurement results were not reported due to poor performance in one or more quality control sample type.

Average concentrations ranged from 0.006 mg/kg for 1-methlynaphthalene to 24 mg/kg for bis(2-ethylhexyl) phthalate. The average mean sum of 15 PAHs was 19 mg/kg. Averaged benzothiazole and 2-hydroxybenzothiazole mean concentrations were 4.3 mg/kg and 9.4 mg/kg, respectively.

Table 4-37. Exposure Pilot Study Field Dust Sampling SVOC Measurements[a,b]

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Field Dust Sample Mean (mg/kg)	Field Dust Sample Standard Deviation (mg/kg)	Field Dust Sample Maximum (mg/kg)
Phenanthrene	100	0.85	0.61	1.2
Fluoranthene	100	2.2	1.4	3.5
Pyrene	100	5.5	3.4	8.1

Table 4-37. Continued

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Field Dust Sample Mean (mg/kg)	Field Dust Sample Standard Deviation (mg/kg)	Field Dust Sample Maximum (mg/kg)
Benzo[a]pyrene	100	0.71	0.36	1.1
Benzo[ghi]perylene	100	3.7	0.97	4.8
Sum15PAH[c]	N/A[d]	19	9.9	29
Benzothiazole	100	4.3	1.5	5.9
2-Hydroxybenzothiazole	100	9.4	6.6	14
Dibutyl phthalate	67	0.33	0.46	0.86
Bis(2-ethylhexyl) phthalate	100	24	16	43
4-tert-octylphenol	100	5.2	4.1	8.6
n-Hexadecane	100	0.14	0.22	0.40
1-Methylnaphthalene	100	0.0063	0.0025	0.0086
2-Methylnaphthalene	0	0.014	0.0061	0.020
Acenaphthylene	100	0.012	0.0038	0.016
Fluorene	100	0.034	0.024	0.050
Anthracene	100	0.15	0.10	0.25
1-Methylphenanthrene	100	0.52	0.39	0.83
2-Methylphenanthrene	100	0.63	0.48	1.0
3-Methylphenanthrene	100	0.71	0.55	1.2
Benz[a]anthracene	100	0.38	0.27	0.67
Chrysene	100	3.0	1.9	5.1
Benzo(b)fluoranthene	100	1.4	1.0	2.6
Benzo(k)fluoranthene	100	0.32	0.24	0.60
Benzo(e)pyrene	100	1.5	0.48	2.0
DBA + ICDP[e]	100	0.65	0.34	1.0
Coronene	100	1.9	0.45	2.4
Dibenzothiophene	100	0.10	0.080	0.17
Dimethyl phthalate	67	0.029	0.046	0.082
Diethyl phthalate	33	0.10	0.13	0.25
Diisobutyl phthalate	100	0.29	0.34	0.66
Benzyl butyl phthalate	100	15	24	43
Di-n-octyl phthalate	67	0.14	0.12	0.23
2,6-Di-tert-butyl-p-cresol	100	0.11	0.063	0.15

[a] Results from samples collected across the three exposure pilot study synthetic turf fields. At each field, dust was collected from three on-field locations (Figure 4-11, locations S1, S2 and S5) and combined to create a single composite sample for the field.

[b] Although several chemicals had ≤67% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of mean values.

[c] Sum15PAH = Sum of 15 of the 16 EPA 'priority' PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

[d] N/A = not applicable

[e] DBA + ICDP = Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene

SVOCs in Field Surface Wipe Samples - The field surface wipe samples collected using wipe sample media pre-wetted with isopropanol were analyzed for SVOCs. Field surface wipe SVOC measurement results are shown in Table 4-38. Of the 31 target SVOC analytes reported in Table 4-38, 17 were measured above the minimum quantifiable limit in 100% of the samples. Some negative values are reported as a result of field blank subtractions. Measurement results below the minimum quantifiable limit were included in calculation of average results. Aniline, n-butylbenzene, diethyl phthalate, n-hexadecane, 2-bromomethylnaphthalene, 2-hydroxybenzothiazole, diisobutyl phthalate, dibutyl phthalate, benzyl butyl phthalate, and bis(2,2,6,6-tetramethyl-4piperidyl) sebacate measurement results were not reported due to poor performance in one or more quality control sample type.

Average surface loading values ranged from 0.12 to 0.20 ng/cm^2 for benzothiazole, 0.13 to 0.18 ng/cm^2 for bis(2-ethylhexyl) phthalate, 0.08 to 0.12 ng/cm^2 for 4-tert-octylphenol, and 0.08 to 0.11 ng/cm^2 for the sum of 15 PAHs. Most other SVOC analytes had average surface loading values that were < 0.03 ng/cm^2.

Table 4-38. Exposure Pilot Study Field Surface Wipe Sampling SVOC Measurements[a,b]

Semivolatile Organic Compound (SVOC)	**> Minimum Quantifiable Limit (%)**	**Surface Wipe Sample – Location S1 Mean (ng/cm^2)**	**Surface Wipe Sample – Location S2 Mean (ng/cm^2)**	**Surface Wipe Sample – Location S5 Mean (ng/cm^2)**	**Surface Wipe Sample Maximum (ng/cm^2)**
Phenanthrene	89	0.0050	0.0059	0.0037	0.0098
Fluoranthene	100	0.014	0.015	0.011	0.024
Pyrene	100	0.028	0.034	0.023	0.064
Benzo[a]pyrene	78	0.0039	0.0049	0.0029	0.0086
Benzo[ghi]perylene	100	0.019	0.020	0.015	0.033
Sum15PAH[c]	N/A[d]	0.099	0.11	0.078	0.19
Benzothiazole	100	0.16	0.20	0.12	0.26
Bis(2-ethylhexyl) phthalate	100	0.18	0.15	0.13	0.28
4-tert-octylphenol	100	0.12	0.12	0.079	0.30
Naphthalene	0	0.00002	0	0	0.00006
1-Methylnaphthalene	100	0.00035	0.00076	0.00058	0.0010
2-Methylnaphthalene	0	0.00059	0.0015	0.0011	0.0017
Acenaphthylene	67	0.00035	0.00031	0.0001	0.00064
Fluorene	89	0.00008	0.00017	0.00003	0.00032
Anthracene	100	0.00057	0.00083	0.0004	0.00155
1-Methylphenanthrene	100	0.0032	0.0039	0.0029	0.0077
2-Methylphenanthrene	67	0.0031	0.0039	0.0024	0.0061
3-Methylphenanthrene	100	0.0034	0.0043	0.0029	0.0069
Benz[a]anthracene	89	0.0023	0.0034	0.0019	0.0063
Chrysene	100	0.017	0.018	0.013	0.027
Benzo(b)fluoranthene	100	0.0046	0.0054	0.0035	0.0091
Benzo(k)fluoranthene	67	0.0011	0.0012	0.00096	0.0021
Benzo(e)pyrene	100	0.0061	0.0069	0.0049	0.011
DBA + ICDP[e]	89	0.0026	0.0031	0.0022	0.0057
Coronene	100	0.015	0.016	0.011	0.029
Dibenzothiophene	78	0.00022	0.00039	0.00015	0.00097
Dimethyl phthalate	33	0.00034	0.00016	0.00009	0.00089

Table 4-38. Continued

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Surface Wipe Sample – Location S1 Mean (ng/cm2)	Surface Wipe Sample – Location S2 Mean (ng/cm2)	Surface Wipe Sample – Location S5 Mean (ng/cm2)	Surface Wipe Sample Maximum (ng/cm2)
Di-n-octyl phthalate	100	0.0018	0.0028	-0.0017	0.0071
2,6-Di-tert-butyl-p-cresol	100	0.0061	0.010	0.0097	0.023
Cyclohexylisothiocyanate	56	0.035	-0.018	-0.012	0.059
bis(2-Ethylhexyl) adipate	100	0.057	0.031	0.018	0.095

[a] Average results from samples collected across the three exposure pilot study synthetic turf fields. Each set of field measurements had wipe samples collected at three on-field locations (Figure 4-11, locations S1, S2 and S5).

[b] Although several chemicals had ≤67% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of mean values.

[c] Sum15PAH = Sum of 15 of the 16 EPA 'priority' PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

[d] N/A = not applicable

[e] DBA + ICDP = Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene

SVOCs in Field Drag Sled Samples - The field drag sled samples collected using dry wipe sample media attached to a weighted drag sled body were analyzed for SVOCs. Field drag sled SVOC measurement results are shown in Table 4-39. Of the 35 target SVOC analytes reported in Table 4-39, 32 were measured above the minimum quantifiable limit in 100% of the samples. Aniline, n-butylbenzene, cyclohexylisothiocyanate, 2-bromomethylnaphthalene, bis(2-ethylhexyl) phthalate, and bis(2,2,6,6-tetramethyl-4piperidyl) sebacate measurement results were not reported due to poor performance in one or more quality control sample type.

Average transferrable residue values ranged from 0.011 to 0.019 ng/cm^2 for benzothiazole, 0.031 to 0.054 ng/cm^2 for 2-hydroxybenzothiazole, 0.010 to 0.015 ng/cm^2 for 4-tert-octylphenol, and 0.019 to 0.033 ng/cm^2 for the sum of 15 PAHs. Most other SVOC analytes had transferrable residue values that were < 0.01 ng/cm^2.

Table 4-39. Exposure Pilot Study Field Drag Sled Sampling SVOC Measurements[a]

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Drag Sled Sample – Location S1 Mean (ng/cm^2)	Drag Sled Sample – Location S2 Mean (ng/cm^2)	Drag Sled Sample – Location S5 Mean (ng/cm^2)	Drag Sled Sample Maximum (ng/cm^2)
Phenanthrene	100	0.0012	0.0020	0.0016	0.0036
Fluoranthene	100	0.0027	0.0045	0.0035	0.0079
Pyrene	100	0.0053	0.0088	0.0070	0.015
Benzo[a]pyrene	100	0.00095	0.0017	0.0016	0.0038
Benzo[ghi]perylene	100	0.0029	0.0048	0.0037	0.0079
Sum15PAH[b]	N/A[c]	0.019	0.033	0.027	0.058
Benzothiazole	100	0.011	0.019	0.016	0.034
2-Hydroxybenzothiazole	100	0.031	0.054	0.049	0.094
Dibutyl phthalate	100	0.00099	0.00005	0.0005	0.0021
4-tert-octylphenol	100	0.010	0.015	0.012	0.026

Table 4-39. Continued

Semivolatile Organic Compound (SVOC)	> Minimum Quantifiable Limit (%)	Drag Sled Sample – Location S1 Mean (ng/cm2)	Drag Sled Sample – Location S2 Mean (ng/cm2)	Drag Sled Sample – Location S5 Mean (ng/cm2)	Drag Sled Sample Maximum (ng/cm2)
n-Hexadecane	100	0.00095	0.0012	0.0013	0.0022
Naphthalene	100	0.0001	0.00011	0.00012	0.00028
1-Methylnaphthalene	100	0.00006	0.00008	0.00006	0.00017
2-Methylnaphthalene	100	0.00009	0.0001	0.00009	0.00026
Acenaphthylene	89	0.00002	0.00004	0.00003	0.00008
Fluorene	100	0.00006	0.00007	0.00006	0.00011
Anthracene	100	0.00015	0.00025	0.00018	0.00034
1-Methylphenanthrene	100	0.00069	0.0011	0.00083	0.0016
2-Methylphenanthrene	100	0.00086	0.0014	0.0012	0.0026
3-Methylphenanthrene	100	0.00098	0.0016	0.0013	0.0030
Benz[a]anthracene	100	0.00057	0.0010	0.00078	0.0019
Chrysene	100	0.0032	0.0058	0.0046	0.011
Benzo(b)fluoranthene	100	0.0008	0.0012	0.0010	0.0023
Benzo(k)fluoranthene	89	0.00045	0.0019	0.0018	0.0039
Benzo(e)pyrene	100	0.0024	0.0044	0.0037	0.0085
DBA + ICDP[d]	100	0.00035	0.0006	0.00045	0.0010
Coronene	100	0.0016	0.0022	0.0015	0.0028
Dibenzothiophene	100	0.00007	0.00012	0.00008	0.00016
Dimethyl phthalate	100	0.00014	0.00006	0.00007	0.00026
Diethyl phthalate	100	0.0019	0.00058	0.00094	0.0042
Diisobutyl phthalate	100	0.0019	0.00077	0.00099	0.0029
Benzyl butyl phthalate	100	0.021	0.010	0.0083	0.042
Di-n-octyl phthalate	100	0.0023	0.0011	0.00091	0.0055
2,6-Di-tert-butyl-p-cresol	100	0.00078	0.0004	0.00059	0.0018
bis(2-Ethylhexyl) adipate	100	0.0041	0.0030	0.0017	0.0058

[a] Average results from samples collected across the three exposure pilot study synthetic turf fields. Each set of field measurements had drag sled samples collected at three on-field locations (Figure 4-11, locations S1, S2 and S5).

[b] Sum15PAH = Sum of 15 of the 16 EPA ‘priority’ PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

[c] N/A = not applicable

[d] DBA + ICDP = Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene

4.5.1.3 Comparisons of Tire Crumb Rubber Infill, Field Surface Wipe, Drag Sled, and Dust Measurement Results

Comparisons of metal and SVOC measurement results from tire crumb rubber infill (sampled as part of the tire crumb rubber characterization efforts), field dust, field surface wipe, and field drag sled samples collected at the three exposure pilot study synthetic turf fields were made to assess differences in the chemicals and chemical patterns among the environmental measurements and the chemicals associated with the tire crumb rubber.

Metal Measurement Comparisons - Table 4-40 shows the comparisons for average metal measurement results across the three exposure measurement pilot study fields. Zinc and cobalt, found to be chemical constituents of tire crumb rubber in the tire crumb characterization, had higher concentrations in the tire crumb rubber as compared to concentrations measured in dust. Lead, on the other hand, had concentrations in field dust that were higher than in the tire crumb rubber. Higher levels of lead in dust and relatively higher levels in surface loadings as compared to zinc and cobalt, suggests another source of lead, in addition to tire crumb rubber infill. Most other metals also had higher average concentrations in field dust compared to the tire crumb rubber infill. Again, this suggests another source or sources of metals in addition to the tire crumb rubber infill. Many of the metals (e.g. aluminum, iron, magnesium) are found in crustal materials, and may be from components of sand or other materials used in field construction, blown-in soil from other sources, or track-in by the many field users. Several of the metals also are used in stainless steel, and the stainless-steel sieve used for dust sample collection can't be ruled out as a source of iron, chromium, manganese, molybdenum and nickel. Interpretation of differences between concentrations in tire crumb rubber and surface loadings of metals measured using surface wipes is more difficult. In general, the ratios of metals in tire crumb rubber infill and surface loadings measured with surface wipe samples were higher for most metals than those measured for zinc and cobalt, again perhaps suggesting non-infill sources contributing to overall surface metal levels.

Table 4-40. Comparison of Average Tire Crumb Rubber Infill, Field Dust, and Field Surface Wipe Metal Measurement Results from the Three Exposure Pilot Study Fields[a]

Metal	Tire Crumb Rubber Infill Average (mg/kg)	Field Dust Average (mg/kg)	Field Surface Wipe Average (ng/cm^2)
Arsenic	0.12	0.5	0.016
Cadmium	0.63	0.044	0.0061
Chromium	1.1	13[b]	0.62
Cobalt	118	45	0.81
Lead	16	38	1.7
Zinc	13900	9400	130
Aluminum	1200	4700	120
Antimony	0.80	1.9	0.11
Barium	69	93	1.4
Beryllium	0.066	0.14	0.0003
Copper	14	140	0.93
Iron	500	7700[b]	160
Magnesium	270	1700	24
Manganese	6.3	170[b]	2
Molybdenum	0.15	0.99[b]	0.031
Nickel	2.3	8.9[b]	0.14
Rubidium	1.9	10	0.16
Strontium	4.1	26	0.38
Tin	1.6	1.8	0.33
Vanadium	1.9	7.4	0.31

[a] Average results from samples collected across the three exposure pilot study synthetic turf fields.

[b] These metals may be components of stainless steel 316; a stainless-steel sieve was used to collect dust samples.

SVOC Measurement Comparisons - Comparisons for SVOCs measured in tire crumb rubber infill, field dust, field surface wipe, and field drag sled samples are shown in Table 4-41 for analytes with acceptable performance in at least three of the four sample types. Concentrations in tire crumb rubber infill were higher than those in field dust by a factor of 1.3 to 3-fold for benzothiazole, pyrene, the sum of 15 PAHs, 4-tert-octylphenol, and bis(2-ethyhexyl) phthalate. Concentrations of several 5- and 6-ring PAHs in tire crumb rubber infill were generally similar to or slightly higher than those in field dust, while the opposite was observed for benzo[ghi]perylene and coronene. Field surface loading measurements from surface wipes were generally 3 to 10 times higher than transferrable residues from the drag sled measurements.

For most of the measured SVOC analytes, there did not appear to be appreciable contributions to the dust and surfaces from sources other than the tire crumb rubber, or at least not as great as those potentially seen for many metal analytes. The PAHs benzo[ghi]perylene and coronene were modestly higher in field dust than in the tire crumb rubber infill, on average and benzyl butyl phthalate was 21 times higher in dust versus infill, suggesting a possible non-infill source.

Table 4-41. Comparison of Average Tire Crumb Rubber Infill, Field Dust, Field Wipe, and Drag Sled SVOC Measurement Results from the Three Exposure Pilot Study Fields[a,b]

Semivolatile Organic Compound (SVOC)	Tire Crumb Infill Average (mg/kg)	Field Dust Average (mg/kg)	Field Surface Wipe Average (ng/cm^2)	Field Drag Sled Average (ng/cm^2)
Phenanthrene	1.6	0.85	0.0049	0.0016
Fluoranthene	4.1	2.2	0.013	0.0036
Pyrene	12	5.5	0.028	0.0070
Benzo[a]pyrene[c]	0.93	0.71	0.0039	0.0014
Benzo[ghi]perylene[c]	1.9	3.7	0.018	0.0038
Sum15PAH[c]	28	19	0.096	0.026
Benzothiazole	5.5	4.3	0.16	0.015
Dibutyl phthalate	1.2	0.33	NR	0.00051
Bis(2-ethylhexyl) phthalate	73	24	0.15	NR
4-tert-octylphenol	15	5.2	0.11	0.012
n-Hexadecane	0.47	0.14	NR	0.0012
1-Methylnaphthalene	0.0057	0.0063	0.00056	0.00007
2-Methylnaphthalene	0.011	0.014	0.0011	0.00009
Acenaphthylene	0.022	0.012	0.00025	0.00003
Fluorene	0.062	0.034	0.00009	0.00006
Anthracene	0.24	0.15	0.0006	0.00019
1-Methylphenanthrene	1.2	0.52	0.0033	0.00087
2-Methylphenanthrene	1.2	0.63	0.0031	0.0012
3-Methylphenanthrene	1.7	0.71	0.0035	0.00129
Benz[a]anthracene	0.76	0.38	0.0025	0.00078
Chrysene	4.1	3.0	0.016	0.0045
Benzo(b)fluoranthene[c]	1.4	1.4	0.0045	0.001
Benzo(k)fluoranthene[c]	0.50	0.32	0.0011	0.0014
Benzo(e)pyrene[c]	2.2	1.5	0.0060	0.0035
DBA + ICDP[c,e]	0.68	0.65	0.0026	0.00047
Coronene[c]	0.74	1.9	0.014	0.0018

Table 4-41. Continued

Semivolatile Organic Compound (SVOC)	Tire Crumb Infill Average (mg/kg)	Field Dust Average (mg/kg)	Field Surface Wipe Average (ng/cm2)	Field Drag Sled Average (ng/cm2)
Dibenzothiophene	0.21	0.10	0.00025	0.00009
Dimethyl phthalate	0.0031	0.029	0.00020	0.00009
Diethyl phthalate	0.13	0.10	NR	0.0011
Diisobutyl phthalate	0.71	0.29	NR	0.0012
Benzyl butyl phthalate	0.70	15	NR	0.013
Di-n-octyl phthalate	0.51	0.14	0.00097	0.0014
Bis(2-ethylhexyl) adipate	2.4	NR	0.035	0.0029
2,6-Di-tert-butyl-p-cresol	0.097	0.11	0.0086	0.00059
2-Hydroxybenzothiazole	15	9.4	NR	0.045

[a] Average results from three exposure pilot study fields.

[b] NR = not reported

[c] Group of 5 and 6-ring polycyclic aromatic hydrocarbons (PAHs)

[d] Sum15PAH = Sum of 15 of the 16 EPA ‘priority’ PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

[e] DBA + ICDP = Sum of Dibenz[a,h]anthracene and Indeno(1,2,3-cd)pyrene

Overall, these results provide evidence that chemicals associated with tire crumb rubber are present in field dust, on field surfaces, and in transferrable residues, where they are available for field user exposures through inhalation, dermal, and ingestion pathways. For many metals, and possibly some SVOCs, there is evidence that sources other than the tire crumb rubber are adding to amounts found in the dust and on surfaces, potentially leading to exposures above those that could be attributed solely to the tire crumb rubber.

4.5.2 Personal Sample Measurements

4.5.2.1 Personal Air Samples

Personal air sample collection during athlete activities on synthetic fields is of interest for understanding inhalation exposures closer in proximity to the person than can be accounted for by the field samplers. There are constraints on personal sampling devices due to available device sizes, the relatively high sampling rates required, and participant safety requirements for athlete personal air monitoring, especially when working with child research participants. In this study, a small, high-sampling-rate passive VOC air sampler was used to attempt personal air sample collection during athlete activities. The passive VOC air sampler was attached to the upper backs of a pinnie (i.e., practice jersey) worn by study participants during their usual athletic practice sessions on synthetic turf fields. When collecting air samples from the football players, one sampler was destroyed and another damaged during drills that involved ground contact. Otherwise, all personal air samples were successfully collected and did not appear to interfere with any athlete activities.

To be useful for quantitative measurements of VOCs in air, the effective sampling rates of the target analytes had to be determined. Effective sampling rates were measured in two ways – in chambers under controlled conditions of temperature, humidity, ventilation and target analyte concentrations; and in field tests, where the passive VOC samplers were placed next to the active field air VOC samplers. Test results showed that the passive VOC sampler did not perform as desired in this exposure measurement pilot study, with inconsistent effective sampling rates measured for laboratory chamber and field conditions, and low recoveries of the two highest concentration analytes, benzothiazole and methyl isobutyl ketone. Therefore, no personal air sample VOC results are reported here.

Additional research would be required to determine if any personal air sampling devices can be successfully used in research studies with youth participants, with sufficiently large effective sampling rates, and with no safety or activity limitation constraints. It may be necessary to limit personal air sampling to adult volunteers willing to wear more bulky samplers with pumps; however, this may limit the types of activities that can be monitored. It is difficult to envision a pump-based sampler that could be worn successfully and safely during football activities that involve tackling, or by other sports players, such as soccer goalkeepers and rugby players.

4.5.2.2 Dermal Wipe Samples

Dermal wipe samples were collected from exposure measurement pilot study participants following their sport practice activities on synthetic turf fields with tire crumb rubber infill. Wipe samples were collected by wiping an entire hand, and wiping 112-cm^2 areas on the arm and leg that were not covered by clothing during their practice. Samples were collected from the right hand, arm, and leg for metals and from the left hand, arm, and leg for SVOCs. For both metals and SVOCs, the same types of wipe materials used to collect field surface wipes were used for dermal wipe sampling.

Dermal wipe measurement results were compiled as median and maximum values for hand, arm, and leg wipes for three groups of participants:

- Soccer players, 11 to 21 years old (n = 11),
- Soccer players, 7 to 10 years old (n = 6), and
- Football players, 13 to 14 years old (n = 8)

There are limitations for dermal wipe sampling. First, samples were collected only at the end of practice because the time burden for collection and availability of athletes with sufficient lead times prior to practice was limited. This means that a portion of some chemicals collected at the end of the practice period may have been from exposures that occurred before the athletes practiced on the fields; in this case, the measured amounts may overestimate the exposures that occurred during the sports practice. Second, the sampling efficiencies for the numerous target analytes have not been tested for the wipe methods that were used for this study. Thus, the amount of chemicals collected from the skin may be underestimates. Finally, dermal sampling can only collect chemicals present at the skin surface at the time of sampling. This approach cannot account for chemicals that may have already been absorbed into or through the skin, nor can it provide an accurate measurement of what would be absorbed through skin following the measurement. For example, chemicals on the skin may be removed after a sports practice due to dislodgement, hand washing and/or showering. Despite these limitations, the dermal wipe sampling provided valuable information about the potential for dermal exposures that had previously been identified as a large data gap in understanding potential tire crumb rubber exposures on athletic fields.

Metals - Dermal wipe samples were collected using Ghost wipe sample media pre-wetted with water. Mean dermal wipe metals measurement results are shown in Table 4-42. Selenium was not measured above the method detection limit in any sample. The remaining metals were measured at concentrations above the minimum reporting limit in 100% of the samples, with exception of beryllium, which was measured above the minimum reporting limit in 61% or more of the samples. Some negative values are reported as a result of field blank subtractions. Median dermal loading values for zinc and cobalt, two tire material constituents, ranged from 4.1 to 54 ng/cm^2 and from 0.012 to 0.084 ng/cm^2, respectively. Ranges of median lead and chromium dermal loadings were 0.027 to 0.27 ng/cm^2 and 0.027 to 0.31 ng/cm^2, respectively. Cadmium and arsenic were measured at median surface loadings that were < 0.1 ng/cm^2. Other metals commonly found in crustal particles, including aluminum, iron and magnesium, were found at median levels that ranged from 9.9 - 140 ng/cm^2.

There was considerable variability in dermal loading measurements within sport/age groups, with percent relative standard deviation (%RSD) values often exceeding 100% (data not shown). Due to these large variabilities and the relatively small sample sizes, statistical comparisons between groups were not performed. In general, median dermal loadings for hand measurements in soccer players age 7 to 10 were higher than those in the other two groups for most metal analytes. Otherwise, there were no clear patterns of differences in dermal loading between the sports and/or age groups.

Table 4-42. Exposure Pilot Study Participant Dermal Wipe Measurement Results for Selected Metals [a]

Metal	Participants	% > Minimum Reporting Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm)^2	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Arsenic	Soccer Players, Age 11 – 21	100	0.031	0.055	0.059	0.11	0.072	0.18
Arsenic	Soccer Players, Age 7 – 10	100	0.020	0.22	0.021	0.041	0.018	0.14
Arsenic	Football Players, Age 13 – 14	100	0.024	0.059	0.070	0.34	0.073	0.19
Cadmium	Soccer Players, Age 11 – 21	100	0.007	0.013	0.005	0.054	0.009	0.046
Cadmium	Soccer Players, Age 7 – 10	100	0.010	0.016	0.0084	0.012	0.007	0.013
Cadmium	Football Players, Age 13 – 14	100	0.006	0.042	0.019	0.14	0.014	0.038
Chromium	Soccer Players, Age 11 – 21	100	0.098	0.19	0.027	0.37	0.090	1.1
Chromium	Soccer Players, Age 7 – 10	100	0.31	0.59	0.16	0.34	0.30	0.71
Chromium	Football Players, Age 13 – 14	100	0.10	0.53	0.23	0.31	0.28	0.69
Cobalt	Soccer Players, Age 11 – 21	100	0.020	0.047	0.027	0.13	0.012	0.51
Cobalt	Soccer Players, Age 7 – 10	100	0.082	0.46	0.063	0.10	0.084	0.45
Cobalt	Football Players, Age 13 – 14	100	0.033	0.12	0.023	0.080	0.080	0.20
Lead	Soccer Players, Age 11 – 21	100	0.056	0.16	0.027	0.28	0.043	1.2
Lead	Soccer Players, Age 7 – 10	100	0.20	0.41	0.076	0.33	0.18	0.34
Lead	Football Players, Age 13 – 14	100	0.085	0.38	0.093	0.24	0.27	0.66

Table 4-42. Continued

Metal	Participants	% > Minimum Reporting Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm)^2	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Zinc	Soccer Players, Age 11 – 21	100	18	65	15	170	38	230
Zinc	Soccer Players, Age 7 – 10	100	41	140	17	120	13	170
Zinc	Football Players, Age 13 – 14	100	4.1	28	40	98	54	86
Aluminum	Soccer Players, Age 11 – 21	100	30	65	41	160	25	430
Aluminum	Soccer Players, Age 7 – 10	100	100	330	65	210	97	270
Aluminum	Football Players, Age 13 – 14	100	43	150	33	110	110	320
Antimony	Soccer Players, Age 11 – 21	100	0.032	0.061	-0.0048	0.10	0.010	0.22
Antimony	Soccer Players, Age 7 – 10	100	0.079	0.20	0.04	0.098	0.045	0.33
Antimony	Football Players, Age 13 – 14	100	0.033	0.14	0.053	0.59	0.064	0.17
Barium	Soccer Players, Age 11 – 21	100	0.81	6.0	1.2	2.6	0.45	4.2
Barium	Soccer Players, Age 7 – 10	100	1.8	5.3	1.1	2.7	1.3	4.8
Barium	Football Players, Age 13 – 14	100	1.1	2.7	0.83	4.2	1.8	4.2
Beryllium	Soccer Players, Age 11 – 21	91	0.001	0.004	0.0045	0.011	0.006	0.010
Beryllium	Soccer Players, Age 7 – 10	61	-0.001	0.004	-0.0026	0	-0.003	0.003
Beryllium	Football Players, Age 13 – 14	100	-0.001	0.003	-0.0035	0	-0.002	0.004
Copper	Soccer Players, Age 11 – 21	100	0.99	1.9	0.89	4.4	1.1	5.9
Copper	Soccer Players, Age 7 – 10	100	1.5	2.3	1.2	3.9	1.8	3.1
Copper	Football Players, Age 13 – 14	100	0.72	1.9	1.1	2.5	1.2	5.2
Iron	Soccer Players, Age 11 – 21	100	29	66	29	150	21	640
Iron	Soccer Players, Age 7 – 10	100	110	220	50	170	93	170
Iron	Football Players, Age 13 – 14	100	37	180	36	97	140	320

Table 4-42. Continued

Metal	Participants	% > Minimum Reporting Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm)^2	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Magnesium	Soccer Players, Age 11 – 21	100	15	25	12	56	20	110
Magnesium	Soccer Players, Age 7 – 10	100	42	76	26	87	49	73
Magnesium	Football Players, Age 13 – 14	100	9.9	38	11	32	33	70
Manganese	Soccer Players, Age 11 – 21	100	0.54	1.5	0.83	2.1	0.49	6.0
Manganese	Soccer Players, Age 7 – 10	100	1.9	4.2	0.95	3.6	1.7	3.2
Manganese	Football Players, Age 13 – 14	100	1.4	6.2	1.3	3.6	3.8	10
Molybdenum	Soccer Players, Age 11 – 21	100	0.010	0.052	-0.0064	0.043	0.016	0.10
Molybdenum	Soccer Players, Age 7 – 10	100	0.028	0.11	0.023	0.039	0.022	0.039
Molybdenum	Football Players, Age 13 – 14	100	0.010	0.067	0.034	0.069	0.054	0.22
Nickel	Soccer Players, Age 11 – 21	100	0.14	0.52	0.38	4.6	0.37	1.1
Nickel	Soccer Players, Age 7 – 10	100	0.63	1.3	0.41	1.0	0.48	1.5
Nickel	Football Players, Age 13 – 14	100	0.11	0.53	0.29	3.3	0.50	1.8
Rubidium	Soccer Players, Age 11 – 21	100	0.90	3.9	1.4	2.1	1.7	4.0
Rubidium	Soccer Players, Age 7 – 10	100	2.1	2.9	1.5	3.5	2.4	3.0
Rubidium	Football Players, Age 13 – 14	100	0.37	2.6	0.73	2.2	2.5	5.4
Strontium	Soccer Players, Age 11 – 21	100	0.20	0.48	0.11	0.51	0.13	0.86
Strontium	Soccer Players, Age 7 – 10	100	0.65	1.1	0.33	0.92	0.57	0.91
Strontium	Football Players, Age 13 – 14	100	0.28	1.1	0.31	1.1	0.86	2.0
Tin	Soccer Players, Age 11 – 21	100	0.039	0.20	-0.012	0.02	-0.046	0.18
Tin	Soccer Players, Age 7 – 10	100	0.23	0.28	0.024	0.16	0.06	0.14
Tin	Football Players, Age 13 – 14	100	0.093	0.35	0.15	0.47	0.31	0.62

Table 4-42. Continued

Metal	Participants	% > Minimum Reporting Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm)^2	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Vanadium	Soccer Players, Age 11 – 21	100	0.050	0.14	0.064	0.22	0.036	0.75
Vanadium	Soccer Players, Age 7 – 10	100	0.19	0.45	0.11	0.37	0.17	0.36
Vanadium	Football Players, Age 13 – 14	100	0.097	0.50	0.092	0.27	0.30	0.84

[a] Soccer players, 11 to 21 years old (n = 11); Soccer players, 7 to 10 years old (n = 6); Football players, 13 to 14 years old (n = 8)

Distributions of hand, arm, and leg dermal wipe measurement results for cobalt, lead, and zinc are shown in Figure 4-15. The zinc results are impacted by the relatively high background levels measured in the wipe material, resulting in some background corrected values below zero.

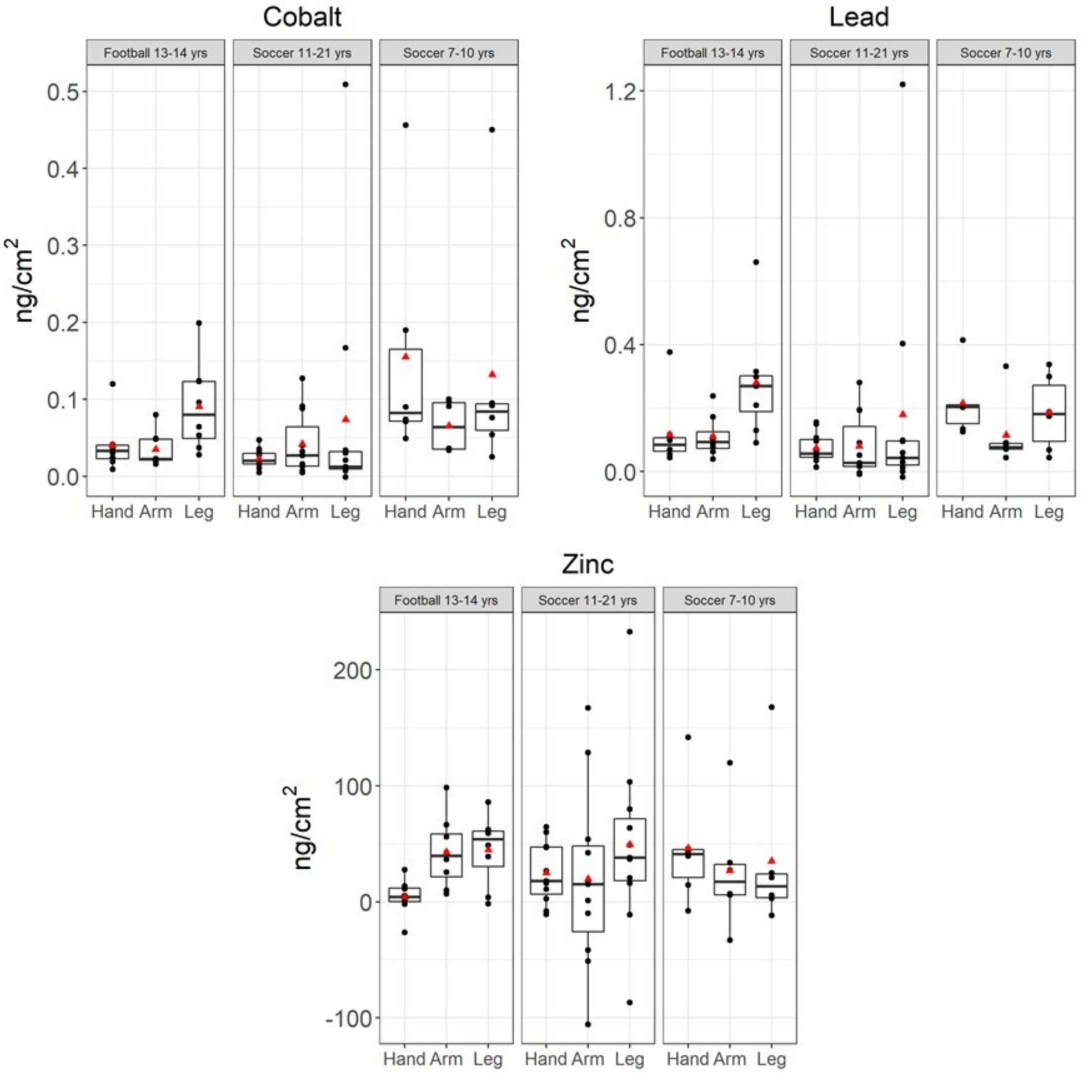

Figure 4-15. Distributions of hand, arm and leg dermal measurement results for cobalt, lead and zinc.

SVOCs - Dermal wipe samples were collected using wipe sample media pre-wetted with isopropanol.

Median and maximum dermal wipe SVOC measurement results are shown in Table 4-43. Distributions of hand, arm and leg dermal wipe measurement results in the three age/sport groups are shown in Figure 4-16 for fluoranthene, the sum of 15 PAHs, benzothiazole and di-n-octyl phthalate. There was a wide range for the percent of measurements greater than the minimum quantifiable limit across the SVOC analytes. Several analytes were measured above the minimum quantifiable limit in 100% of the samples, including benzothiazole, bis(2-ethylhexyl) phthalate, benzyl butyl phthalate, 2,6-di-tert-butyl-p-cresol and bis(2-ethylhexyl) adipate. Some negative values are reported as a result of field blank subtractions. Measurement results below the minimum quantifiable limit were included in calculation of results. Cyclohexylisothiocyanate, dimethyl phthalate, diethyl phthalate, 2-bromomethylnaphthalene, 2-hydroxybenzothiazole, anthracene, diisobutyl phthalate, dibutyl phthalate, and bis(2,2,6,6-tetramethyl-4piperidyl) sebacate measurement results were not reported due to poor performance in one or more quality control sample type.

Median dermal loading values ranged from 0.057 to 0.17 ng/cm^2 for benzothiazole, 1.7 to 7.0 ng/cm^2 for bis(2-ethylhexyl) phthalate, 0.0021 to 0.019 ng/cm^2 for fluoranthene, and 0.018 to 0.13 ng/cm^2 for the sum of 15 PAHs. Several phthalates and other analytes had median dermal loading values > 0.1 ng/cm^2 in some participant groups, but the majority of analytes had median dermal loadings of < 0.1 ng/cm^2, with some analytes measuring < 0.01 ng/cm^2 (although a majority of measurements in this latter group were not above the minimum quantifiable limit).

There was considerable variability in SVOC dermal loading measurements within sport/age groups, with %RSD values often exceeding 100% (data not shown). Due to these large variabilities and the relatively small sample sizes, statistical comparisons between groups was not performed. For many but not all SVOC analytes, average dermal loadings for hand, arm and leg measurements from soccer players age 7 to 10 were higher than those in the other two groups. This occurred most often for SVOCs found at lower concentrations, and the percent of measurements above the minimum quantifiable limit was often higher for soccer players age 7 to 10 than the other two groups. Observations of potential differences among groups should be treated with caution due to the small sample sizes, high variability, and small percentages of measurements above the minimum quantifiable limits for some analytes.

Overall, the dermal measurement results for metals and SVOCs showed that dermal exposures to chemicals associated with tire crumb rubber are likely occurring for athletes participating in sports activities. However, there may be contributions from sources other than the tire crumb rubber for many of the metals and for some SVOCs, especially the phthalate analytes. Since no pre-activity dermal sampling was performed, it is not possible to attribute all the measured dermal loading to exposures that occurred at the synthetic turf fields.

Table 4-43. Exposure Pilot Study Dermal Wipe Measurement Results for Select SVOCs [a,b,c]

Semivolatile Organic Compound (SVOC)	Participants	% > Minimum Quantifiable Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm^2)	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Phenanthrene	Soccer Players, Age 11 – 21	27	0.0023	0.018	0.0076	0.060	0.0060	0.080
Phenanthrene	Soccer Players, Age 7 – 10	44	0.014	0.018	0.034	0.12	0.027	0.035
Phenanthrene	Football Players, Age 13 – 14	21	0.0014	0.0044	0.0046	0.0099	0.0033	0.0039

Table 4-43. Continued

Semivolatile Organic Compound (SVOC)	Participants	% > Minimum Quantifiable Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm^2)	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Fluoranthene	Soccer Players, Age 11 – 21	94	0.0036	0.011	0.0069	0.044	0.0092	0.094
Fluoranthene	Soccer Players, Age 7 – 10	100	0.019	0.023	0.018	0.34	0.017	0.055
Fluoranthene	Football Players, Age 13 – 14	92	0.0024	0.0096	0.0024	0.035	0.0021	0.011
Pyrene	Soccer Players, Age 11 – 21	21	0.0035	0.0061	0.0033	0.029	0.0021	0.10
Pyrene	Soccer Players, Age 7 – 10	50	0.0096	0.040	0.014	0.11	0.0081	0.11
Pyrene	Football Players, Age 13 – 14	17	0.0037	0.012	0.0048	0.027	0.0057	0.019
Benzo[a]pyrene	Soccer Players, Age 11 – 21	6	0.0013	0.0031	0.003	0.013	0.0006	0.026
Benzo[a]pyrene	Soccer Players, Age 7 – 10	28	0.0052	0.0066	0.012	0.023	0.0070	0.014
Benzo[a]pyrene	Football Players, Age 13 – 14	13	0.0005	0.0051	-0.00025	0.036	-0.0008	0.0034
Benzo[ghi]perylene	Soccer Players, Age 11 – 21	36	0.0033	0.0095	0.0044	0.034	0.0073	0.10
Benzo[ghi]perylene	Soccer Players, Age 7 – 10	61	0.014	0.033	0.022	0.046	0.018	0.069
Benzo[ghi]perylene	Football Players, Age 13 – 14	46	0.0032	0.015	0.00075	0.038	0.0018	0.019
Sum15PAH[d]	Soccer Players, Age 11 – 21	N/A	0.022	0.051	0.049	0.23	0.056	0.56
Sum15PAH	Soccer Players, Age 7 – 10	N/A	0.11	0.14	0.13	1.2	0.098	0.34
Sum15PAH	Football Players, Age 13 – 14	N/A	0.018	0.063	0.020	0.26	0.020	0.14
Benzothiazole	Soccer Players, Age 11 – 21	100	0.057	1.3	0.086	0.99	0.065	1.3
Benzothiazole	Soccer Players, Age 7 – 10	100	0.16	0.24	0.17	0.38	0.16	0.47
Benzothiazole	Football Players, Age 13 – 14	100	0.088	0.49	0.14	0.26	0.12	0.38
Bis(2-ethylhexyl) phthalate	Soccer Players, Age 11 – 21	100	1.7	3.2	4.0	9.9	3.9	5.5
Bis(2-ethylhexyl) phthalate	Soccer Players, Age 7 – 10	100	2.2	2.8	4.4	6.5	4.3	6.4
Bis(2-ethylhexyl) phthalate	Football Players, Age 13 – 14	100	2.0	2.3	6.2	16	7.0	11

Table 4-43. Continued

Semivolatile Organic Compound (SVOC)	Participants	% > Minimum Quantifiable Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm^2)	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Aniline	Soccer Players, Age 11 – 21	45	0.018	0.26	0	0.70	0	0.81
Aniline	Soccer Players, Age 7 – 10	61	0.047	0.13	0.036	0.13	0.082	0.31
Aniline	Football Players, Age 13 – 14	46	0.017	0.12	0	0.15	0.069	0.21
4-tert-octylphenol	Soccer Players, Age 11 – 21	100	0.10	1.4	0.10	1.2	0.13	1.6
4-tert-octylphenol	Soccer Players, Age 7 – 10	100	-0.061	0.48	-0.16	-0.13	-0.11	0.62
4-tert-octylphenol	Football Players, Age 13 – 14	92	0.096	0.46	0.17	0.39	0.21	0.60
n-Hexadecane	Soccer Players, Age 11 – 21	100	0.11	0.44	0.38	1.4	0.69	2.2
n-Hexadecane	Soccer Players, Age 7 – 10	100	-0.0061	0.48	0.21	2.9	0.13	0.53
n-Hexadecane	Football Players, Age 13 – 14	92	NR	NR	NR	NR	NR	NR
Naphthalene	Soccer Players, Age 11 – 21	24	0.0019	0.0033	0.0066	0.0091	0.0068	0.012
Naphthalene	Soccer Players, Age 7 – 10	17	0.0029	0.0038	0.0048	0.0072	0.0046	0.0069
Naphthalene	Football Players, Age 13 – 14	17	-0.0001	0.0015	-0.0006	0.0029	-0.0012	0.002
2-Methylnaphthalene	Soccer Players, Age 11 – 21	12	0.0025	0.0099	0.0018	0.033	0.0008	0.042
2-Methylnaphthalene	Soccer Players, Age 7 – 10	6	0.0092	0.015	0.022	0.029	0.021	0.031
2-Methylnaphthalene	Football Players, Age 13 – 14	21	0.0022	0.0061	0.0028	0.014	0.0021	0.0095
Fluorene	Soccer Players, Age 11 – 21	12	0.0002	0.0003	0.0003	0.0027	0.0004	0.0021
Fluorene	Soccer Players, Age 7 – 10	17	-0.0002	0.0002	-0.0004	0.0004	-0.0005	0.0003
Fluorene	Football Players, Age 13 – 14	21	0.0002	0.0008	-0.0004	0.0038	-0.0004	0.0001
1-Methylphenanthrene	Soccer Players, Age 11 – 21	88	0.0007	0.0048	0.0010	0.011	0.0003	0.015
1-Methylphenanthrene	Soccer Players, Age 7 – 10	44	0.0007	0.0087	0.0016	0.0060	0.0028	0.013
1-Methylphenanthrene	Football Players, Age 13 – 14	100	0.0021	0.0043	0.0032	0.014	0.0030	0.0058

Table 4-43. Continued

Semivolatile Organic Compound (SVOC)	Participants	% > Minimum Quantifiable Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm^2)	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
Benz(a)anthracene	Soccer Players, Age 11 – 21	0	0.0009	0.0021	0.0010	0.0087	0.0016	0.014
Benz(a)anthracene	Soccer Players, Age 7 – 10	28	0.0036	0.0038	0.0071	0.046	0.0058	0.011
Benz(a)anthracene	Football Players, Age 13 – 14	13	-0.0001	0.0020	-0.0007	0.020	-0.0008	0.14
Chrysene	Soccer Players, Age 11 – 21	48	0.0031	0.0070	0.0056	0.019	0.0028	0.066
Chrysene	Soccer Players, Age 7 – 10	89	0.014	0.017	0.013	0.11	0.013	0.049
Chrysene	Football Players, Age 13 – 14	42	0.0029	0.010	0.0013	0.031	0.0031	0.013
Benzo(b)fluoranthene	Soccer Players, Age 11 – 21	12	0.0009	0.0041	0	0.015	0.0015	0.037
Benzo(b)fluoranthene	Soccer Players, Age 7 – 10	61	0.010	0.018	0.015	0.29	0.013	0.023
Benzo(b)fluoranthene	Football Players, Age 13 – 14	4	0	0.0024	0	0.030	0	0
Benzo(k)fluoranthene	Soccer Players, Age 11 – 21	15	0.0001	0.0013	0.0017	0.0077	0.0008	0.012
Benzo(k)fluoranthene	Soccer Players, Age 7 – 10	67	0.0026	0.0059	0.0077	0.085	0.0041	0.0092
Benzo(k)fluoranthene	Football Players, Age 13 – 14	8	0.0006	0.0017	0.0018	0.017	0.0013	0.0044
Benzo(e)pyrene	Soccer Players, Age 11 – 21	6	0.0001	0.0016	0	0.0063	0	0.027
Benzo(e)pyrene	Soccer Players, Age 7 – 10	39	0.0046	0.010	0.0069	0.048	0.0028	0.022
Benzo(e)pyrene	Football Players, Age 13 – 14	17	0.0001	0.0046	-0.0012	0.022	-0.0012	0.0027
Coronene	Soccer Players, Age 11 – 21	18	0	0.010	0	0.071	0	0.24
Coronene	Soccer Players, Age 7 – 10	44	0.015	0.024	0.013	0.037	0.0092	0.038
Coronene	Football Players, Age 13 – 14	8	0	0.0039	0	0.0096	0	0
Dibenzothiophene	Soccer Players, Age 11 – 21	39	-0.0001	0.0010	-0.0004	0.0052	-0.0004	0.0043
Dibenzothiophene	Soccer Players, Age 7 – 10	67	-0.0005	0.0031	-0.0009	0.0032	0	0.0031
Dibenzothiophene	Football Players, Age 13 – 14	25	0.0002	0.0018	-0.0002	0.0049	-0.0015	0.0004

Table 4-43. Continued

Semivolatile Organic Compound (SVOC)	Participants	% > Minimum Quantifiable Limit	Hand Wipe Median (ng/cm^2)	Hand Wipe Maximum (ng/cm^2)	Arm Wipe Median (ng/cm^2)	Arm Wipe Maximum (ng/cm^2)	Leg Wipe Median (ng/cm^2)	Leg Wipe Maximum (ng/cm^2)
n-Butylbenzene	Soccer Players, Age 11 – 21	70	-0.0042	0.11	0.013	0.23	-0.025	0.046
n-Butylbenzene	Soccer Players, Age 7 – 10	61	0.017	0.033	0.0066	0.14	-0.047	0.063
n-Butylbenzene	Football Players, Age 13 – 14	75	-0.0008	0.023	-0.0081	0.068	-0.025	0.082
Benzyl butyl phthalate	Soccer Players, Age 11 – 21	100	0.21	3.8	0.78	12	0.75	16
Benzyl butyl phthalate	Soccer Players, Age 7 – 10	100	1.1	2.9	0.79	1.7	1.1	3.9
Benzyl butyl phthalate	Football Players, Age 13 – 14	100	NR	NR	NR	NR	NR	NR
Di-n-octyl phthalate	Soccer Players, Age 11 – 21	94	0.054	0.86	0.15	4.0	0.18	2.3
Di-n-octyl phthalate	Soccer Players, Age 7 – 10	89	0.10	0.37	0.088	0.59	0.22	0.84
Di-n-octyl phthalate	Football Players, Age 13 – 14	100	0.058	0.13	0.23	0.65	0.13	0.44
2,6-Di-tert-butyl-p-cresol	Soccer Players, Age 11 – 21	100	0.024	0.14	0.074	0.59	0.13	0.39
2,6-Di-tert-butyl-p-cresol	Soccer Players, Age 7 – 10	100	0.033	0.083	0.079	0.30	0.020	0.06
2,6-Di-tert-butyl-p-cresol	Football Players, Age 13 – 14	100	0.035	0.068	0.092	0.21	0.15	0.19
bis(2-Ethylhexyl) adipate	Soccer Players, Age 11 – 21	100	0.59	3.5	0.73	8.9	0.76	19
bis(2-Ethylhexyl) adipate	Soccer Players, Age 7 – 10	100	0.94	5.3	2.2	19	1.9	3.5
bis(2-Ethylhexyl) adipate	Football Players, Age 13 – 14	100	0.68	1.9	3.0	15	1.8	3.4

[a] Soccer players, 11 to 21 years old (n = 11); Soccer players, 7 to 10 years old (n = 6); Football players, 13 to 14 years old (n = 8)

[b] Although several chemicals had <50% of the measured values above the quantifiable limits, all measured values from the analysis, including those reported by the laboratory that were below the quantifiable limits, were used in the calculation of median values; chemicals that did not have at least 20% of measurements above the method quantifiable limit in one of the three sport/age groups were not included

[c] N/R = not reported

[d] Sum15PAH = Sum of 15 of the 16 EPA 'priority' PAHs, including Acenaphthylene, Anthracene, Benz[a]anthracene, Benzo[a]pyrene, Benzo(b)fluoranthene, Benzo[ghi]perylene, Benzo(k)fluoranthene, Chrysene, Dibenz[a,h]anthracene, Fluoranthene, Fluorene, Indeno(1,2,3-cd)pyrene, Naphthalene, Phenanthrene, Pyrene

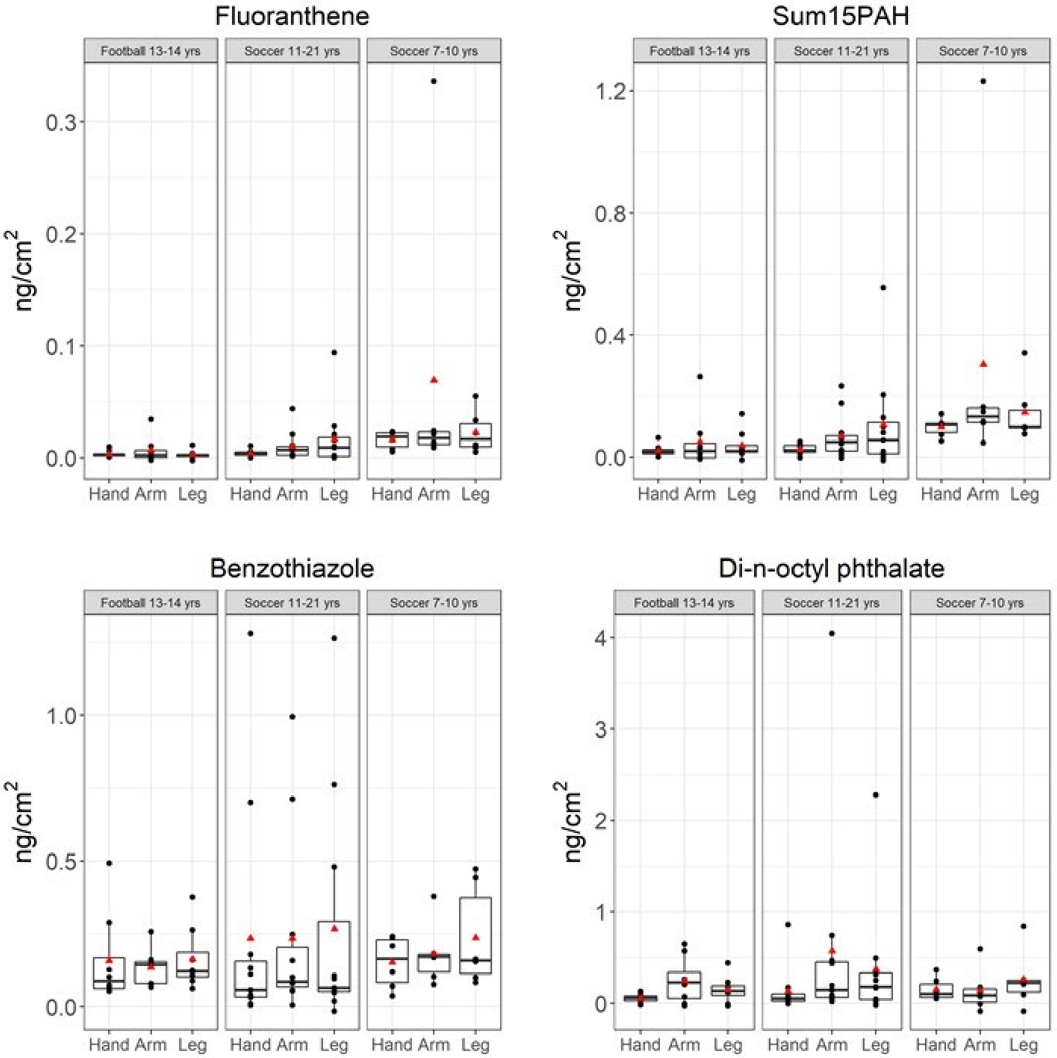

Figure 4-16. Distributions of dermal measurement results for fluoranthene, the sum of 15 PAHs, benzothiazole, and di-n-octyl phthalate.

4.5.3 Pilot-Scale Biological Sample Measurements

4.5.3.1 Urine and Blood Samples

Urine and blood samples were collected from select pilot study participants before and after practicing on synthetic turf fields with tire crumb rubber infill. Participants were provided with a sealed sterile urine collection cup to collect the urine samples on-site in facility restrooms. For blood and serum samples, blood draws were administered on-site at a designated area by a certified phlebotomist. Biological samples were collected from participants at two outdoor fields on multiple days prior to and after football and soccer practices. Results are provided in this section for urine and blood measurements performed for pilot study participants. Results for the supplemental biomonitoring study are presented in Appendix A.

As previously reported, a total of 13 participants gave blood specimens and 14 participants provided urine specimens. Participants included soccer players 11 to 21 years of age (n = 7) and football players 13 to 14 years of age (n = 7). For two of the participants, the phlebotomist was unable to obtain blood samples following their practice activities; this may have been due to dehydration after rigorous on-field activity. For the urine collection, participants were directed to not touch the inside of the urine specimen container so as to not contaminate the sample. However, we cannot confirm that all participants followed the specified procedures.

A variety of measures were used to assess normality of the distribution of biological sample measurement results, including the Shapiro-Wilk test, as well as skewness and kurtosis values. As the data were not normally distributed, a Wilcoxon Signed-Rank Test was performed to determine any pre-activity and post-activity differences for all participants combined and then separately by sport. The Wilcoxon Signed-Rank Test is a non-parametric statistical hypothesis test that can be used to compare repeated measurements. Additionally, t-tests were performed and the corresponding p-values included for comparison. Skewness and kurtosis are measures of a shape of the distribution of measurements.

Urinary PAHs - Exposure pilot study pre- and post-activity measurements for several PAH urinary biomarkers are shown in Tables 4-44 and 4-45. Individual differences in pre- and post-activity urinary PAH concentrations are illustrated in Figures 4-17 through 4-2. All measurements were creatinine-adjusted to account for urinary dilution; measurements were also adjusted for specific-gravity Table 4-46).

Table 4-44. Exposure Pilot Study Pre- and Post-Activity Creatinine-Adjusted Urinary PAH Measurements[a,b]

PAH	Pre-Activity Mean	Pre-Activity Standard Deviation	Pre-Activity Geo Mean	Pre-Activity 95% CI	Post-Activity Mean	Post-Activity Standard Deviation	Post-Activity Geo Mean	Post-Activity 95% CI
1-Hydroxynaphthalene (µg/g)	1.32	1.51	0.90	0.58 – 1.39	1.40	1.78	0.90	0.57 – 1.41
2-Hydroxynaphthalene (µg/g)	7.85	4.49	6.53	4.63 – 9.19	10.31	5.81	8.74	6.37 – 12.00
1-Hydroxyphenanthrene (ng/g)	102	89.9	80.9	57.9 – 113	114	111	91.1	66.9 – 124
2 & 3-Hydroxyphenanthrene (ng/g)	145	171	111	81 – 152	155	216	110	78.7 – 154
2-Hydroxyfluorene (ng/g)	188	128	162	125 – 211	193	150	164	125 – 214
3-Hydroxyfluorene (ng/g)	69	65.4	56.3	42.3 – 74.9	73.0	87.5	54.2	38.5 – 76.4
1-Hydroxypyrene (ng/g)	104	85.1	84.6	62.1 – 115	90.2	73.7	73.8	54.1 – 101

[a] PAH = Polycyclic aromatic hydrocarbon; Geo = Geometric; CI = Confidence interval

[b] Number of samples = 14

Table 4-45. Exposure Pilot Study Pre- and Post-Activity Creatinine-Adjusted Urinary PAH Measurements, by Sport[a, b]

PAH	Sport	Pre-Activity Mean	Pre-Activity Standard Deviation	Pre-Activity Geo Mean	Pre-Activity 95% CI	Post-Activity Mean	Post-Activity Standard Deviation	Post-Activity Geo Mean	Post-Activity 95% CI
1-Hydroxynaphthalene (µg/g)	Soccer	1.66	2.06	0.943	0.428 – 2.08	1.79	2.42	0.974	0.439 – 2.16
1-Hydroxynaphthalene (µg/g)	Football	0.987	0.645	0.850	0.571 – 1.26	1.01	0.816	0.829	0.532 – 1.29
2-Hydroxynaphthalene (µg/g)	Soccer	8.26	4.42	6.91	4.20 – 11.4	10.4	6.41	8.73	5.46 – 13.9
2-Hydroxynaphthalene (µg/g)	Football	7.45	4.86	6.17	3.84 – 9.91	10.2	5.65	8.76	5.68 – 13.5
1-Hydroxyphenanthrene (ng/g)	Soccer	128	121	97.4	58.1 – 164	142	156	101	57.3 – 177
1-Hydroxyphenanthrene (ng/g)	Football	75.1	35.3	67.1	46.1 – 97.8	86.2	26.9	82.5	65.5 – 104
2- & 3-Hydroxyphenanthrene (ng/g)	Soccer	188	241	123	67.1 – 225	207	307	121	62.3 – 233
2- & 3-Hydroxyphenanthrene (ng/g)	Football	102	22.3	100	85.0 – 118	102	17.2	101	88.8 – 115
2-Hydroxyfluorene (ng/g)	Soccer	220	173	179	114 – 282	225	206	177	110 – 285
2-Hydroxyfluorene (ng/g)	Football	156	58.3	147	114 – 190	160	61.5	151	118 – 194
3-Hydroxyfluorene (ng/g)	Soccer	85.3	91.0	63.8	38.7 – 105	95.3	123	61.9	33.4 – 115
3-Hydroxyfluorene (ng/g)	Football	52.6	18.9	49.7	38.4 – 64.3	50.7	19.6	47.4	35.8 – 62.8
1-Hydroxypyrene (ng/g)	Soccer	115	111	87.6	53.0 – 145	109	101	82.5	48.5 – 140
1-Hydroxypyrene (ng/g)	Football	92.9	55.1	81.7	56.6 – 118	71.3	28.7	66.0	48.4 – 89.9

[a] PAH = Polycyclic aromatic hydrocarbon; Geo = Geometric; CI = Confidence interval

[b] Number of soccer player samples = 7; Number of football player samples = 7

Table 4-46. Exposure Pilot Study Pre- and Post-Activity Specific-Gravity-Adjusted Urinary PAH Measurements, by Sport[a, b]

PAH	Sport	Pre-Activity Mean	Pre-Activity Standard Deviation	Pre-Activity Geo Mean	Pre-Activity 95% CI	Post-Activity Mean	Post-Activity Standard Deviation	Post-Activity Geo Mean	Post-Activity 95% CI
1-Hydroxynaphthalene (µg/g)	Soccer	2.40	3.43	1.41	0.712 – 2.80	4.34	6.52	2.51	1.29 – 4.89
1-Hydroxynaphthalene (µg/g)	Football	1.27	0.861	1.08	0.718 – 1.63	2.00	1.60	1.61	1.01 – 2.58
2-Hydroxynaphthalene (µg/g)	Soccer	11.2	4.70	10.3	7.60 – 14.1	26.6	18.4	22.5	14.8 – 34.0
2-Hydroxynaphthalene (µg/g)	Football	9.71	6.87	7.84	4.79 – 12.8	19.7	10.7	17.1	11.2 – 26.0
1-Hydroxyphenanthrene (ng/g)	Soccer	196	204	146	86.8 – 245	365	420	259	150 – 446
1-Hydroxyphenanthrene (ng/g)	Football	102	63.0	85.4	54.3 – 134	177	76.5	161	114 – 227
2- & 3-Hydroxyphenanthrene (ng/g)	Soccer	295	408	184	98.5 – 343	549	828	310	155 – 619
2- & 3-Hydroxyphenanthrene (ng/g)	Football	136	51.7	127	97.2 – 167	208	71.5	197	151 – 256
2-Hydroxyfluorene (ng/g)	Soccer	356	315	268	156 – 460	629	608	455	258 – 805
2-Hydroxyfluorene (ng/g)	Football	205	89.1	187	133 – 262	318	133	295	220 – 396
3-Hydroxyfluorene (ng/g)	Soccer	136	157	95.4	55.0 – 166	261	338	159	81.4 – 312
3-Hydroxyfluorene (ng/g)	Football	67.4	26.4	63.2	48.2 – 82.7	98.7	38.1	92.5	70.6 – 121
1-Hydroxypyrene (ng/g)	Soccer	175	189	131	79.9 – 215	271	265	212	134 – 335
1-Hydroxypyrene (ng/g)	Football	119	72.2	104	70.5 – 153	144	61.9	129	86.8 - 191

[a] PAH = Polycyclic aromatic hydrocarbon; Geo = Geometric; CI = Confidence interval

[b] Number of soccer player samples = 7; Number of football player samples = 7

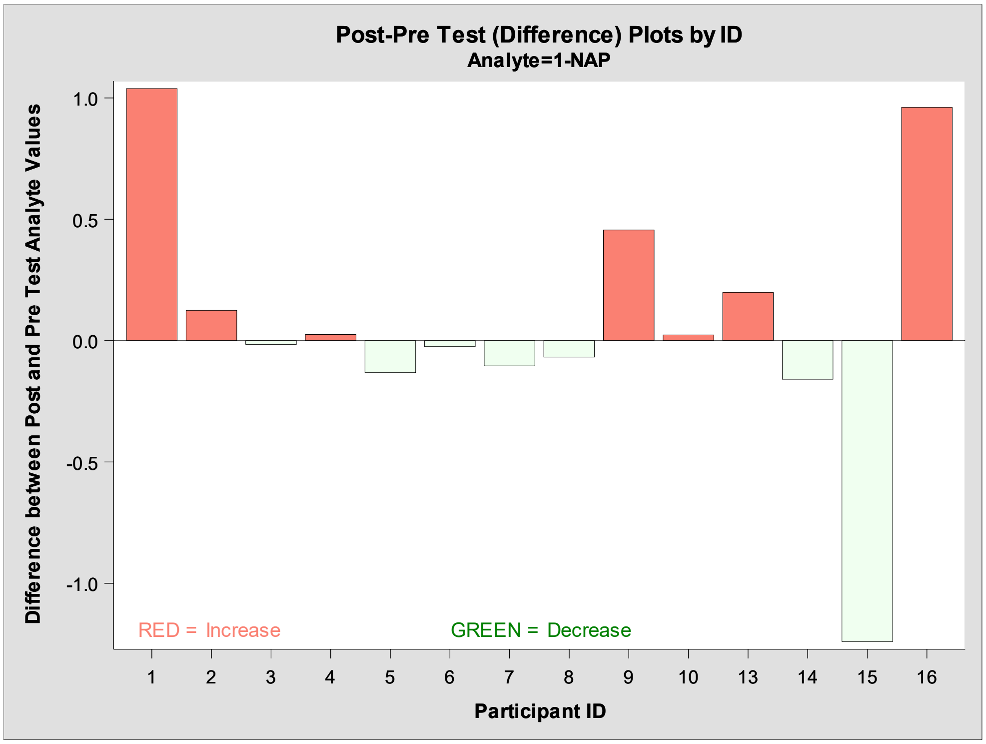

Figure 4-17. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 1-hydroxynaphthalene measurements (µg/g), by participant.

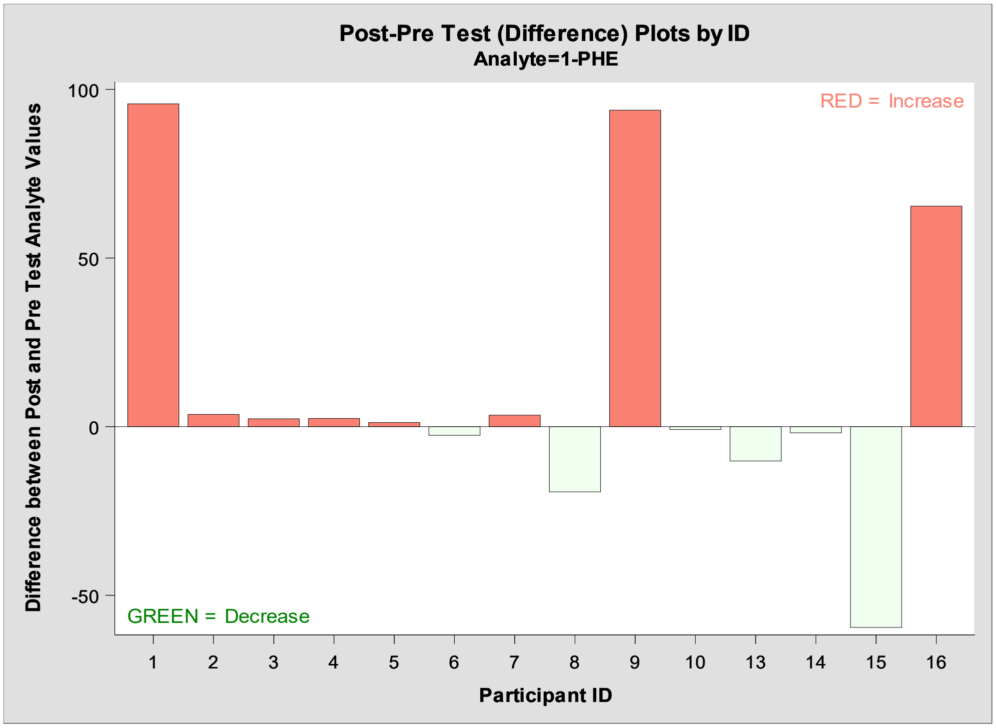

Figure 4-18. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 1-hydroxyphenanthrene measurements (ng/g), by participant.

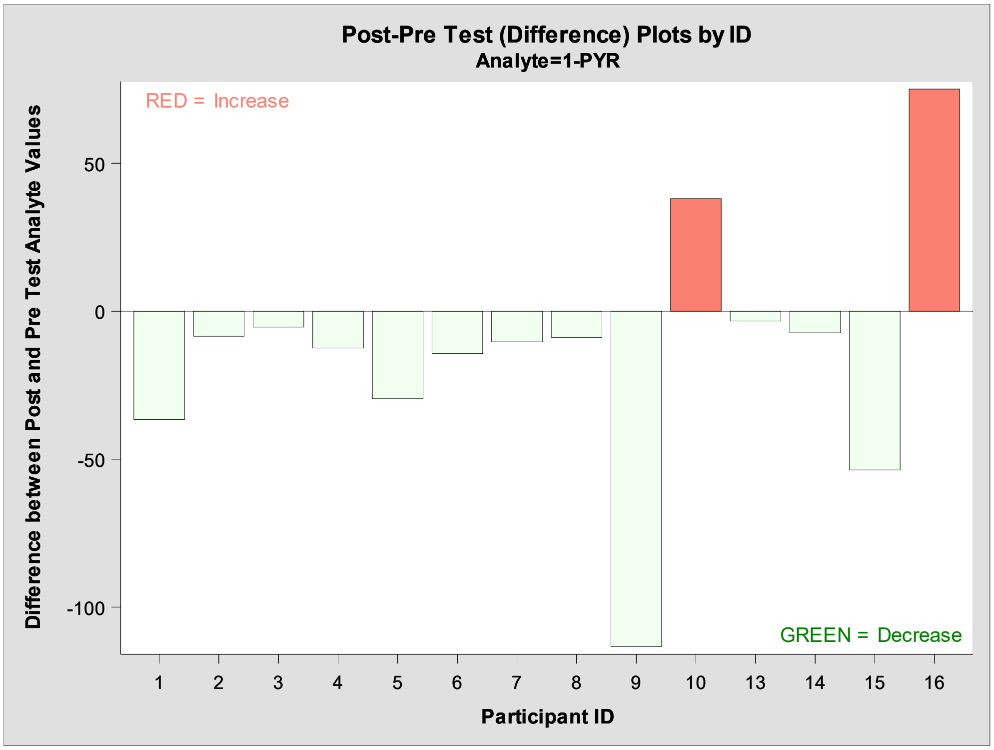

Figure 4-19. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 1-hydroxypyrene measurements (ng/g), by participant.

Figure 4-20. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 2- & 3-hydroxyphenanthrene measurements (ng/g), by participant.

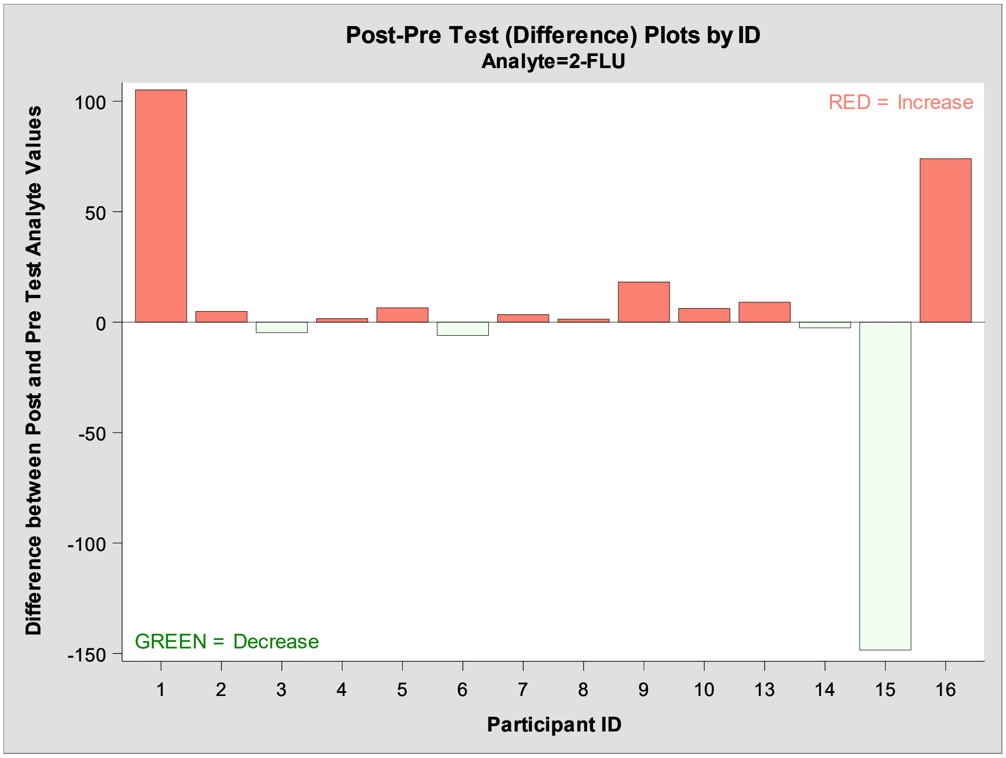

Figure 4-21. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 2-hydroxyfluorene measurements (ng/g), by participant.

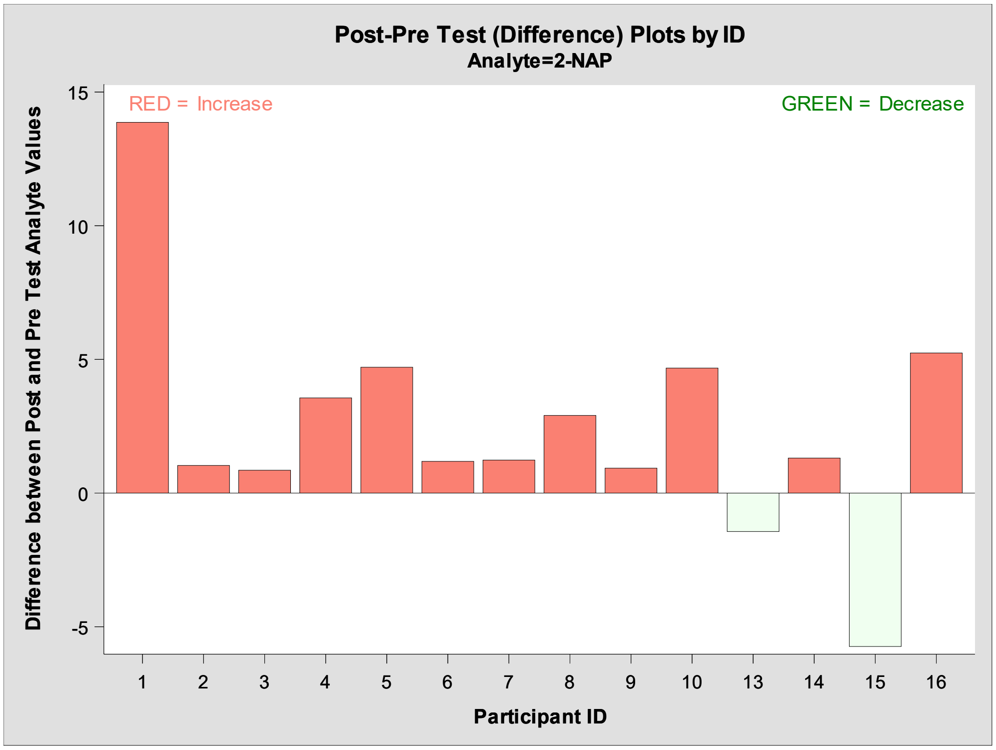

Figure 4-22. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 2-hydroxynaphthalene measurements (µg/g), by participant.

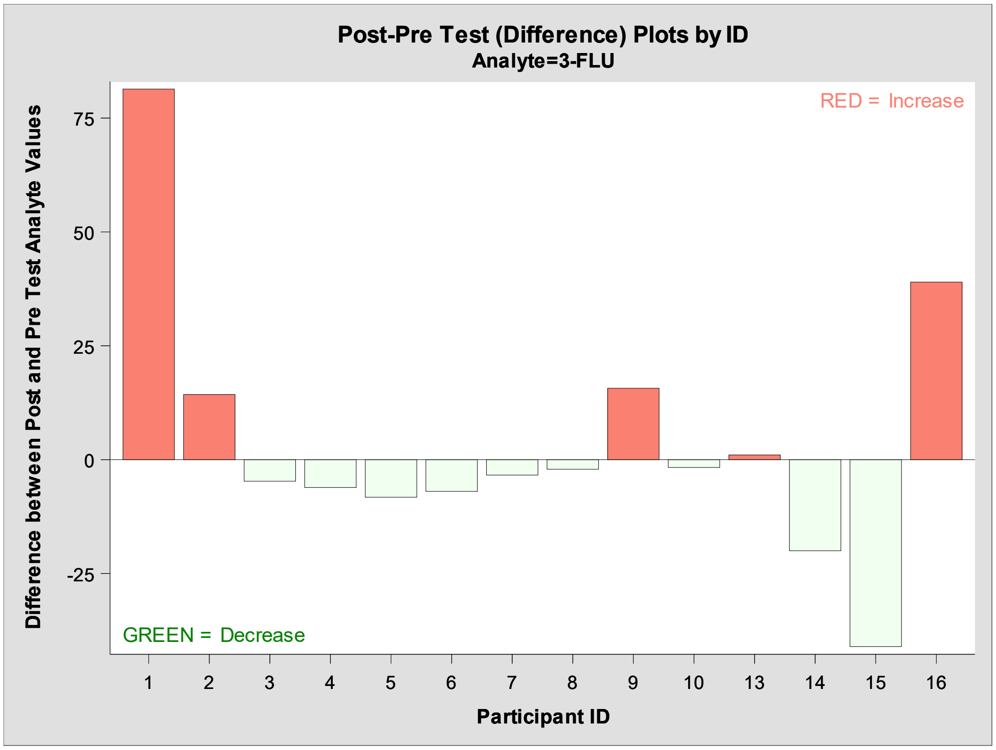

Figure 4-23. Exposure pilot study pre- and post-activity differences in creatinine-adjusted 3-hydroxyfluorene measurements (ng/g), by participant.

The urinary PAH data were not normally distributed as shown in the Shapiro-Wilk test *p*-values and skewness and kurtosis values in Tables 4-47 and 4-48. For all participants, 2-hydroxynaphthalene had the highest pre-activity mean concentration [geometric mean = 6.53 µg/g; 95% confidence interval (CI): 4.63 – 9.19 µg/g], as well as post-activity mean concentration (geometric mean = 8.74 µg/g; 95% CI: 6.37 – 12.00 µg/g). There was a significant difference in mean concentrations when comparing pre- and post-activity levels for 2-hydroxynaphthalene (*p*-value = 0.041; Table 4-47). This difference was increased when comparing pre- and post-activity concentrations from football players only (*p*-value = 0.016; Table 4-48). Although there is weak evidence for a difference in pre- and post-activity for 2-hydroxynaphthalene (*p*-value = 0.041), a Bayes Factor was calculated and confirmed no indication for a real effect. However, there is weak evidence for a difference in pre- and post-activity concentrations of 2-hydroxynaphthalene in football players (*p*-value = 0.016; Table 4-48). All seven football players had increases in 2-hydroxynaphthalene post-activity. While the calculated Bayes Factor indicates weak evidence, this may largely be a result of the small sample size. In general, the small sample size for these statistical analyses is a significant limitation, as statistical power was near or below 20% for most of the statistical tests performed on the data. Note that naphthalene had low values in the field measurement data sets, including tire crumb rubber infill, field air, field dust, field wipe, and drag sled averages, and naphthalene was 4 to over 100 times lower than phenanthrene in these media. Only 17% of the dermal wipe naphthalene measurements were above the quantifiable limit for the football players (Table 4-43).

Table 4-47. Statistical Analysis of Differences in Exposure Pilot Study Pre- and Post-Activity Creatinine-Adjusted Urinary PAH Measurements

PAH	Minimum Difference[a]	Maximum Difference [a]	Median	Mean	Standard Deviation	Skewness	Kurtosis	ProbN[b]	Probt[c]	Probsr[d]
1-Hydroxynaphthalene (µg/g)	-1.25	1.05	0.00	0.08	0.54	-0.43	2.78	0.023	0.596	0.618
2-Hydroxynaphthalene (µg/g)	-5.75	13.9	1.28	2.45	4.32	1.00	3.79	0.048	0.053	0.041
1-Hydroxyphenanthrene (ng/g)	-59.6	95.7	1.78	12.4	43.11	0.94	0.70	0.006	0.301	0.463
2- & 3-Hydroxyphenanthrene (ng/g)	-120	172	0.63	9.12	62.4	0.95	4.42	0.001	0.594	0.820
2-Hydroxyfluorene (ng/g)	-148	105	4.13	4.88	54.7	-1.25	5.44	0.001	0.744	0.153
3-Hydroxyfluorene (ng/g)	-41.1	81.4	-2.75	4.08	28.6	1.51	3.78	0.018	0.603	0.715
1-Hydroxypyrene (ng/g)	-113	75.1	-9.60	-13.6	42.2	-0.28	2.76	0.068	0.249	0.078

[a] These values represent the difference in the pre- and post-activity polycyclic aromatic hydrocarbon (PAH) concentrations. Number of samples = 14.

[b] Shapiro-Wilk test for normality *p*-value

[c] T-test *p*-value

[d] Wilcoxon Signed-Rank test *p*-value

Table 4-48. Statistical Analysis of Differences in Exposure Pilot Study Pre- and Post-Activity Creatine-Adjusted Urinary PAH Measurements, by Sport

PAH	Sport	Minimum Difference[a]	Maximum Difference[a]	Median	Mean	Standard Deviation	Skewness	Kurtosis	ProbN[b]	Probt[c]	Probsr[d]
1-Hydroxynaphthalene (µg/g)	Soccer	-1.25	1.05	0.1	0.13	0.77	-0.68	1.08	0.424	0.673	0.688
1-Hydroxynaphthalene (µg/g)	Football	-0.15	0.45	0	0.03	0.2	2.01	4.66	0.023	0.715	0.875
2-Hydroxynaphthalene (µg/g)	Soccer	-5.75	13.85	1.05	2.16	6.13	1.1	2.16	0.38	0.388	0.578
2-Hydroxynaphthalene (µg/g)	Football	0.95	4.7	2.9	2.75	1.64	0.13	-2.14	0.143	0.004	0.016
1-Hydroxyphenanthrene (ng/g)	Soccer	-59.6	95.7	2.35	13.64	51.32	0.48	0.09	0.45	0.508	0.578
1-Hydroxyphenanthrene (ng/g)	Football	-19.4	93.85	1.2	11.16	37.27	2.39	6.13	0.001	0.458	0.688
2- & 3-Hydroxyphenanthrene (ng/g)	Soccer	-120	172.3	-0.7	18.48	90.25	0.38	1.29	0.326	0.608	1
2- & 3-Hydroxyphenanthrene (ng/g)	Football	-14.2	11.75	0.7	-0.24	9.04	-0.4	-0.54	0.636	0.946	0.813
2-Hydroxyfluorene (ng/g)	Soccer	-148	105.1	4.85	5.31	80.1	-1.05	2.31	0.204	0.866	0.578
2-Hydroxyfluorene (ng/g)	Football	-6.05	18.15	3.4	4.45	7.35	0.81	2.21	0.489	0.16	0.109
3-Hydroxyfluorene (ng/g)	Soccer	-41.1	81.35	1.05	9.99	40.32	0.8	0.66	0.83	0.537	0.813
3-Hydroxyfluorene (ng/g)	Football	-8.25	15.7	-3.4	-1.83	8.12	2.14	5.03	0.009	0.573	0.297
1-Hydroxypyrene (ng/g)	Soccer	-53.7	75.05	-7.3	-5.66	40.4	1.36	3.13	0.101	0.724	0.297
1-Hydroxypyrene (ng/g)	Football	-113	38.05	-12.5	-21.5	45.58	-1.38	3.65	0.066	0.258	0.219

[a] These values represent the difference in the pre- and post-activity polycyclic aromatic hydrocarbon (PAH) concentrations in soccer players (number of samples = 7) and football players (number of samples = 7).

[b] Shapiro-Wilk test for normality *p*-value

[c] T-test *p*-value

[d] Wilcoxon Signed-Rank test *p*-value

When compared with PAH analytes reported in the NHANES data (CDC 2013-2014) for ages 11 to 21 (Table 4-49), the synthetic turf field users had similar mean PAH concentrations for the analytes measured, with exception of 1-hydroxypyrene, 2-hydroxynaphthalene, and 3-hydroxyfluorene (Figure 4-24). The NHANES geometric mean for 1-hydroxypyrene (156 ng/g) was greater than the exposure pilot study participants' pre-activity and post-activity geometric means (84.6 ng/g and 73.8 ng/g, respectively), and the same was true for 3-hydroxyfluorene. The NHANES geometric mean for 3-hydroxyfluorene (80.7 ng/g) was also greater than the exposure pilot study participants' pre- and post-activity geometric means (56.3 ng/g and 54.2 ng/g, respectively). However, for 2-hydroxynaphthalene, the exposure pilot study participants' pre-activity (6.53 µg/g) and post-activity (8.74 µg/g) geometric means were greater than the NHANES geometric mean (4.89 µg/g), but less than and similar to the 2013–2014 NHANES 75th percentile (8.20 µg/g; 95 % CI: 6.52–9.59 µg/g) for 12 to 19 year olds. Pre-activity and post-activity geometric means from the exposure pilot study and the NHANES (CDC 2013-2014) comparison values are presented in Figure 4-24.

Table 4-49. NHANES Weighted and Design-Adjusted Urinary PAH Values (2013-2014) for Ages 11 to 21[a, b]

PAH	Minimum	Maximum	Median	Mean	95% CI	Geo Mean	Standard Error
1-Hydroxynaphthalene (µg/g Crea)	0.13	48.3	0.88	2.47	1.89 – 3.05	1.11	0.08
2-Hydroxynaphthalene (µg/g Crea)	0.58	96.7	4.72	6.98	6.11 – 7.84	4.89	0.25
1-Hydroxyphenanthrene (ng/g Crea)	5.66	830	87.9	112	102 – 121	90.0	3.49
2 & 3-Hydroxyphenanthrene (ng/gCrea)	25.3	1386	107	145	127 – 163	118	5.45
2-Hydroxyfluorene (ng/g Crea)	18.4	1937	148	255	215 – 294	173	9.31
3-Hydroxyfluorene (ng/g Crea)	11.9	1541	68.6	139	109 – 170	80.7	4.72
1-Hydroxypyrene (ng/g Crea)	19.6	2010	147	200	176 – 225	156	8.15

[a] Values from 580 National Health and Nutrition Examination Survey (NHANES 2013-2014) participants, age 11 to 21.

[b] PAH = polycyclic aromatic hydrocarbons; CI = confidence interval; Geo = geometric; Crea = creatine

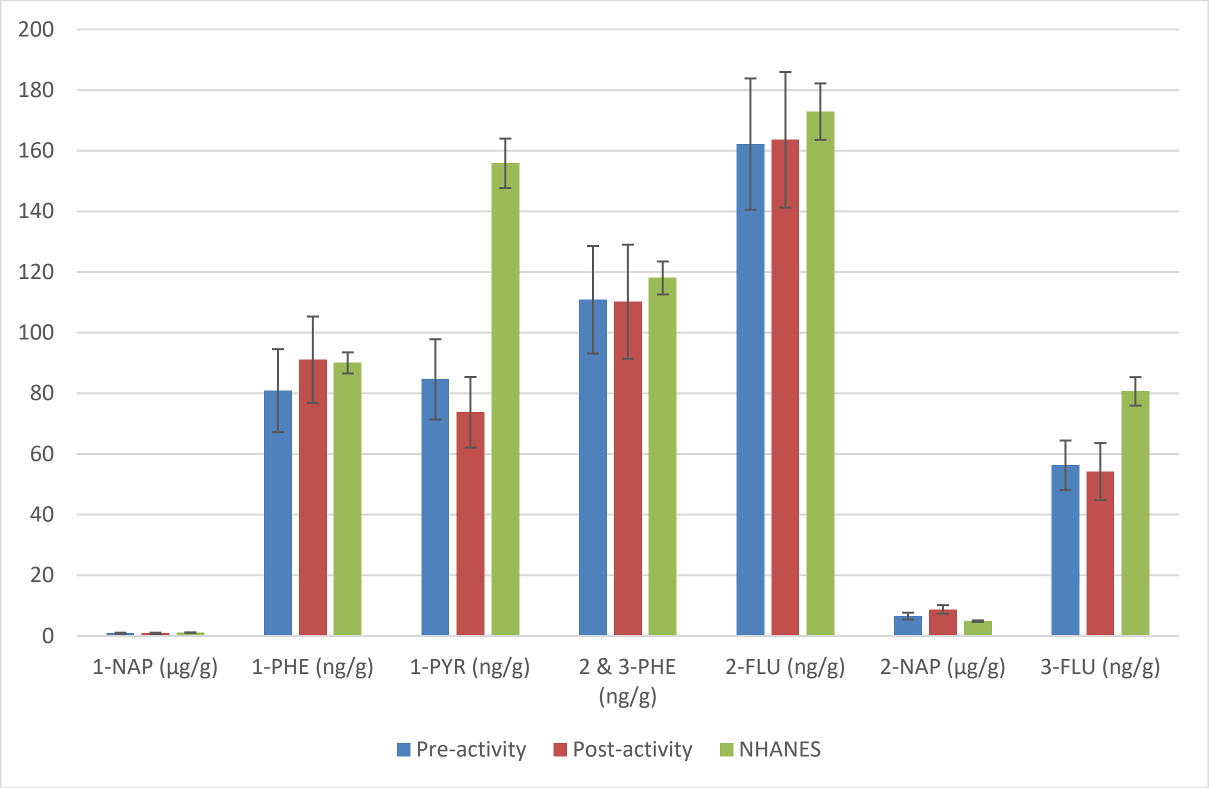

Figure 4-24. Exposure pilot study pre-activity and post-activity creatinine-adjusted urinary PAH geometric means compared to NHANES (2013-2014) geometric mean values for ages 11 to 21.
[PAH = polycyclic aromatic hydrocarbon; 1-NAP = 1-Hydroxynaphthlaene; 1-PHE = 1-Hydroxyphenanthrene; 1-PYR = 1-Hydroxypyrene; 2 & 3-PHE = 2- & 3-Hydroxyphenanthrene; 2-FLU = 2-Hydroxyfluorene; 2-NAP = 2-Hydroxynaphthlaene; 3-FLU = 3-Hydroxyfluorene]

Metals in blood/serum - Pre-activity and post-activity concentrations of metals in blood and serum samples taken in the exposure pilot study are shown in Tables 4-50 and 4-51. When comparing pre-activity measurements to post-activity measurements, there were no significant differences observed in the mean or geometric mean for any of the whole blood metals. Additionally, there were no significant differences observed in pre- and post-activity concentrations for the serum metals (Table 4-52). There were also no significant differences in mean concentrations for pre-activity levels and post-activity levels in football players or in soccer players (Table 4-53). However, toxicokinetics would suggest that few differences in blood or serum metal concentrations would be expected over the short timeframe of a football or soccer practice. Individual differences in pre- and post-activity blood/serum metals concentrations are illustrated in Figures 4-25 through 4-32.

Table 4-50. Exposure Pilot Study Pre- and Post-Activity Blood and Serum Metal Measurements[a, b]

Medium/Metal	Pre-Activity Mean	Pre-Activity Standard Deviation	Pre-Activity Geo Mean	Pre-Activity 95% CI	Post-Activity Mean	Post-Activity Standard Deviation	Post-Activity Geo Mean	Post-Activity 95% CI
Blood cadmium (µg/L)	0.23	0.06	0.22	0.20 – 0.24	0.20	0.07	0.21	0.18 – 0.24
Blood manganese (µg/L)	9.84	2.69	9.51	8.22 – 11.0	9.91	3.63	9.40	7.76 – 11.4
Blood lead (µg/dL)	0.43	0.14	0.41	0.35 – 0.49	0.44	0.16	0.41	0.33 – 0.51
Blood mercury, total (µg/L)	0.78	0.96	0.51	0.32 – 0.81	0.92	1.13	0.61	0.37 – 1.01
Blood selenium (µg/L)	217	15.5	216	208 – 225	222	24.8	221	207 – 235
Serum copper (µg/dL)	99.2	9.19	98.8	94.0 – 104	98.3	11.4	97.7	91.2 – 105
Serum selenium (µg/L)	125	9.67	124	120 – 129	127	13.5	127	120 – 134
Serum zinc (µg/dL)	83.7	10.1	83.1	78.0 – 88.6	83.4	10.5	82.7	76.2 – 90.0

[a] Geo = Geometric; CI = Confidence interval; dL = deciliter

[b] Number of samples = 13 (6 soccer players and 7 football players)

Table 4-51. Exposure Pilot Study Pre- and Post-Activity Blood and Serum Metal Measurements, by Sport

Medium/Metal	Sport	Pre-Activity Mean	Pre-Activity Standard Deviation	Pre-Activity Geo Mean	Pre-Activity 95% CI	Post-Activity Mean	Post-Activity Standard Deviation	Post-Activity Geo Mean	Post-Activity 95% CI
Blood cadmium (µg/L)	Soccer	0.24	0.08	0.22	0.18 – 0.27	0.23	0.08	0.22	0.17 – 0.28
Blood cadmium (µg/L)	Football	0.21	0.02	0.21	0.2 – 0.23	0.18	0.04	0.19	0.17 – 0.21
Blood manganese (µg/L)	Soccer	8.58	2.23	8.32	6.78 – 10.2	8.37	2.09	8.12	6.62 – 9.96
Blood manganese (µg/L)	Football	10.9	2.73	10.7	9.07 – 12.51	11.8	4.43	11.2	8.56 – 14.6
Blood lead (µg/dL)	Soccer	0.42	0.17	0.39	0.29 – 0.52	0.43	0.18	0.39	0.28 – 0.54
Blood lead (µg/dL)	Football	0.44	0.11	0.43	0.36 – 0.52	0.45	0.15	0.44	0.34 – 0.56
Blood mercury, total (µg/L)	Soccer	0.59	0.27	0.52	0.35 – 0.79	0.61	0.29	0.54	0.35 – 0.83
Blood mercury, total (µg/L)	Football	0.94	1.31	0.5	0.22 – 1.09	1.3	1.66	0.71	0.27 – 1.84
Blood selenium (µg/L)	Soccer	215	20.7	214	200 – 230	220	32.9	218	196 – 243
Blood selenium (µg/L)	Football	219	10.7	218	211 – 226	224	13.4	224	213 – 235
Serum copper (µg/dL)	Soccer	99.3	10.4	99.0	91.4 – 107	99.7	12.8	99.0	89.8 – 109
Serum copper (µg/dL)	Football	99	8.93	99.0	92.7 – 105	96.6	10.8	96.1	87.8 – 105
Serum selenium (µg/L)	Soccer	127	13.7	126	117 – 136	132	16.0	131	120 – 143
Serum selenium (µg/L)	Football	123	4.88	123	120 – 126	122	8.37	122	115 – 129
Serum zinc (µg/dL)	Soccer	87.7	13.5	86.7	76.8 – 97.9	82.5	13.5	81.4	70.9 – 93.5
Serum zinc (µg/dL)	Football	80.3	4.54	80.2	77.1 – 83.4	84.4	6.77	84.2	78.9 – 89.8

[a] Geo = Geometric; CI = Confidence interval; dL = deciliter

[b] Number of soccer player samples = 6; Number of football player samples = 7

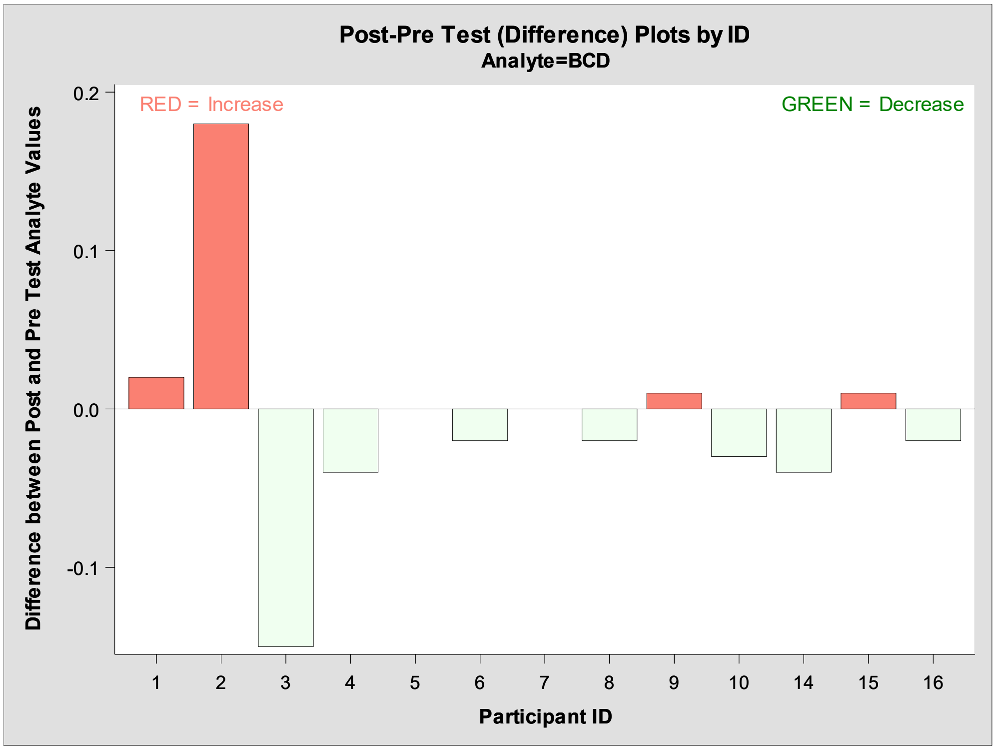

Figure 4-25. Exposure pilot study pre- and post-activity differences in blood cadmium measurements (μg/L), by participant.

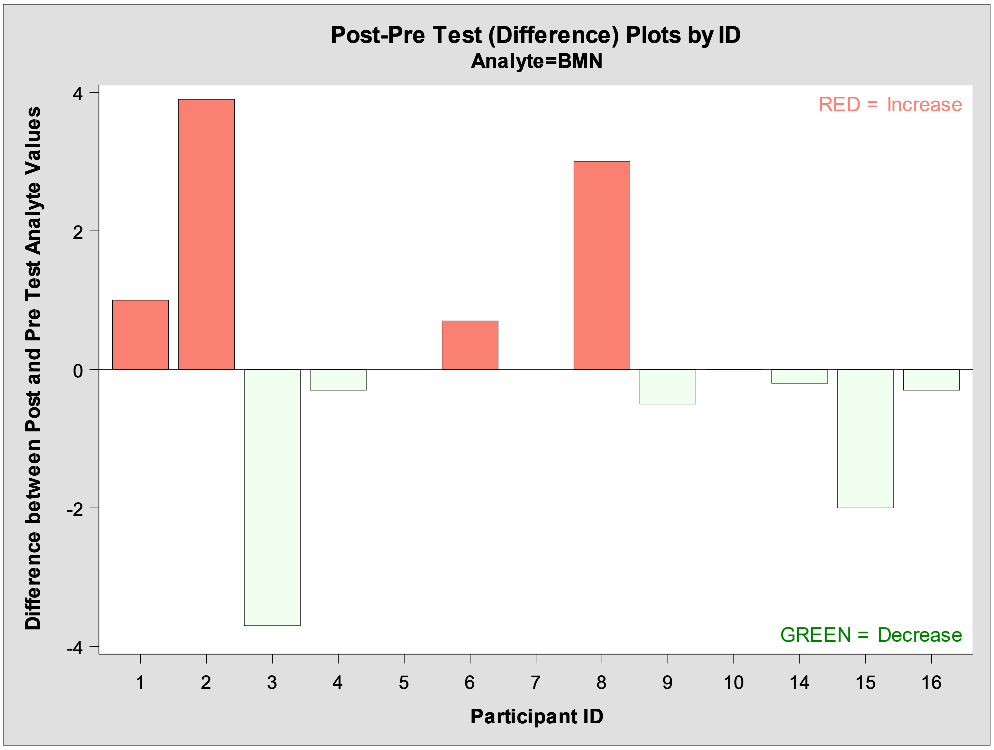

Figure 4-26. Exposure pilot study pre- and post-activity differences plots in blood manganese measurements (μg/L), by participant.

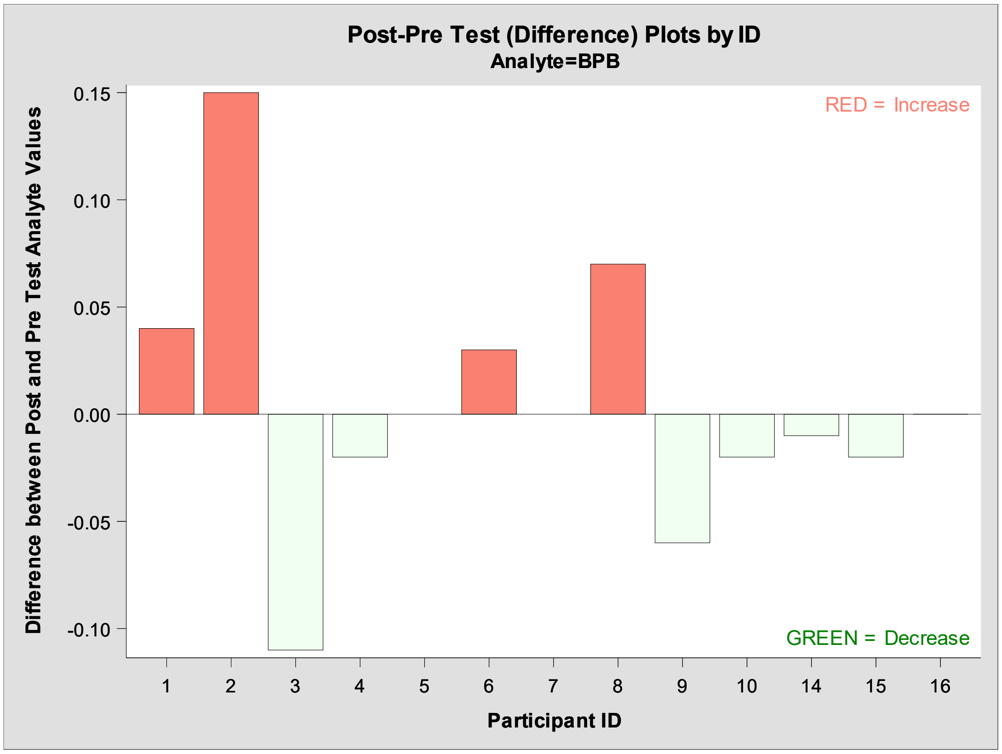

Figure 4-27. Exposure pilot study pre- and post-activity differences in blood lead measurements (µg/dL), by participant.

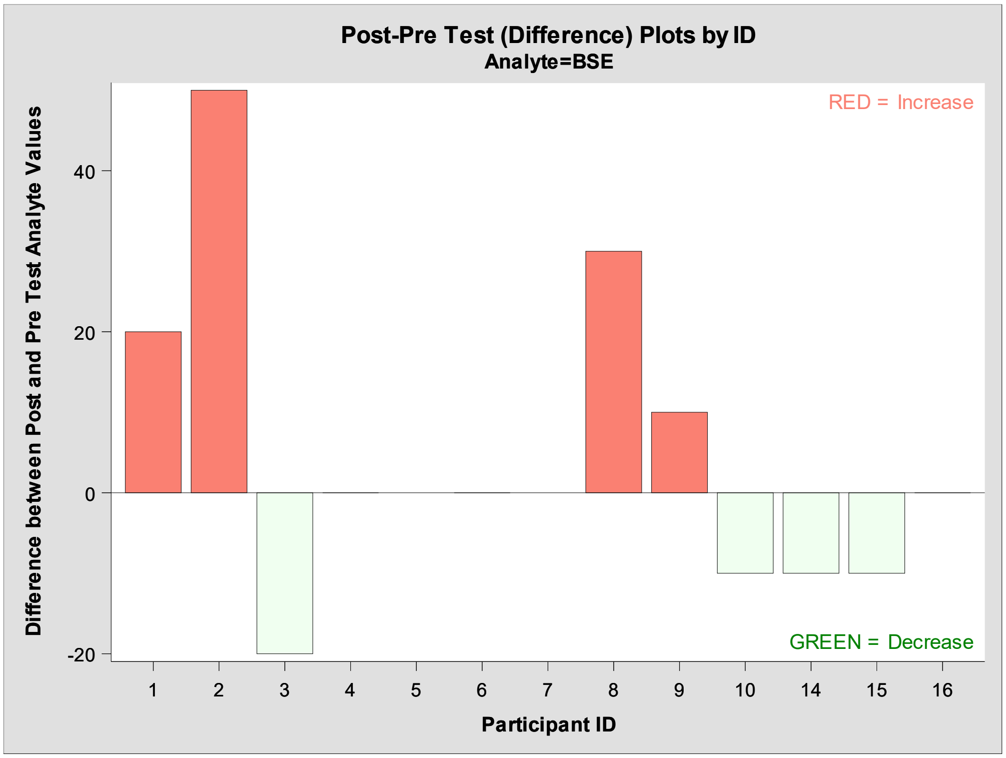

Figure 4-28. Exposure pilot study pre- and post-activity differences in blood selenium measurements (µg/L), by participant.

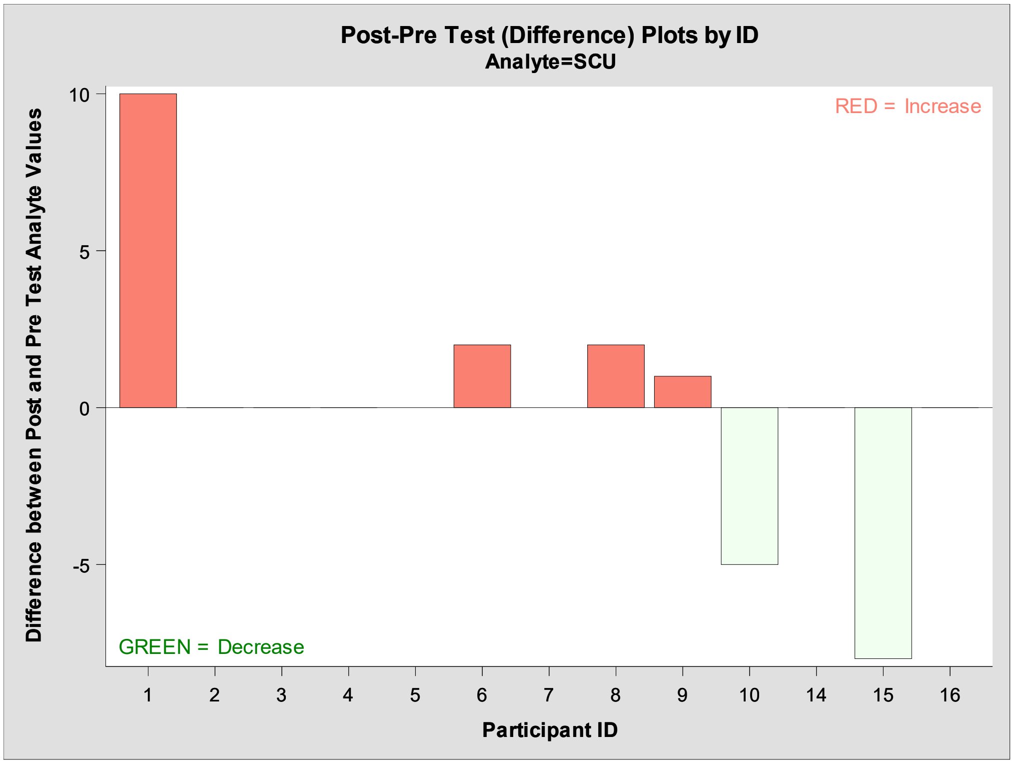

Figure 4-29. Exposure pilot study pre- and post-activity differences in serum copper measurements (µg/dL), by participant.

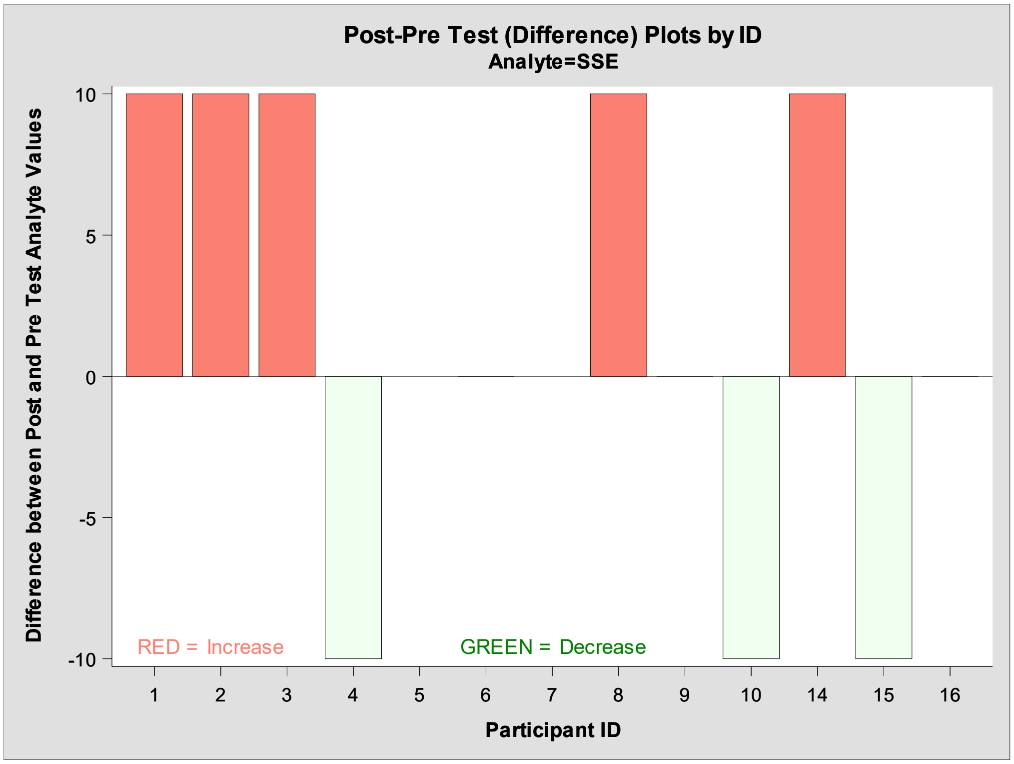

Figure 4-30. Exposure pilot study pre- and post-activity differences in serum selenium measurements (µg/L), by participant.

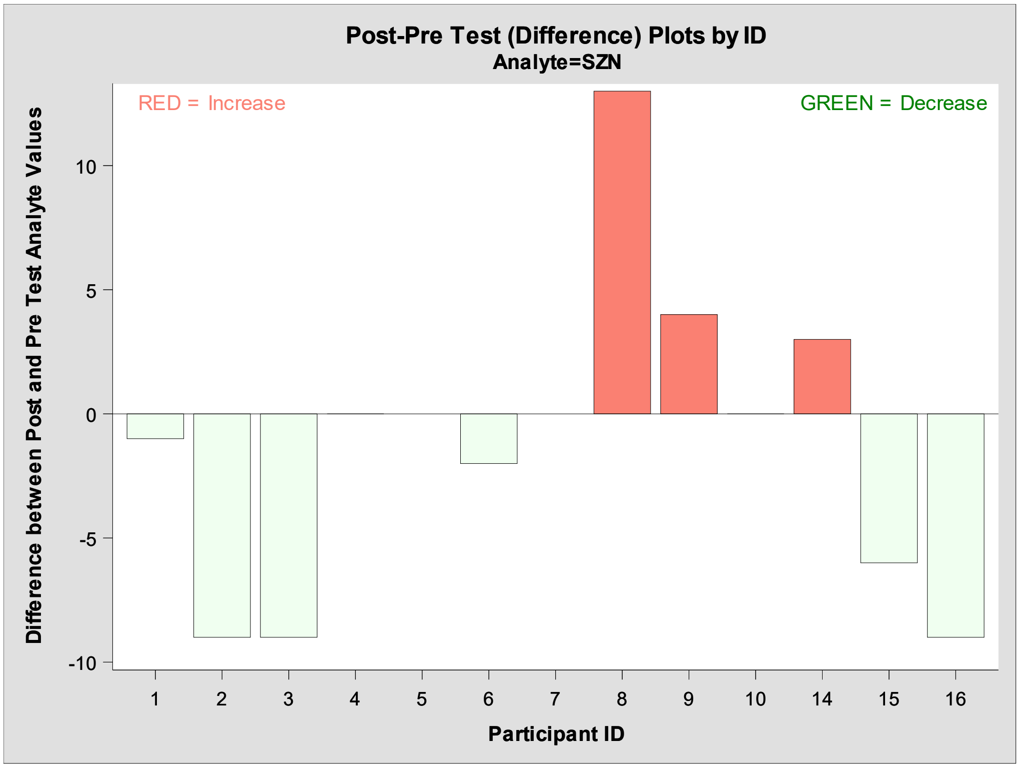

Figure 4-31. Exposure pilot study pre- and post-activity differences in serum zinc measurements (µg/dL), by participant.

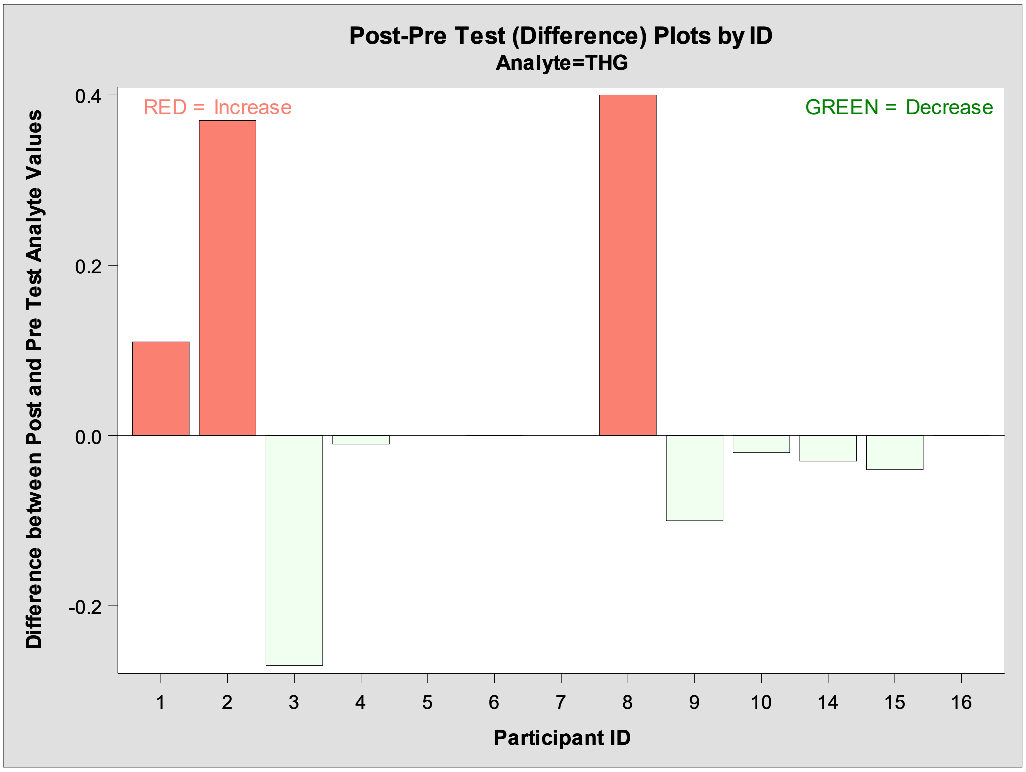

Figure 4-32. Exposure pilot study pre- and post-activity differences in total blood mercury measurements (µg/L), by participant.

Overall, the blood metals and serum metals results showed no difference in concentrations before or after practice on a synthetic turf field with tire crumb rubber infill.

Table 4-52. Statistical Analysis of Differences in Exposure Pilot Study Pre- and Post-Activity Whole Blood Metals and Serum Metals Measurements

Metal	Minimum Difference[a]	Maximum Difference[a]	Median	Mean	Standard Deviation	Skewness	Kurtosis	ProbN[b]	Probt[c]	Probsr[d]
Blood cadmium (µg/L)	-0.15	0.20	0.00	-0.01	0.08	1.31	4.72	0.004	0.724	0.563
Blood manganese (µg/L)	-3.70	3.90	-0.20	0.15	2.09	0.13	0.71	0.567	0.822	0.902
Blood lead (µg/dL)	-0.10	0.15	0.00	0.01	0.06	0.45	1.82	0.229	0.493	0.656
Blood mercury, total (µg/L)	-0.25	0.40	0.00	0.04	0.19	0.94	0.82	0.065	0.537	0.703
Blood selenium (µg/L)	-20.0	50.00	0.00	5.45	20.7	1.08	0.79	0.200	0.402	0.555
Serum copper (µg/dL)	-8.00	10.00	0.00	0.18	4.45	0.38	2.65	0.049	0.895	0.813
Serum selenium (µg/L)	-10.0	10.00	0.00	1.82	8.74	-0.41	-1.62	0.006	0.506	0.727
Serum zinc (µg/dL)	-9.00	13.00	-1.00	-1.45	6.74	0.75	0.72	0.243	0.491	0.492

[a] These values represent the difference in the pre- and post-activity whole blood and serum metals concentrations. Number of samples = 11.

[b] Shapiro-Wilk test for normality *p*-value

[c] T-test *p*-value

[d] Wilcoxon Signed-Rank test *p*-value

Table 4-53. Statistical Analysis of Differences in Exposure Pilot Study Pre- and Post-Activity Whole Blood Metals and Serum Metals Measurements, by Sport

Metal	Sport	Minimum Difference[a]	Maximum Difference[a]	Median	Mean	Standard Deviation	Skewness	Kurtosis	ProbN[b]	Probt[c]	Probsr[d]
Blood cadmium (µg/L)	Soccer	-0.15	0.2	0	0	0.11	0.91	2.5	0.266	1	1
Blood cadmium (µg/L)	Football	-0.05	0	0	-0.02	0.03	-0.61	-3.33	0.006	0.178	0.5
Blood manganese (µg/L)	Soccer	-3.7	3.9	-0.25	-0.22	2.6	0.4	0.61	0.927	0.846	0.844
Blood manganese (µg/L)	Football	-0.5	3	0	0.58	1.43	1.73	2.96	0.096	0.415	0.625
Blood lead (µ/dL)	Soccer	-0.1	0.15	0	0.02	0.08	0.44	1.67	0.48	0.638	0.75
Blood lead (µ/dL)	Football	-0.05	0.05	0	0.01	0.04	-0.51	-0.61	0.314	0.621	1
Blood mercury, total (µg/L)	Soccer	-0.25	0.35	-0.03	0.02	0.2	0.69	1.53	0.678	0.846	1
Blood mercury, total (µg/L)	Football	-0.1	0.4	0	0.06	0.19	1.94	4.17	0.018	0.529	1
Blood selenium (µg/L)	Soccer	-20	50	-5	5	25.9	1.25	0.99	0.272	0.656	0.938
Blood selenium (µg/L)	Football	-10	30	0	6	15.2	1.12	1.46	0.492	0.426	0.75
Serum copper (µg/dL)	Soccer	-8	10	0	0.33	5.72	0.52	2.64	0.088	0.892	1
Serum copper (µg/dL)	Football	-5	2	1	0	2.92	-1.82	3.38	0.05	1	0.875
Serum selenium (µg/L)	Soccer	-10	10	10	5	8.37	-1.54	1.43	0.006	0.203	0.375
Serum selenium (µg/L)	Football	-10	10	0	-2	8.37	0.51	-0.61	0.314	0.621	1
Serum zinc (µg/dL)	Soccer	-9	3	-7.5	-5.17	5.08	1.03	-0.56	0.075	0.055	0.094
Serum zinc (µg/dL)	Football	-2	13	0	3	6	1.59	2.41	0.14	0.326	0.5

[a] These values represent the difference in the pre- and post-activity whole blood and serum metals concentrations in soccer players (number of samples = 6) and football players (number of samples = 5).

[b] Shapiro-Wilk test for normality *p*-value

[c] T-test *p*-value

[d] Wilcoxon Signed-Rank test *p*-value

When compared with NHANES (2013-2014) weighted and design-adjusted blood and serum metal mean concentrations for ages 11 to 21 (Table 4-54), the whole blood or serum metal levels for the synthetic turf field users were similar, with the exception of blood selenium. The pre-activity (216 µg/g) and post-activity (221 µg/g) geometric means for blood selenium were greater than the NHANES geometric mean (190 µg/g). However, selenium was below detection limits in the tire crumb rubber analyses and field environmental media measurements. Pre-activity, post-activity, and the NHANES comparison values are illustrated in Figures 4-33 and 4-34.

Table 4-54. NHANES Weighted and Design-Adjusted Blood and Serum Metal Values (2013-2014) for Ages 11 to 21[a,b]

PAH	Minimum	Maximum	Median	Mean	95% CI	Geo Mean	Standard Error
Blood cadmium (µg/L)	0.07	3.54	0.12	0.22	0.18 – 0.26	0.14	0.01
Blood lead (µg/dL)	0.07	15.6	0.47	0.65	0.56 – 0.75	0.51	0.03
Blood manganese (µg/L)	4.33	29.2	9.77	10.6	10.1 – 11.1	10.1	0.23
Blood mercury, total (µg/L)	0.20	13.3	0.37	0.63	0.52 – 0.74	0.42	0.02
Blood selenium (µg/L)	129	272	191	191	188 – 195	190	1.72
Serum copper (µg/dL)	60.9	298	105	111	109 – 114	108	1.13
Serum selenium (µg/L)	87.4	183	123	125	123 – 128	124	1.28
Serum zinc (µg/dL)	44.5	146	83.1	84.33	81.7 – 87.0	82.9	1.20

[a] Values from 548 National Health and Nutrition Examination Survey (NHANES 2013-2014) participants, age 11 to 21.

[b] PAH = polycyclic aromatic hydrocarbons; CI = confidence interval; Geo = geometric

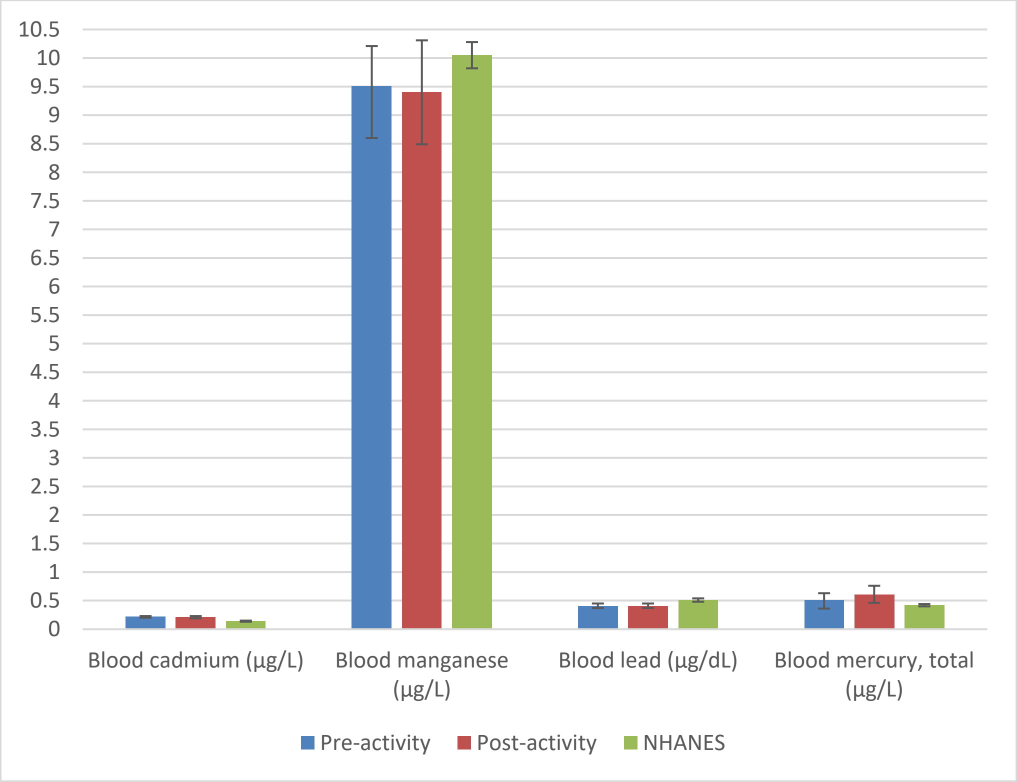

Figure 4-33. Exposure pilot study pre-activity and post-activity blood cadmium, blood manganese, blood lead and total blood mercury geometric mean levels compared to NHANES (2013-2014) weighted and design-adjusted values for Ages 11-21.

[NHANES = National Health and Nutrition Examination Survey]

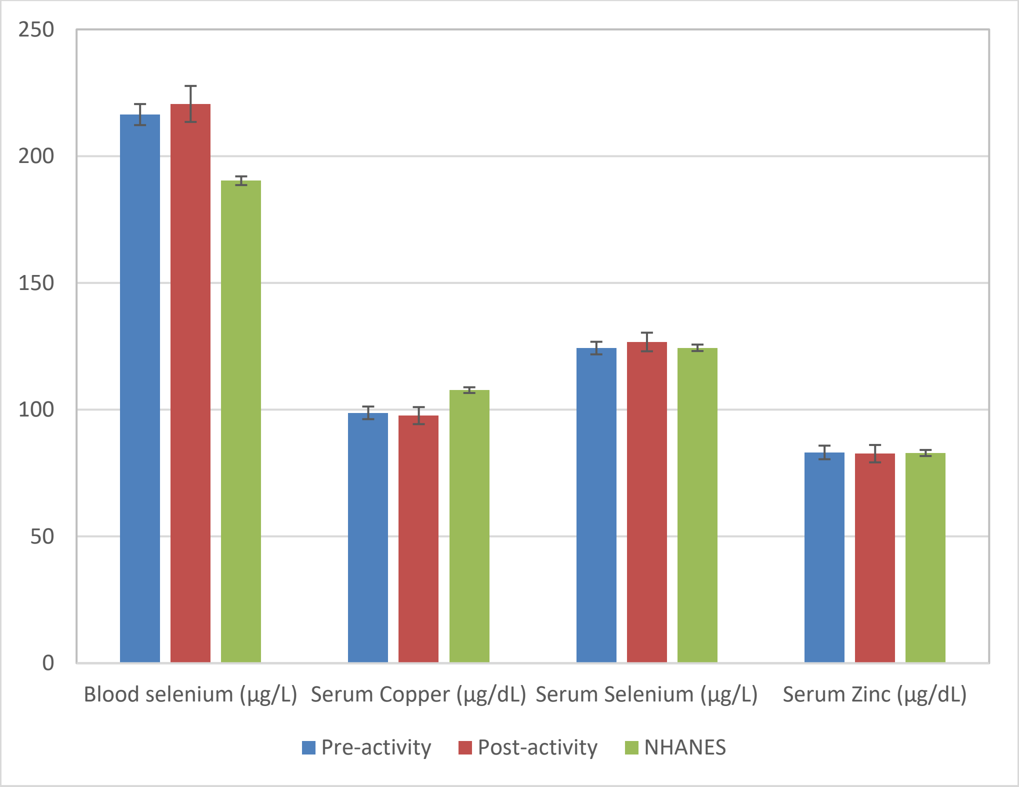

Figure 4-34. Exposure pilot study pre-activity and post-activity blood selenium, serum copper, serum selenium and serum zinc geometric mean levels compared to NHANES (2013-2014) weighted and design-adjusted values for ages 11-21. [NHANES = National Health and Nutrition Examination Survey]

4.6 Initial Testing of Silicone Wristbands

Collecting samples to measure personal exposures to chemicals is very challenging for people engaged in sport activities on synthetic turf fields and for athletic and physical training activities in general. Personal sampling devices must be relatively small, must not restrict research participant activities, and must be safe to wear, even during vigorous activities. Due to the relatively short activity periods and relatively low concentrations of chemicals, personal sampling devices must also overcome the challenge of collecting sufficient chemical amounts for accurate measurements.

The use of silicone wristbands as a tool for personal and area chemical sample collection is an active area of exposure assessment research. Silicone wristbands can serve as passive samplers for many types of organic chemicals and are especially effective for chemicals present in air. With no power requirements, minimal participant burden and interaction requirements and their ease of use, these silicone wristbands may be useful for personal sample collection during sport activities. There is interest in how silicone wristbands might be used in future exposure measurement studies for synthetic field users, where bulky air sampling equipment can’t be worn safely during intense athletic activity.

A critical question regarding their suitability for synthetic turf field personal sampling is whether, and at what rate, they collect chemicals of interest associated with tire crumb rubber or other field materials. The Part 1 Report described initial wristband testing in the presence of tire crumb rubber in controlled dynamic chamber experiments. Another important question is the amount of time needed for wristbands to be able to collect sufficient amounts of chemicals emitted from tire crumb rubber in synthetic field environments to enable successful analysis. In order to further assess the potential utility of wristbands for synthetic field users, a set of experiments was performed by deploying wristbands as passive samplers for organic chemicals in the air at an indoor and outdoor synthetic turf field.

4.6.1 Feasibility Assessment of Wristbands at Synthetic Turf Fields

A pilot-scale feasibility assessment was implemented through a contract with Oregon State University (OSU) to evaluate the performance of silicone wristbands deployed at indoor and outdoor synthetic turf field facilities with tire crumb rubber infill. The overall goal of the study was to evaluate the effectiveness of the approach for measuring tire crumb rubber related chemicals in the air at synthetic turf fields using the wristbands as stationary fixed monitors. Wristbands were deployed for seven days at multiple locations in or near one indoor and one outdoor synthetic turf field facility with tire crumb rubber, and in the outdoor ambient air generally upwind and away from fields and other local emission sources. The wristbands were analyzed quantitatively for select PAHs, select oxygenated-PAHs, and select VOCs. Another analysis method was applied that provides screening results for approximately 1500 chemicals. The OSU sampling and analysis report is provided in Appendix H.

Three wristband sampling locations were deployed at various locations inside an indoor facility containing a synthetic turf field with tire crumb rubber. Three wristband sampling locations were deployed at the perimeter of an outdoor synthetic turf field with tire crumb rubber. A final sampling location was placed on a lamppost above a natural grass area next to a walkway, approximately 18 meters from the outdoor field to serve as a background air sampler. Samplers were deployed for a seven-day duration. On six of those seven days the prevailing wind across the outdoor field was in a direction away from the lamppost-mounted background air sampler. Temperatures during deployment ranged from 3.1 to 22.7 °C with a mean of 9.7 °C.

A sum measure of 63 PAH analytes was obtained for the silicone wristband samplers following the 7-day deployment. The ∑PAH results ranged from 72 to 105 ng/g for three indoor samplers, 29 to 34 ng/g for three outdoor field samplers, and 32 ng/g for the background sampler. Field blank values for ∑PAH were 0 ng/g. The number of individual targeted PAHs with measurable amounts ranged from 13 to 17. A set of 22 oxidized PAH (OPAH) derivatives were also measured. The amounts of OPAH analytes were below the detection limit for all samples and blanks, with the exception of benzo(c)phenanthrene(1,4)quinone (6.7 ng/g) and benzo(cd)pyrenone (0.8 ng/g) measured in one outdoor field sample.

A sum measure of 29 VOC analytes was also obtained. At two of the indoor locations, measured ∑VOC values were 69 and 87 ng/g, while at the third location (a doorway atrium) the measured value was 7.1 ng/g. At the outdoor location, the ∑VOC values were 2.1, 39, and 90 ng/g. The background air value was 32 ng/g. Field blank values for ∑VOC were 0.3 and 15 ng/g. The number of individual targeted VOCs with measurable amounts ranged from 1 in one of the blanks to 9 in one of the outdoor field locations. Several of the VOCs measured in field samples were also measured in the background air sample and three were also measured in at least one of the two field blanks.

Additional wristband analyses included a broad analyte presence/absence screen for 1528 chemicals. Between two and eight analytes were detected in the field samples. More analytes were detected in indoor field samples (6 to 8) than outdoor field samples (2 – 4). Benzothiazole, a chemical associated with tire crumb rubber, was observed in all field samples and was absent in the background air sample. Three analytes (naphthalene, bis(2-ethylhexyl)phthalate, and 1-methylnapthalene) were measured in the background air sample, and these analytes also appeared in one or more field sample.

In general, more targeted analytes were detectable and sometimes found at higher concentrations in the indoor field wristband samples compared to samples collected at the outdoor field and in the background air sample. Samples collected at the outdoor field had ∑PAH concentrations similar to the background air level. ∑VOC measurements were more variable, with some but not all indoor and outdoor field samples having higher levels than the background air. Relatively few of the 1528 screening analytes were detected in any sample.

While this feasibility study provided information on the potential for silicone wristbands to be used as synthetic turf field facility area monitors, additional research will be needed to further assess the silicone wristbands for possible use as personal monitors for synthetic turf field users in the future.

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5.0 Assessing Exposure Pathway Modeling

5.1 Exposure Pathway Modeling Methods

5.1.1 Research Design Summary

Accurate estimates of exposures to chemicals from tire crumb rubber on synthetic turf fields are needed to investigate potential health risks among athletes and bystanders. Athletes may be exposed via the inhalation, dermal and ingestional routes, while bystanders are likely to encounter only downwind gasses and experience much lower exposures. Several approaches for calculating such estimates have been reported (Peterson, Lemay, Shubin, & Prueitt, 2018; RIVM, 2017; Ginsberg, et al., 2011; ECHA, 2017; Kim, et al., 2012). Accurate exposure estimates require sufficient information on chemical concentrations in all relevant exposure media, an understanding of how people come into contact with those media under different conditions and scenarios, and knowledge of the extent to which chemicals are transferred to people and into relevant tissues. Unfortunately, information for many of these important parameters either remains relatively limited or does not yet exist, particularly for dermal and ingestion pathways from synthetic turf field sources. In lieu of such information, researchers have made necessary assumptions for some exposure parameters and have often used what are believed to be conservative values when data are not available. More data are needed to reduce reliance on these assumptions and improve modeling of inhalation, dermal and ingestion pathways for human exposure to tire crumb rubber chemicals at synthetic turf fields.

Exposure pathway modeling for athletes using synthetic turf fields with tire crumb rubber infill was performed using data available from the literature and supplemented with data collected in this exposure pilot study. The four primary objectives of this modeling were to:

- Elucidate which exposure pathways are likely to be the biggest contributors to total exposure for different types of tire crumb rubber constituents;
- Explore whether data produced in the federal study can improve our exposure estimates, particularly for the dermal and ingestion pathways;
- Assess the availability, robustness and adequacy of tire crumb rubber data, exposure measurement data and the data needed for exposure model parameters to determine the accuracy and uncertainties in exposure estimations for athletes using synthetic turf fields; and
- Prepare modeled estimates of background exposures from residential and dietary sources for comparison with exposure estimates for synthetic turf field users.

Six chemical substances associated with synthetic turf fields and tire crumb rubber were selected for exposure pathway modeling – benzo[a]pyrene, pyrene, benzothiazole, methyl isobutyl ketone, lead and zinc. They were selected based on the availability of previous measurement data and represent a range of physical and chemical properties (Table 5-1). Pyrene was selected because it is often reported in the highest concentrations among polycyclic aromatic hydrocarbons (PAHs) in tire crumb rubber, while benzo[a]pyrene has very low volatility and has been measured in tire crumb rubber in several studies. Benzothiazole is on the more volatile end of the semivolatile organic compound (SVOC) spectrum and has been measured in both synthetic turf field air and tire crumb rubber. Methyl isobutyl ketone is a volatile organic compound (VOC) constituent of tire crumb rubber that has been measured in the air above synthetic turf fields. Lead and zinc are among the metals most often measured in tire crumb rubber studies.

Table 5-1. Select Physico-chemical Properties of Chemicals Used in Exposure Pathway Modeling in this Study (Kim, et al., 2016; U.S. EPA, 2016; Sander, 2015)[a]

Chemical	CAS Number[b]	Class	Molecular Weight (g/mol)	LogK_{ow}[c]	Henry's Law Constant	Vapor Pressure (mmHg)	Density (g/cm^3)	Solubility (mg/L @ 25 °C, where applicable)
Benzo[a]pyrene	50-32-8	PAH SVOC	252.32	6.13	4.57E-07 atm-m^3/mol	5.49E-09 @ 25 °C	1.35	1.62E-03 in H_2O; soluble in benzene, toluene, xylene and ether; slightly soluble in alcohol
Pyrene	129-00-0	PAH SVOC	202.26	4.88	1.19E-05 atm-m^3/mol	4.50E-06 @ 25 °C	1.27	0.135 in H_2O; soluble in ethanol, ethyl ether, benzene and toluene; slightly soluble in carbon tetrachloride
Benzothiazole	95-16-9	SVOC	135.18	2.0 (experimental)	3.70E-07 atm-m^3/mol	0.014 @ 25 °C	1.25	Slightly soluble in H_2O; very soluble in ether; soluble in acetone
Methyl isobutyl ketone	108-10-1	VOC	100.16	1.31	7.00E-2 mol/m^3 Pa	19.9 @ 25 °C	0.80	19,000 in H_2O; miscible with ethanol, ether, acetone, benzene and most organic solvents; soluble in chloroform
Lead (elemental)	7439-92-1	Metal	207.20	No Data	No Data	1.77 @ 1000 °C	11.3	Insoluble in H_2O;[d] Soluble in dilute HNO_3
Zinc (elemental)	7440-66-6	Metal	65.38	No Data	No Data	1.10E-08 @ 127 °C	7.1	Insoluble in H_2O; [d] Soluble in acids/alkalines

[a] PAH = polycyclic aromatic hydrocarbons; SVOC = semivolatile organic compound; VOC = volatile organic compound; mmHg = millimeters of mercury; H_2O = water; HNO_3 = nitric acid

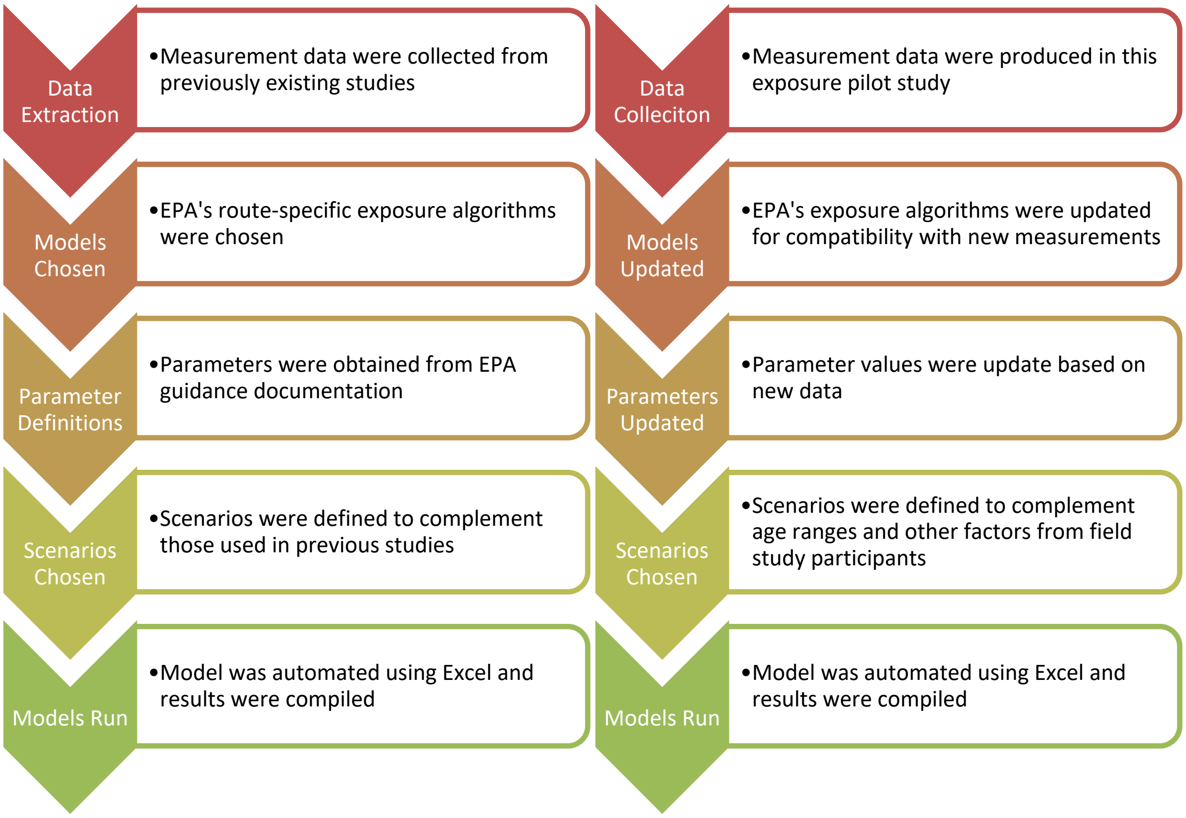
[b] Unique numerical identifier assigned by the Chemical Abstracts Service (CAS)

[c] K_{ow} = octanol/water partition coefficient

[d] Metal salts are soluble in water

Exposure pathway algorithms published in EPA's Guidelines for Exposure Assessment (U.S. EPA, 1992) were employed in this exposure pathway modeling as standard approaches for exposure estimation (U.S. EPA, 2013). Model parameter values were taken from EPA's Exposure Factors Handbook (U.S EPA, 2011b), where these values were judged to be applicable (e.g., inhalation rates). Where not applicable, parameter values more appropriate for the athlete exposure scenarios (e.g., exposure durations) were obtained from the literature or other EPA documents, as presented in section 5.1.2. Exposure scenarios were developed for youth and adult athletes, informed in part by scenarios considered by other researchers. Exposure factor and scenario values were compared to those used by several other research organizations.

Inhalation, dermal and ingestion exposure pathway estimates were calculated for the select tire crumb rubber constituents using an algorithm-based approach, extant data from previous studies and data from field measurements in this exposure pilot study. The pathway-specific exposure estimates were calculated for each of the six chemical substances using the extant data and were compared to identify the dominant pathway of exposure for each chemical substance (with the exception of methyl isobutyl ketone, for which only the inhalation pathway was estimated). The pathway-specific estimates were then re-calculated using tire crumb measurement data and exposure measurement data produced in this exposure pilot study. These results were compared with the previous pathway-specific estimates generated using the extant data from other studies to assess whether additional information from the field surface wipe, dust and dermal measurements (not previously available) might change estimates for dermal and ingestion pathways. This process is presented in Figure 5-1.


Data Extraction
- Measurement data were collected from previously existing studies

Models Chosen
- EPA's route-specific exposure algorithms were chosen

Parameter Definitions
- Parameters were obtained from EPA guidance documentation

Scenarios Chosen
- Scenarios were defined to complement those used in previous studies

Models Run
- Model was automated using Excel and results were compiled

Data Colleciton
- Measurement data were produced in this exposure pilot study

Models Updated
- EPA's exposure algorithms were updated for compatibility with new measurements

Parameters Updated
- Parameter values were update based on new data

Scenarios Chosen
- Scenarios were defined to complement age ranges and other factors from field study participants

Models Run
- Model was automated using Excel and results were compiled

Figure 5-1. Process for generating pathway-specific exposure estimates using both existing data (on left) and new data from this exposure pilot study (on right).

Finally, the availability, robustness and adequacy of tire crumb rubber data, exposure measurement data and the data needed for exposure model parameters were assessed to determine the accuracy and uncertainty of individual and cumulative chemical exposure estimates.

5.1.2 Synthetic Turf Field User Exposure Estimation Using Existing Measurements

To aid in exposure characterization, extant data from previous studies were used to obtain chemical concentration information, define parameter values and identify exposure scenarios to be applied for inhalation, dermal and ingestion exposure pathway estimates (Figure 5-2). Initially, five chemicals of interest were identified – lead, methyl isobutyl ketone, benzothiazole, pyrene and benzo[a]pyrene. Upon further discussion, zinc was added to the chemicals of interest due to its presence in tire crumb rubber at relatively high concentrations.

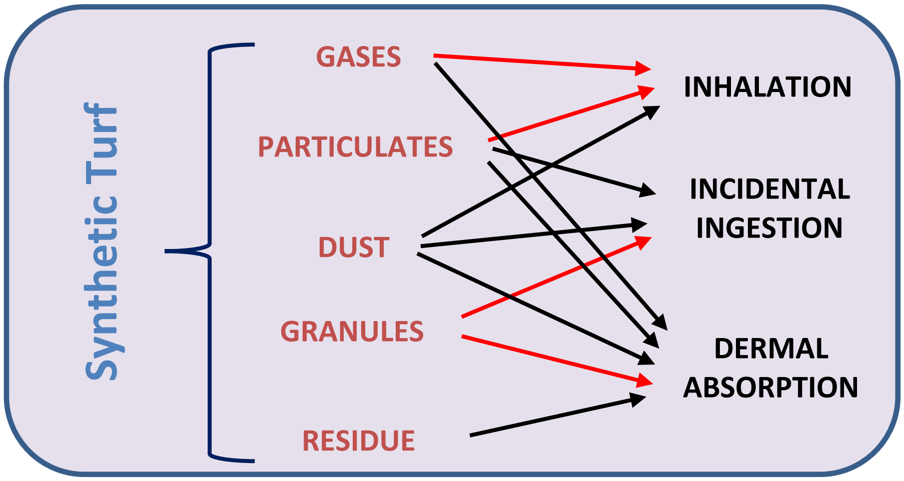


Figure 5-2. Diagram of exposure pathway modeling, showing possible media for each route-specific exposure estimate. Red arrows designate media employed for estimates using data from previous studies.

Measurement values for each chemical of interest were initially identified and extracted from the Literature Review/Gap Analysis (LRGA) spreadsheet available in Appendix C of the Part 1 Report (U.S. EPA, CDC/ ATSDR, & CPSC, 2016b). The original study documents referenced in the LRGA spreadsheet were then reviewed for additional data on the chemicals of interest. Air, dust, tire crumb or crumb rubber granules, field surface residue and bioaccessibility measurements (i.e., quantity of a compound released from its matrix) measurements in synthetic fluids were determined to be relevant measurements of interest for the exposure pathway modeling effort. Leachate studies and their measurement values (deemed more relevant for ecological studies) were excluded from the data extraction, as were measurements from turf blades and material classified as anything other than tire crumb or crumb rubber.

A new Excel spreadsheet was created that included for the chemicals of interest, an entry for each relevant reference study identified in the LRGA, sortable by chemical name and reference number (as found in the LRGA spreadsheet). For each entry, data extraction was carried out by performing a multiple keyword search for each chemical in the reference study (e.g., for lead, both "lead" and "Pb" were searched). The following study-specific data were extracted for each entry, where available: reference information; location of the study; chemical name; medium; medium type; additional information to classify the medium; number of measured values; limit of detection (LOD), if given;

percent of samples greater than the LOD; minimum and maximum measured values; and reported descriptive statistics, including arithmetic and geometric means and standard deviations, where available.

Measurement values for each entry were recorded and added to the spreadsheet based on available data. Data for air concentrations included sample measurements collected at different heights above the field, although this height distinction was not made when recording the data in the spreadsheet; however, a distinction was made in the spreadsheet between indoor, outdoor and personal air sample collections. All excluded measurements were explained in each entry’s comments section on the spreadsheet.

Before calculating descriptive statistics, measured values for each medium (air, dust, tire crumb or crumb rubber, field surface residue and synthetic fluids) were converted to consistent units where necessary. Air concentrations were converted to ng/m^3, dust concentrations to ng/g, crumb rubber concentrations to ng/g, residue concentrations to ng/m^2 and bioaccessibility synthetic fluid concentrations to ng/g. Where necessary, reported masses were converted to loadings. For example, in the Consumer Product Safety Commission’s (CPSC) 2008 report, field surface wipe data for lead was originally reported as 98.7 µg, collected using a 15×15-cm wipe, rubbed along 50 cm (CPSC, 2008). The entire area for wipe sampling was found by multiplying 15 cm (wipe height) by 50 cm (surface length), giving a total wipe sampling surface area of 750 cm^2. Dividing the total mass of residue found on the wipe (98.7 µg) by the total surface area wiped (750 cm^2), a mass per unit area loading of 0.132 µg/cm^2 was obtained; this value was then converted to ng/m^2.

Mean, median, geometric mean, and arithmetic standard deviation values were calculated for each chemical in each medium, using the ‘=AVERAGE’ (arithmetic mean), ‘=STDEV.P’, ‘=MEDIAN’ and ‘=GEOMEAN’ (geometric mean) functions in Excel. Geometric standard deviation was calculated in a separate spreadsheet by listing all the measured values, taking the natural logarithm of each of those numbers, calculating the standard deviation of those natural log values, and then taking the inverse natural logarithm (exponential function) of that standard deviation value (Figure 5-3). In studies where the value was reported as less than the LOD, ½ LOD was used in the calculations.

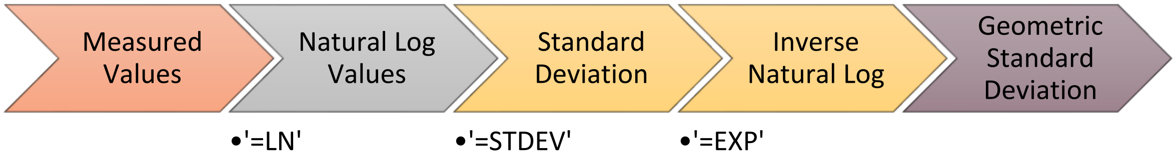


Figure 5-3. Process flowchart of the commands used in Excel to calculate the geometric standard deviation.

Once all measurement values were extracted from the literature and summary statistics were calculated, specific parameter values were obtained using a weighted average for both the arithmetic and geometric means for each chemical in each medium (Tables 5-2 and 5-3). Weighted averages were calculated by multiplying each mean value from the study by the number of sample measurements taken, adding all those values together and dividing by the total number of sample measurements of all the studies. In studies that reported only minimum and maximum values, the maximum was used along with mean values from other studies in calculating weighted averages, but these studies did not provide enough information to be included in calculations of arithmetic and geometric standard deviations.

Table 5-2. Weighted Arithmetic Means for Chemicals of Interest in Exposure Pathway Modeling[a]

Chemical	Air – Outdoor (ng/m^3)	Air – Indoor (ng/m^3)	Air – Combined (ng/m^3) [b]	Air – Personal (ng/m^3)	Tire Crumb (ng/g)	Field Surface Wipes Without Contaminated Blades (ng/m^2) [c]
Benzo[a]pyrene	0.066	0.708[d]	0.062	N/A	1640	N/A
Pyrene	2.41	5.71	2.95	3.19[d]	13100[e]	723
Benzothiazole	235	12300	1040	4050	2700[f]	N/A
Methyl isobutyl ketone	742	36000[g]	12000	11600	N/A	N/A
Lead	0.978	N/A	N/A	N/A	41300	6010[d]
Zinc	18	N/A	N/A	N/A	9580000	273000

[a] Arithmetic mean for each chemical was calculated from measurement values found in reference studies identified in the Literature Review/Gaps Analysis; N/A = not available.

[b] "Combined" air includes both indoor and outdoor air without distinction between the two.

[c] Does not include measurements from fields that were likely to have blades with lead-containing pigments.

[d] Benzo[a]pyrene indoor air concentration, pyrene personal air concentration, and lead field surface wipe concentration each represent the arithmetic mean from one study.

[e] Pyrene tire crumb concentration contains a reported maximum value of 28700 ng/g, which skews the weighted average.

[f] Benzothiazole tire crumb concentration is the reported median from one study.

[g] Methyl isobutyl ketone indoor air concentration arithmetic mean is based on two data points.

Table 5-3. Weighted Geometric Means for Chemicals of Interest in Exposure Pathway Modeling[a]

Chemical	Air – Outdoor (ng/m^3)	Air – Indoor (ng/m^3)	Air – Combined (ng/m^3) [b]	Air – Personal (ng/m^3)	Tire Crumb (ng/g)	Field Surface Wipes Without Contaminated Blades (ng/m^2)[c]
Benzo[a]pyrene	0.073	0.636	0.069	N/A	998	N/A
Pyrene	1.22	5.68	1.77	3.06	12400	679
Benzothiazole	159	12200	575	2440	2700[d]	N/A
Methyl isobutyl ketone	742	36000[e]	2280	11900	N/A	N/A
Lead	0.98[f]	N/A	N/A	N/A	28300	4490
Zinc	15.9	N/A	N/A	N/A	7660000	255000

[a] Geometric mean for each chemical was calculated from measurement values found in reference studies identified in the Literature Review/Gaps Analysis; NA = not available.

[b] "Combined" air includes both indoor and outdoor air without distinction between the two.

[c] Does not include measurements from fields likely to have blades with lead-containing pigments.

[d] Benzothiazole tire crumb concentration is the reported median from one study.

[e] Methyl isobutyl ketone indoor air concentration geometric mean is based on two data points.

[f] Lead outdoor air concentration calculated using maximum values.

Upper confidence limits (UCLs) of the means were obtained by using ProUCL 5.1 software (U.S. EPA, Washington, DC; https://www.epa.gov/land-research/proucl-software). In most cases, the ProUCL-recommended values were used (i.e., the software uses several methods for calculating point estimates and identifies the recommended one), except where the value exceeded the maximum observation. UCLs are shown in Table 5-4.

Table 5-4. Upper Confidence Limits (UCLs) for Chemicals of Interest in Exposure Pathway Modeling[a]

Chemical	Air – Outdoor (ng/m^3)	Air – Indoor (ng/m^3)	Air – Combined (ng/m^3) [b]	Air – Personal (ng/m^3)	Tire Crumb (ng/g)	Field Surface Wipes Without Contaminated Blades (ng/m^2)[c]
Benzo[a]pyrene	0.145	1.097[d]	0.615	NC	2758	NC
Pyrene	5.549	10.53	5.873	NC	11877	1288
Benzothiazole	297.7	13731	5148	9422	NC	NC
Methyl isobutyl ketone	586.5	NC	NC	47955	NC	NC
Lead	NC	NC	NC	NC	77584	8583
Zinc	37.58	NC	NC	NC	19960747	318805

[a] Upper confidence limits were recommended values from the ProUCL 5.1 software (U.S. EPA, Washington, DC), unless otherwise noted. NC= not calculated due to limited data.

[b] "Combined" air includes both indoor and outdoor air without distinction between the two.

[c] Does not include measurements from fields likely to have blades with lead-containing pigments.

[d] Benzo[a]pyrene indoor air ProUCL-recommended upper confidence limit exceeded the maximum observation; 95% Central Limit Theorem UCL was used.

Three age ranges available from EPA's Exposure Factors Handbook (U.S. EPA, 2011b) were selected for use in the exposure pathway modeling and are shown in Table 5-5. These three age ranges used for modeling are based on the availability of exposure factor information for specific age ranges; however, they differ somewhat from the age ranges used for reporting exposure pilot study participant results in Section 4. The age ranges reported in Section 4 were based on numbers of participants of different ages in the two sport types. Inhalation and ingestion rates were obtained from the Handbook (U.S. EPA, 2011b) and converted to the units needed for each exposure algorithm. Short-term inhalation rates corresponding to a high intensity activity level were extracted and converted from units of cubic meters per minute (m^3/min) to hourly rates (m^3/hr) by multiplying each rate value by 60 minutes per hour (U.S. EPA, 2011b).

Table 5-5. Age Ranges from the EPA Exposure Factors Handbook (U.S. EPA, 2011b)

Age Group	Age Range
Children	6 to <11 years
Adolescents	11 to <16 years
Young Adults	16 to <21 years

Average daily dose (ADD, expressed as mg/kg-day) over a year from use of fields was calculated using equations 5-1 through 5-3 and route-specific spreadsheets modified to include route-specific absorption fractions for the inhalation and ingestion routes. Estimates of daily dose on a day that included synthetic turf field activity were obtained by multiplying the ADD output by Averaging Time (AT) / Exposure Frequency (EF).

Inhalation $$ADD_{abs} = (C_{air} \times InhR \times ET \times EF \times ED \times ABS)/(BW \times AT) \quad \text{(Equation 5-1)}$$

Ingestion $$ADD_{abs} = (C_{solid} \times IngR \times EF \times ED \times ABS)/(BW \times AT) \quad \text{(Equation 5-2)}$$

Dermal $$ADD_{abs} = (C_{solid} \times Adh \times SA \times EF \times ED \times ABS)/(BW \times AT) \quad \text{(Equation 5-3)}$$

Where:

ADD_{abs} = average daily dose absorbed (mg/kg-day)
C_{air} = concentration of contaminant in air (mg/m^3)
$InhR$ = inhalation rate (m^3/hour)
ET = exposure time (hours/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
ABS = fraction absorbed (%/100)
BW = body weight (kg)
AT = averaging time (days)
C_{solid} = concentration of contaminant in crumb rubber (mg/g)
$IngR$ = ingestion rate (g/day)
Adh = Solids adherence on skin (g/cm^2-day)
SA = skin surface area available for contact (cm^2)

Exposure scenarios from several other studies that examined exposure to tire crumb rubber constituents from synthetic turf provided potential parameter input values for the modeling (Table 5-6). Parameter input values for each exposure route used in this exposure pathway modeling are shown in Table 5-7. Age-specific adherence factors were calculated by estimating the percentage of a body part exposed while wearing a typical sports uniform during the summer, multiplying those percentages by the total surface area per body part found in EPA's Exposure Factors Handbook (U.S. EPA, 2011b), summing the products and then dividing by the total exposed body surface area of the body parts to get a weighted adherence factor (Equation 5-4); this equation can be found in Chapter 7 of the Handbook (U.S. EPA, 2011b). Body part percentages were assumed to be 100% of the face, 72.5% of the arms, 40% of the legs (to account for socks and short pants), and 100% of the hands.

$$AF_{wtd} = (AF_1 \times SA_1) + (AF_2 \times SA_2) + \cdots (AF_i \times SA_i)/(SA_1 + SA_2 + \cdots SA_i) \qquad \text{(Equation 5-4)}$$

Where:

AF_{wtd} = weighted adherence factor (mg/cm^3)
AF = adherence factor (mg/cm^3)
SA = skin surface area of body part available for contact (cm^3)

Table 5-6. Exposure Scenarios from Several Studies, Including this Exposure Pilot Study[a,b]

Study	Age (years)	Sport[b]	Player	Activity Level	Location
ECHA	3 to 6	Soccer	Not Specified	Heavy Exercise	Not Specified
ECHA	6 to 11	Soccer	Not Specified	Heavy Exercise	Not Specified
ECHA	6 to 11	Soccer	Goalkeepers	Heavy Exercise	Not Specified
ECHA	11 to 18	Soccer	Active, non-professional	Heavy Exercise	Not Specified
ECHA	18 to 31	Soccer	Professional	Heavy Exercise	Not Specified
ECHA	18 to 31	Soccer	Professional Goalkeepers	Heavy Exercise	Not Specified
RIVM	4 to 11	Soccer	Not Specified	Recreational	Outdoor
RIVM	7+	Soccer	Goalkeepers	High Intensity	Outdoor
RIVM	11 to 18	Soccer	Performance	High Intensity	Outdoor
RIVM	18 to 35	Soccer	Performance	High Intensity	Outdoor
Connecticut	6 to 18	Soccer	Not Specified	Not Specified	Outdoor
Connecticut	30	Soccer	Not Specified	Not Specified	Outdoor
Peterson	6 to 18	Soccer	Not Specified	Not Specified	Outdoor

Table 5-6. Continued

Study	Age (years)	Sport[b]	Player	Activity Level	Location
Peterson	6 to 18	Soccer	Not Specified	Not Specified	Indoor
Peterson	6 to 18	Soccer	Not Specified	Not Specified	Composite
Peterson	Adult	N/A	Not Specified	Not Specified	Spectator
Peterson	Child	N/A	Not Specified	Not Specified	Spectator
Pilot Study	6 to <11	N/A	Not Specified	High Intensity	Composite
Pilot Study	11 to <16	N/A	Not Specified	High Intensity	Composite
Pilot Study	16 to <21	N/A	Not Specified	High Intensity	Composite

[a] Exposure scenarios identified from the following studies: ECHA (2017), RIVM (2017), Connecticut (Ginsberg, et al., 2011a), Peterson (Peterson, et al., 2018), and this exposure pilot study.

[b] N/A = not applicable

Table 5-7. Exposure Parameters for Extant Data

Exposure Parameter	Parameter Value	Source
Absorption Fraction – Ingestion (Metals)	30%	Zartarian et al., 2017
Absorption Fraction – Ingestion (All Other Chemicals)	50%	Morgan et al., 2005
Absorption Fraction – Dermal (Metals)	1%	U.S. EPA, 2004
Absorption Fraction – Dermal (All Other Chemicals)	10%	U.S. EPA, 2004
Absorption Fraction – Inhalation	70%	Ross, et al., 2001
Ingestion Rates – 6 to <11 years of age	0.06 g/event	U.S. EPA, 2011b, Chapter 5, Table 5-1 Soil + Dust (converted to g/event, assuming 1 event per day)
Ingestion Rates – 11 to <16 years of age	0.03 g/event	U.S. EPA, 2011b, Chapter 5, Table 5-1 Soil + Dust (converted to g/event, assuming 1 event per day)
Ingestion Rates – 16 to <21 years of age	0.03 g/event	U.S. EPA, 2011b, Chapter 5, Table 5-1 Soil + Dust (converted to g/event, assuming 1 event per day)
Dermal Adherence Factor	2.70E-06 g/cm^2	U.S. EPA, 2011b[a], Chapter 7, Table 7-4
Skin Surface Area – 6 to <11 years of age	3069 cm^2	U.S. EPA, 2011b[a], Chapter 7, Table 7-2
Skin Surface Area – 11 to <16 years of age	4541 cm^2	U.S. EPA, 2011b[a], Chapter 7, Table 7-2
Skin Surface Area – 16 to <21 years of age	5202 cm^2	U.S. EPA, 2011b[a], Chapter 7, Table 7-2
Inhalation Rates – 6 to <11 years of age	2.52 m^3/hr	U.S. EPA, 2011b, Chapter 6, Table 6-2 High Intensity (converted to m^3/hr)
Inhalation Rates – 11 to <16 years of age	2.94 m^3/hr	U.S. EPA, 2011b, Chapter 6, Table 6-2 High Intensity (converted to m^3/hr)
Inhalation Rates – 16 to <21 years of age	2.94 m^3/hr	(U.S. EPA, 2011b) Chapter 6, Table 6-2 High Intensity (converted to m^3/hr)
Bodyweight – 6 to <11 years of age	31.8 kg	U.S. EPA, 2011b, Chapter 8, Table 8-3
Bodyweight – 11 to <16 years of age	56.8 kg	U.S. EPA, 2011b, Chapter 8, Table 8-3
Bodyweight – 16 to <21 years of age	71.6 kg	U.S. EPA, 2011b, Chapter 8, Table 8-3
Exposure Time[b] – 6 to <11 years of age	1 hr/event	Assumed
Exposure Time[b] – 11 to <16 years of age	3 hrs/event	Assumed
Exposure Time[b] – 16 to <21 years of age	2 hrs/event	Assumed

Table 5-7. Continued

Exposure Parameter	Parameter Value	Source
Exposure Frequency – 6 to <11 years of age	78 days/year	Assumed
Exposure Frequency – 11 to <16 years of age	138 days/year	Assumed
Exposure Frequency – 16 to <21 years of age	138 days/year	(Ginsberg, et al., 2011)
Exposure Duration – all ages	1 year	Assumed
Averaging Time – all ages	365 days/year	Assumed

[a] Calculated using body part percentages and adherence factors per body part.

[b] Assumes one event per day.

Comparisons of parameter values from other studies and those used in this study are shown in Table 5-8. Modeling parameter inputs from other studies were chosen using the age groups most analogous with those used in this exposure pilot study. From the European Chemicals Agency (ECHA 2017) study, the 6- to 11- year old non-goalkeeper; 11- to 18-year old active, non-professional; and adult (18- to 31-year old) professional non-goalkeeper scenarios were used. The Netherlands National Institute for Public Health and the Environment (RIVM 2011) scenarios used in modeling were the 4- to 11-year old recreational players and the 11- to 18-year old and 18- to 35-year old performance oriented players. Both Connecticut scenarios (Ginsberg, et al. 2011a) were used – 6- to 18-year old players and 30-year old players. Estimated exposure results were generated for each exposure pathway using the EPA ExpoBox tools (U.S. EPA, 2013). Exposure estimates using extant data are shown in section 5.2.1. The following assumptions were made in the calculations using extant data:

- Adherence of tire crumb to skin was approximated by adherence of soil and dust during similar activities as there is no specific adherence rate available for tire crumb itself.
- Dermal absorption was estimated in the absence of data on the bioaccessibility of chemicals in tire crumb.
- Despite participants in the Exposure Pilot Study reporting occasional abrasions, which could lead to an increase in absorption rate, dermal abrasions were not considered in these modeling exercises due to the complexity of physiological processes involved in vascular absorption and transport.
- Ingestion rates assume tire crumb is ingested at the same rate as that of dust and soil.

Table 5-8. Parameter Input Value Comparisons Among Select Studies[a]

Age (years)	Study	Inhalation Rate (m^3/hr)	Ingestion Rate (g/event)	Dermal Adherence (g/cm^2)	Inhalation Absorption Fraction (%)	Ingestion Absorption Fraction (*100%)	Dermal Absorption Fraction (*100%)	Exposure Time (hrs/day)	Exposure Frequency (days/year)	Weight (kg)	Skin Surface Area (cm^2)
6 to <11	This Study (extant data)	2.52	0.06	2.70E-06	70	0.3 – 0.5[b]	0.01 – 0.1[b]	1	78	31.8	3069
6 to 11	ECHA (non-goalkeeper)	1.92	0.05	0.001	NR	0.5	0.2	1.5	NR	24.3	1750
6 to 18	Connecticut	3.36[c]	N/A	N/A	NR	N/A	N/A	3	138	NR	N/A
4 to 11	RIVM	N/A	0.2	0.001	N/A	0.3	0.2	2	NR	15.7	1260
6 to 18	Peterson et al.	NR	0.05	0.00004	NR	0.06	0.002/0.1[d]	3	138	49	4881
11 to <16	This Study (extant data)	2.94	0.03	2.70E-06	70	0.3 – 0.5[b]	0.01 – 0.1[b]	3	138	56.8	4541
11 to 18	ECHA	2.53	0.01	0.001	NR	0.5	0.2	1.5	NR	44.8	2680
11 to 18	RIVM	N/A	0.05	0.001	N/A	0.3	0.2	1.5	NR	44.8	2680
16 to <21	This Study (extant data)	2.94	0.03	2.70E-06	70	0.3 – 0.5[b]	0.01 – 0.1[b]	2	138	71.6	5202
18 to 31	ECHA	3.07	0.01	0.001	NR	0.5	0.2	4	NR	68.8	3680
30	Connecticut	3.36[c]	N/A	N/A	NR	N/A	N/A	3	138	NR	N/A
18 to 35	RIVM	N/A	0.05	0.001	N/A	0.3	0.2	2	NR	68.8	3680

[a] N/A = Specified pathway not included in study; NR = Parameter value not reported.

[b] This study, using existing measurements (extant data) – Ingestion absorption fraction - 30% metals, 50% all other chemical substances (Zartarian et al., 2017; Morgan et al., 2005); Dermal absorption fraction - 1% metals, 10% all other chemical substances (U.S. EPA, 2004)

[c] Connecticut reported using a mixture of moderate to intense activity levels for inhalation rate – 2.34 m^3/hr for moderate and 4.38 m^3/hr for intense activity; the inhalation rate of 3.36 m^3/hr reported here is the midpoint between the two. They used a ventilation adjustment for adults and children for this reason.

[d] Peterson et al., 2018 – Dermal absorption fraction - 0.002 for PAHs, 0.1 for SVOCs

5.1.3 Synthetic Turf Field User Exposure Estimation Using Exposure Pilot Study Measurements

After collection and analysis of the exposure pilot study field measurements, model concentrations and parameters were updated to reflect measured concentrations from the fields; this included the addition of dermal wipe concentrations, metals bioaccessibility (biological) measurements, and concentrations for some chemical substances that were missing from existing data (Table 5-9). All other parameters used in modeling the exposure pathways using extant data remained the same, apart from the dermal and ingestion absorption factors for metals and the use of field dust concentration measurements for chemical substances that previously used tire crumb concentrations. The dermal absorption factor used for metals was chosen to be 0.1%, because that was the mean percent zinc found to be bioaccessible in simulated sweat and sebum fluid. Lead bioaccessibility measurements were < 0.1%, so the use of 0.1% would provide a conservative estimate. Mean gastric fluid lead and zinc bioaccessibility values for field tire crumb (3.2% for lead and 1.0% for zinc) were used for ingestion (gastrointestinal) absorption.

With the additional dermal wipe sample concentrations, the use of adherence factors was avoided, and loadings on skin were used in the exposure algorithms. The amount of chemical substance directly in contact with the skin (i.e., the "loading on skin") was calculated by multiplying the dermal wipe concentration (C_{wipe}) by the sum of the exposed surface areas of each body part (Equation 5-5). For each scenario, exposed skin surface area was estimated using the percentage of the total surface area found in EPA's Exposure Factors Handbook (U.S. EPA, 2011b) for each body part exposed in a typical player uniform (see Table 5-7).

$$\text{Dermal}_{\text{Pilot}} \qquad ADD_{abs} = \left(C_{wipe} \times SA \times EF \times ED \times ABS\right)/(BW \times AT) \qquad \text{(Equation 5-5)}$$

Loading on skin calculated from dermal wipe concentrations provided a potentially more accurate dermal exposure measurement than using the highly uncertain assumptions concerning amount of tire crumb adhering to skin and amount of chemicals substance transferring from tire crumb onto the skin from the exposure modeling with extant data. There are, however, limitations in dermal measurements as well, including the assumption of 100% wipe efficiency and the possibility that post-activity measurements may have included exposures to the chemical that occurred prior to the synthetic turf field activity.

Despite the collection of air samples from both indoor and outdoor playing fields in the exposure pilot study, the information on the type of sample is not available due to concerns over privacy with the small number of participants in the study. Instead, the medium for the air samples is identified as "combined." Additionally, no attempt was made to quantify dietary ingestion as part of the exposure pilot study.

Table 5-9. Mean Concentrations and Estimated Total Dermal Loads of Chemical Substances Measured in the Exposure Pilot Study [a, b, c]

Chemical	Average Air Concentration - Combined (ng/m^3)	Average Tire Crumb Concentration (ng/g)	Average Dust Concentration (ng/g)	Dermal Loading – Players Age 6 to <11 (ng)	Dermal Loading – Players Age 11 to <16 (ng)	Dermal Loading – Players Age 16 to <21 (ng)
Benzo[a]pyrene	7.00E-03	7.80E+02	7.10E+02	2.93E+01	1.85E+01	2.28E+00
Pyrene	3.57E+00	1.20E+04	5.49E+03	7.77E+01	4.79E+01	8.52E+00
Benzothiazole	3.87E+02	1.10E+04	4.30E+03	6.09E+02	1.06E+03	3.65E+02
Methyl isobutyl ketone	7.87E+02	N/A	N/A	N/A	N/A	N/A
Lead	2.17E+00	2.40E+04	3.80E+04	4.92E+02	7.69E+02	1.88E+02
Zinc	1.57E+02	1.50E+07	9.44E+06	1.13E+05	2.15E+05	7.23E+04

[a] Exposure pilot study measurements used in exposure modeling included both field samples (air, tire crumb, field surface wipes and dust samples) and personal samples (dermal wipe sample). N/A = not applicable (i.e., no measurements obtained)

[b] Temperature and wind conditions at the fields during the air and dermal sample collections are reported in Table 4-27.

[c] Total dermal load calculated by summing products of measured body part-specific dermal loadings and exposed surface areas.

5.1.4 Background Exposure Estimation from Residential and Dietary Sources

Estimates of exposures to chemicals from tire crumb rubber on synthetic turf fields among athletes and bystanders can be put into the context of exposure to these same chemical substances in typical residential settings, including the contribution from dietary sources. The purpose of this comparative analysis was to present "background" concentrations encountered in residences, and the resulting daily intake estimates provide some perspective on the magnitude of the estimated daily dose for synthetic turf field users. The same algorithms used for exposure estimates to chemicals from tire crumb rubber on synthetic turf fields were used for this exercise, except that the exposure factor parameters were altered to represent a 24-hour residential exposure including a dietary component. These changes included: (1) an assumption that 21 hours/day were spent indoors, (2) use of inhalation rates corresponding to long-term inhalation as defined by the Exposure Factors Handbook as "repeated exposure for more than 30 days"(U.S. EPA, 2011b), and (3) application of residential indoor dermal adherence factors. These contrast with the assumptions of 1-3 hours spent on synthetic turf, inhalation rates corresponding to high intensity activity, and dermal adherence factors appropriate to an active setting. The remaining exposure factor parameters remained the same, namely, route-specific absorption fractions, dust/soil ingestion rates, and age-group specific body weights. All exposure factor parameters used to estimate residential and dietary exposures can be found in Table 5-10. Additional literature review was conducted to obtain background concentrations needed to estimate resulting daily doses. The concentration values used for each chemical substance and medium can be found in Table 5-11. Table 5-12 illustrates the types of exposure media that were available for the three modeling exercises.

Table 5-10. Exposure Parameters for Residential and Dietary Estimates

Exposure Parameter	Parameter Value – Age 6 to <11	Parameter Value – Age 11 to <16	Parameter Value – Age 16 to <21	Source
Total Food Intake	1.118 kg/day	1.209 kg/day	1.184 kg/day	U.S. EPA, 2011b, Chapter 14, Table 14-3 (converted to kg/day)
Absorption Fraction – Ingestion (Metals)	30%	30%	30%	Morgan et al., 2005
Absorption Fraction – Dermal (Metals)	1%	1%	1%	U.S. EPA, 2011b
Absorption Fraction –Inhalation	70%	70%	70%	Assumed value
Soil/Dust Ingestion Rates	0.06 g/event	0.03 g/event	0.03 g/event	U.S. EPA, 2011b, Chapter 5, Table 5-1 Soil + Dust (converted to g/event, assuming 1 event per day)
Dermal Adherence Factor	5.00E-06 g/cm^2	5.00E-06 g/cm^2	5.00E-06 g/cm^2	U.S. EPA, 2011b, Chapter 7
Skin Surface Area	3069 cm^2	4541 cm^2	5202 cm^2	U.S. EPA, 2011b, Chapter 7, Table 7-2
Inhalation Rates	0.50 m^3/hr	0.63 m^3/hr	0.68 m^3/hr	U.S. EPA, 2011b, Chapter 6, Table 6-2 Sedentary/Passive activity level (converted to m^3/hr)
Bodyweight	31.8 kg	56.8 kg	71.6 kg	U.S. EPA, 2011b, Chapter 8, Table 8-3
Exposure Time	21 hrs/day	21 hrs/day	21 hrs/day	Assumed for this comparative analysis
Exposure Frequency	365 days/year	365 days/year	365 days/year	Assumed for this comparative analysis
Exposure Duration	1 year	1 year	1 year	Assumed for this comparative analysis
Averaging Time	365 days/year	365 days/year	365 days/year	Assumed for this comparative analysis

This analysis of residential and dietary exposure has several limitations, principally due to the availability of only sparse data, often from studies conducted decades ago. Due to a lack of information on concentration variability, only point estimates of central tendency were used. Exposure was assumed to occur indoors for 21 hours, neglecting commuting and other activities that may lead to higher exposures for some of the candidate chemicals. Additionally, demographic and urban/rural differences were not considered. These assumptions could lead to underestimation of the total amount of exposure for some chemicals.

Table 5-11. Residential and Dietary Concentrations Reported in the Literature for Chemicals of Interest

Chemical [a]	Medium	Mean	Source
Benzo[a]pyrene	Indoor Residential Air	0.224 ng/m^3	Morgan et al., 2005
Benzo[a]pyrene	Food Intake	20-80 ng/day	Ma & Harrad, 2015
Benzo[a]pyrene	Indoor Residential Dust	793 ng/g	Morgan et al., 2005
Pyrene	Indoor Residential Air	1.9 ng/m^3	Clayton et al., 2003
Pyrene	Food Concentration	0.4 µg/kg	Clayton et al., 2003
Pyrene	Indoor Residential Floor Dust	0.43 µg/g	Chuang et al., 1999
Benzothiazole	Indoor Residential Air	41.6 ng/m^3	Wan et al., 2016
Methyl isobutyl ketone	Air (Outdoor)	0.078 µg/m^3	U.S. EPA 2011a
Methyl isobutyl ketone	Food Intake	2 µg/day	World Health Organization, 2013
Lead	Indoor Residential Air	14.4 ng/m^3	Clayton et al., 1999
Lead	Dietary Dose	0.25 µg/kg/day	Thomas et al., 1999
Lead	Indoor Residential dust	463 µg/g	Clayton et al., 1999
Zinc	Dietary Dose	220 µg/kg/day	Thomas et al., 1999
Zinc	Indoor Residential Dust	833 µg/g	Rasmussen et al., 2013

[a] Unique numerical identifier assigned by the Chemical Abstracts Service (CAS) for each chemical: Benzo[a]pyrene (50-32-8), Pyrene (129-00-0), Benzothiazole (95-16-9), Methyl isobutyl ketone (108-10-1), Lead (7439-92-10), Zinc (7440-66-6).

Table 5-12. Data Availability by Chemical and Medium.

Chemical	Medium	Data Available in Previous Studies	Data Available in Current Study	Data Available in Residential Exposure Literature
Benzo[a]pyrene	Outdoor Air	**Y**	N	N
Benzo[a]pyrene	Indoor Air	**Y**	N	**Y**
Benzo[a]pyrene	Combined Air	**Y**	**Y**	N
Benzo[a]pyrene	Personal Air	N	N	N
Benzo[a]pyrene	Tire Crumb	**Y**	**Y**	N
Benzo[a]pyrene	Dust	N	**Y**	**Y**
Benzo[a]pyrene	Field Surface Residue	N	**Y**	N
Benzo[a]pyrene	Dermal Residue	N	**Y**	N
Benzo[a]pyrene	Food Conc./Intake	N	N	**Y**
Benzo[a]pyrene	Bioaccessibility	N	N	N
Pyrene	Outdoor Air	**Y**	N	N
Pyrene	Indoor Air	**Y**	N	**Y**
Pyrene	Combined Air	**Y**	**Y**	N
Pyrene	Personal Air	**Y**	N	N
Pyrene	Tire Crumb	**Y**	**Y**	N
Pyrene	Dust	N	**Y**	**Y**
Pyrene	Field Surface Residue	**Y**	**Y**	N
Pyrene	Dermal Residue	N	**Y**	N
Pyrene	Food Conc./Intake	N	N	**Y**
Pyrene	Bioaccessibility	N	N	N

Table 5-12. Continued

Chemical	**Medium**	**Data Available in Previous Studies**	**Data Available in Current Study**	**Data Available in Residential Exposure Literature**
Benzothiazole	Outdoor Air	**Y**	N	N
Benzothiazole	Indoor Air	**Y**	N	**Y**
Benzothiazole	Combined Air	**Y**	**Y**	N
Benzothiazole	Personal Air	**Y**	N	N
Benzothiazole	Tire Crumb	**Y**	**Y**	N
Benzothiazole	Dust	N	**Y**	N
Benzothiazole	Field Surface Residue	N	**Y**	N
Benzothiazole	Dermal Residue	N	**Y**	N
Benzothiazole	Food Conc./Intake	N	N	N
Benzothiazole	Bioaccessibility	N	N	N
Methyl isobutyl ketone	Outdoor Air	**Y**	N	**Y**
Methyl isobutyl ketone	Indoor Air	**Y**	N	N
Methyl isobutyl ketone	Combined Air	**Y**	**Y**	N
Methyl isobutyl ketone	Personal Air	**Y**	N	N
Methyl isobutyl ketone	Tire Crumb	N	N	N
Methyl isobutyl ketone	Dust	N	N	N
Methyl isobutyl ketone	Field Surface Residue	N	N	N
Methyl isobutyl ketone	Dermal Residue	N	N	N
Methyl isobutyl ketone	Food Conc./Intake	N	N	**Y**
Methyl isobutyl ketone	Bioaccessibility	N	N	N
Lead	Outdoor Air	**Y**	N	N
Lead	Indoor Air	N	N	**Y**
Lead	Combined Air	N	**Y**	N
Lead	Personal Air	N	N	N
Lead	Tire Crumb	**Y**	**Y**	N
Lead	Dust	N	**Y**	**Y**
Lead	Field Surface Residue	**Y**	**Y**	N
Lead	Dermal Residue	N	**Y**	N
Lead	Food Conc./Intake	N	N	**Y**
Lead	Bioaccessibility	N	**Y**	N
Zinc	Outdoor Air	**Y**	N	N
Zinc	Indoor Air	N	N	N
Zinc	Combined Air	N	**Y**	N
Zinc	Personal Air	N	N	N
Zinc	Tire Crumb	**Y**	**Y**	N
Zinc	Dust	N	**Y**	**Y**
Zinc	Field Surface Residue	**Y**	**Y**	N
Zinc	Dermal Residue	N	**Y**	N
Zinc	Food Conc./Intake	N	N	**Y**
Zinc	Bioaccessibility	N	**Y**	N

[a] Y = yes, N = no

5.2 Exposure Pathway Modeling Results

The purpose of this portion of the study was to identify gaps in the data, as well as to compare exposure estimates from this study against those from previous studies. Despite an extensive literature review, data could not be found for components of some key pathways, including dermal residue loadings for dermal exposure and measurements for some of our chemicals of interest in indoor air for inhalation exposure. No measurements of methyl isobutyl ketone were found in tire crumb rubber, despite the compound being measured in air above synthetic turf in multiple studies. Due to the scarcity of chemical measurement data, including limited numbers of studies and typically small numbers of measurements per study (e.g., only one or two measured values), estimates of upper confidence level (UCL) values were not judged to be reliable. For this reason, UCL data was reported, but was not used to calculate estimated exposures. Some key information on exposure factors specific to tire crumb rubber is not known at this time; therefore, some of the exposure factors that were used for tire crumb rubber that are applicable to soil and dust (e.g., adherence to skin and absorption fractions applicable to soil and dust) may not actually be applicable to tire crumb rubber.

5.2.1 Synthetic Turf Field User Exposure Estimation Results Using Extant Measurements

Results from exposure pathway modeling using weighted arithmetic means of extant measurements are shown in Table 5-13. “Average Daily Dose” (i.e., dose averaged over a year using assumed frequency of exposure events) is presented to represent prolonged, repeated exposures, whereas “Daily Dose” represents the exposure on the day of use.

Table 5-13. Estimated Exposure Results Using Extant Measurements, by Exposure Pathway[a]

Chemical	Age (years)	Average Daily Dose – Ingestion (mg/kg-day)	Average Daily Dose – Dermal (mg/kg-day)	Average Daily Dose – Outdoor Inhalation (mg/kg-day)	Average Daily Dose – Indoor Inhalation (mg/kg-day)	Daily Dose – Ingestion (mg/kg-day)	Daily Dose – Dermal (mg/kg-day)	Daily Dose – Outdoor Inhalation (mg/kg-day)	Daily Dose – Indoor Inhalation (mg/kg-day)
Benzo[a]pyrene	6 to <11	3.31E-07	9.13E-09	7.82E-10	8.40E-09	1.55E-06	4.27E-08	3.66E-09	3.93E-08
Benzo[a]pyrene	11 to <16	1.64E-07	1.34E-08	2.71E-09	2.91E-08	4.33E-07	3.54E-08	7.17E-09	7.70E-08
Benzo[a]pyrene	16 to <21	1.30E-07	1.22E-08	1.46E-09	2.36E-08	3.44E-07	3.22E-08	3.87E-09	6.23E-08
Pyrene	6 to <11	2.64E-06	7.29E-08	2.86E-08	6.77E-08	1.24E-05	3.41E-07	1.34E-07	3.17E-07
Pyrene	11 to <16	1.31E-06	1.07E-07	9.90E-08	2.35E-07	3.46E-06	2.83E-07	2.62E-07	6.21E-07
Pyrene	16 to <21	1.04E-06	9.72E-08	5.34E-08	1.90E-07	2.74E-06	2.57E-07	1.41E-07	5.03E-07
Benzothiazole	6 to <11	5.44E-07	1.50E-08	2.79E-06	1.46E-04	2.55E-06	7.03E-08	1.30E-05	6.82E-04
Benzothiazole	11 to <16	2.70E-07	2.20E-08	9.66E-06	5.05E-04	7.13E-07	5.83E-08	2.55E-05	1.34E-03
Benzothiazole	16 to <21	2.14E-07	2.00E-08	5.21E-06	4.09E-04	5.66E-07	5.30E-08	1.38E-05	1.08E-03
Methyl isobutyl ketone	6 to <11	NC	NC	8.80E-06	4.27E-04	NC	NC	4.12E-05	2.00E-03
Methyl isobutyl ketone	11 to <16	NC	NC	3.05E-05	1.48E-03	NC	NC	8.07E-05	3.91E-03
Methyl isobutyl ketone	16 to <21	NC	NC	1.65E-05	1.20E-03	NC	NC	4.35E-05	3.17E-03
Lead	6 to <11	5.00E-06	2.30E-08	1.16E-08	NC	2.34E-05	1.08E-07	5.43E-08	NC
Lead	11 to <16	2.47E-06	3.37E-08	4.02E-08	NC	6.54E-06	8.91E-08	1.06E-07	NC
Lead	16 to <21	1.96E-06	3.06E-08	2.17E-08	NC	5.19E-06	8.10E-08	5.74E-08	NC
Zinc	6 to <11	1.12E-03	5.14E-06	2.13E-07	NC	5.22E-03	2.40E-05	9.98E-07	NC
Zinc	11 to <16	5.53E-04	7.53E-06	7.40E-07	NC	1.46E-03	1.99E-05	1.96E-06	NC
Zinc	16 to <21	4.39E-04	6.85E-06	3.99E-07	NC	1.16E-03	1.81E-05	1.06E-06	NC

[a] Daily Dose is calculated by multiplying Average Daily Dose (ADD) by AT/EF [i.e., averaging time (days)/exposure frequency (days)]; NC = not calculated.

5.2.2 *Synthetic Turf Field User Exposure Estimation Results Using Exposure Pilot Study Measurements*

Results from exposure pathway modeling using the results of modeling using exposure pilot study measurements are shown in Table 5-14.

Table 5-14. Estimated Exposure Results Using Exposure Pilot Study Measurements, by Exposure Pathway[a]

Chemical	Age (years)	Average Daily Dose – Ingestion (mg/kg-day)	Average Daily Dose – Dermal (mg/kg-day)	Average Daily Dose – Combined Inhalation (mg/kg-day)	Daily Dose – Ingestion (mg/kg-day)	Daily Dose – Dermal (mg/kg-day)	Daily Dose – Combined Inhalation[b] (mg/kg-day)
Benzo[a]pyrene	6 to <11	1.43E-07	1.97E-08	8.30E-11	6.70E-07	9.20E-08	3.88E-10
Benzo[a]pyrene	11 to <16	7.09E-08	1.23E-08	2.88E-10	1.88E-07	3.26E-08	7.61E-10
Benzo[a]pyrene	16 to <21	5.62E-08	1.21E-09	1.52E-10	1.49E-07	3.19E-09	4.02E-10
Pyrene	6 to <11	1.11E-06	5.22E-08	4.23E-08	5.18E-06	2.44E-07	1.98E-07
Pyrene	11 to <16	5.48E-07	3.19E-08	1.47E-07	1.45E-06	8.44E-08	3.88E-07
Pyrene	16 to <21	4.35E-07	4.50E-09	7.76E-08	1.15E-06	1.19E-08	2.05E-07
Benzothiazole	6 to <11	8.67E-07	4.09E-07	4.59E-06	4.06E-06	1.91E-06	2.15E-05
Benzothiazole	11 to <16	4.29E-07	7.06E-07	1.59E-05	1.14E-06	1.87E-06	4.21E-05
Benzothiazole	16 to <21	3.41E-07	1.93E-07	8.41E-06	9.01E-07	5.10E-07	2.23E-05
Methyl isobutyl ketone	6 to <11	NC	NC	9.33E-06	NC	NC	4.37E-05
Methyl isobutyl ketone	11 to <16	NC	NC	3.23E-05	NC	NC	8.55E-05
Methyl isobutyl ketone	16 to <21	NC	NC	1.71E-05	NC	NC	4.52E-05
Lead	6 to <11	4.90E-07	3.31E-09	2.58E-08	2.29E-06	1.55E-08	1.21E-07
Lead	11 to <16	2.43E-07	5.12E-09	8.93E-08	6.42E-07	1.35E-08	2.36E-07
Lead	16 to <21	1.93E-07	9.93E-10	4.72E-08	5.09E-07	2.63E-09	1.25E-07
Zinc	6 to <11	3.81E-05	7.58E-07	1.87E-06	1.78E-04	3.55E-06	8.74E-06
Zinc	11 to <16	1.88E-05	1.43E-06	6.47E-06	4.98E-05	3.79E-06	1.71E-05
Zinc	16 to <21	1.50E-05	3.82E-07	3.42E-06	3.95E-05	1.01E-06	9.05E-06

[a] Daily Dose is calculated by multiplying Average Daily Dose (ADD) by AT/EF [i.e., averaging time (days)/exposure frequency (days)]; NC = not calculated.

[b] Combined inhalation includes both indoor and outdoor air.

5.2.3 *Synthetic Turf Field User Estimated Exposures for Chemicals of Interest by Exposure Route*

Route-specific exposures for each chemical of interest are illustrated, using both the extant data and exposure pilot study data, in Figures 5-4 through 5-13.

5.2.3.1 Benzo[a]pyrene Exposure Estimates

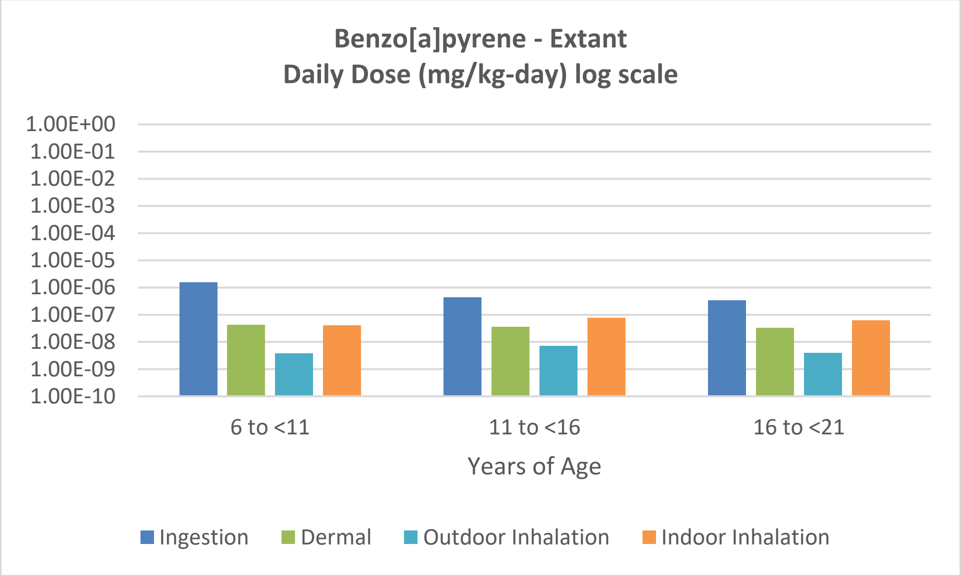


Figure 5-4. Benzo[a]pyrene daily dose calculated for three age groups, by route of exposure, using extant data.

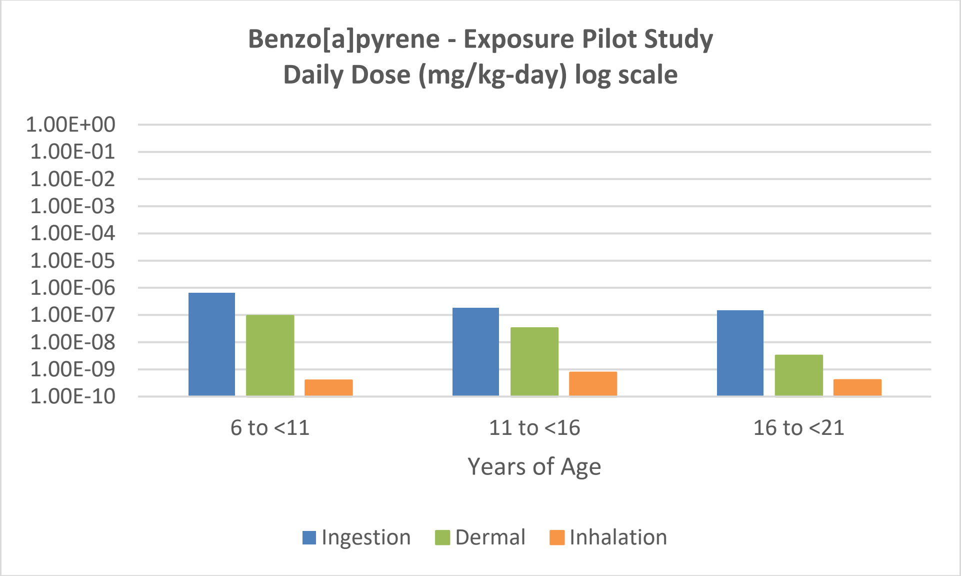


Figure 5-5. Benzo[a]pyrene daily dose calculated for three age groups, by route of exposure, using exposure pilot study data.

5.2.3.2 Pyrene Exposure Estimates

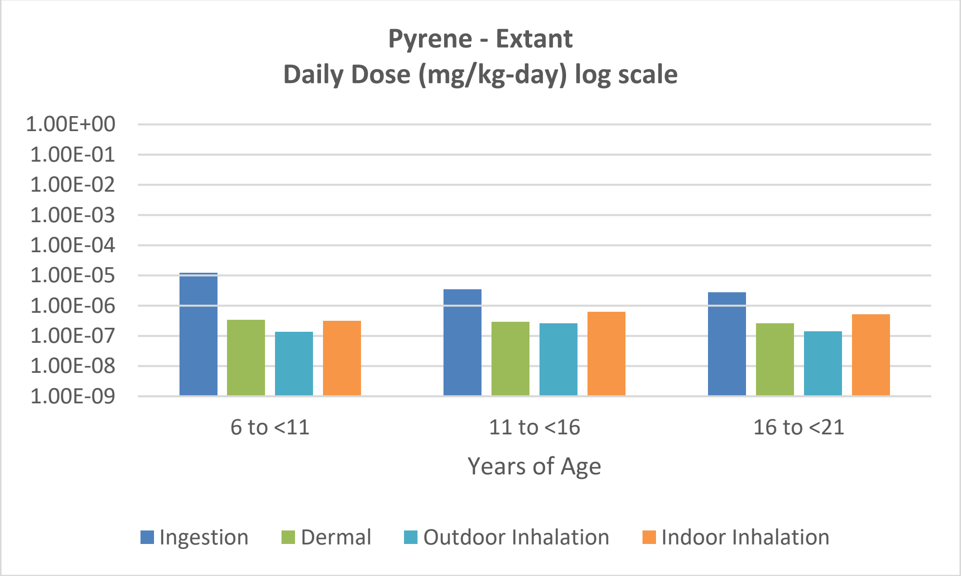


Figure 5-6. Pyrene daily dose calculated for three age groups, by route of exposure, using extant data.

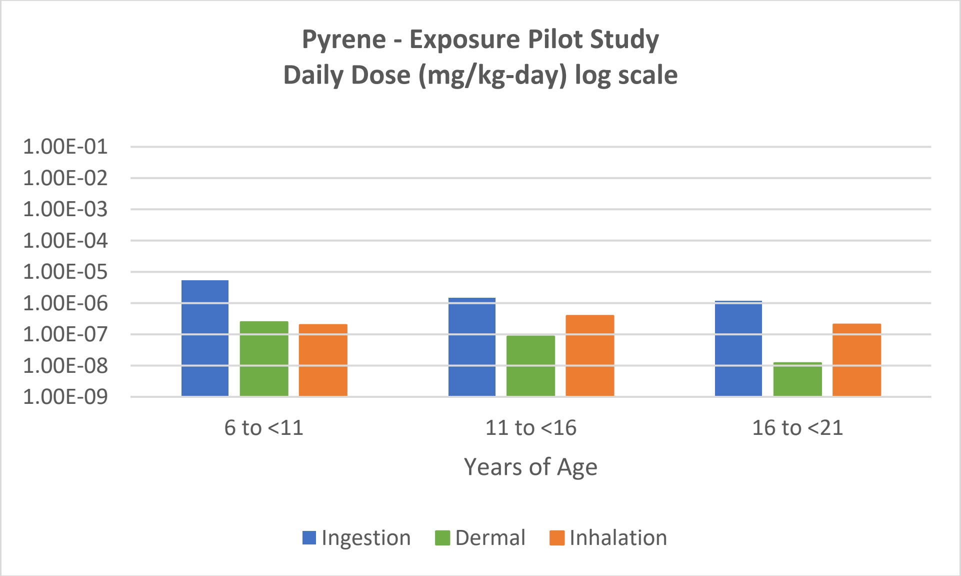


Figure 5-7. Pyrene daily dose calculated for three age groups, across by route of exposure, using exposure pilot study data.

5.2.3.3 Benzothiazole Exposure Estimates

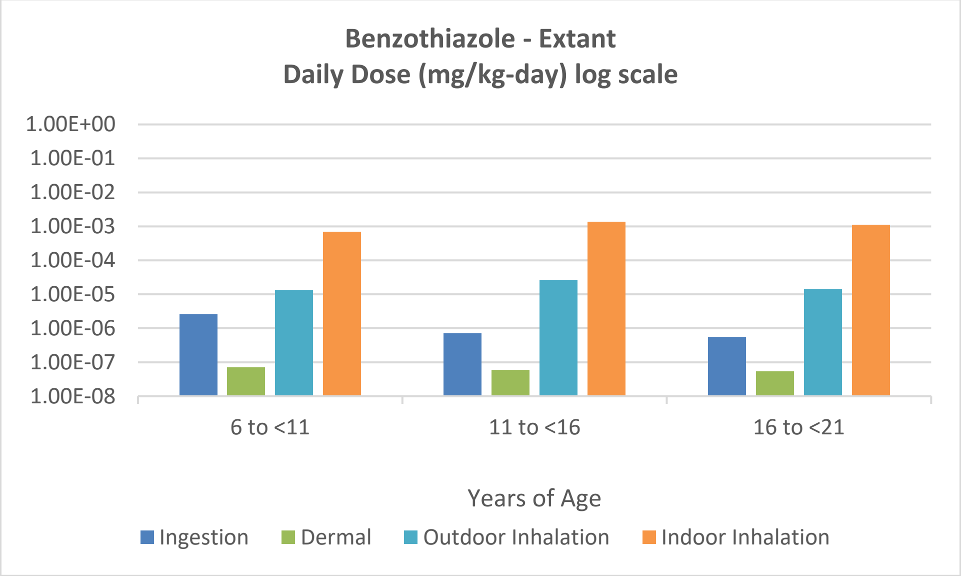


Figure 5-8. Benzothiazole daily dose calculated for three age groups, by route of exposure, using extant data.

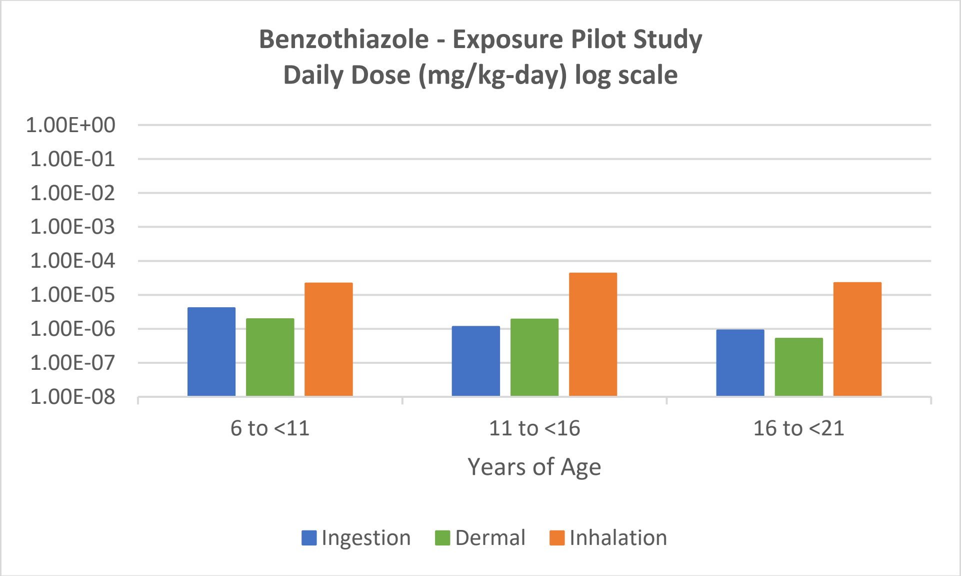


Figure 5-9. Benzothiazole daily dose calculated for three age groups, by route of exposure, using exposure pilot study data.

5.2.3.4 Methyl Isobutyl Ketone Exposure Estimates

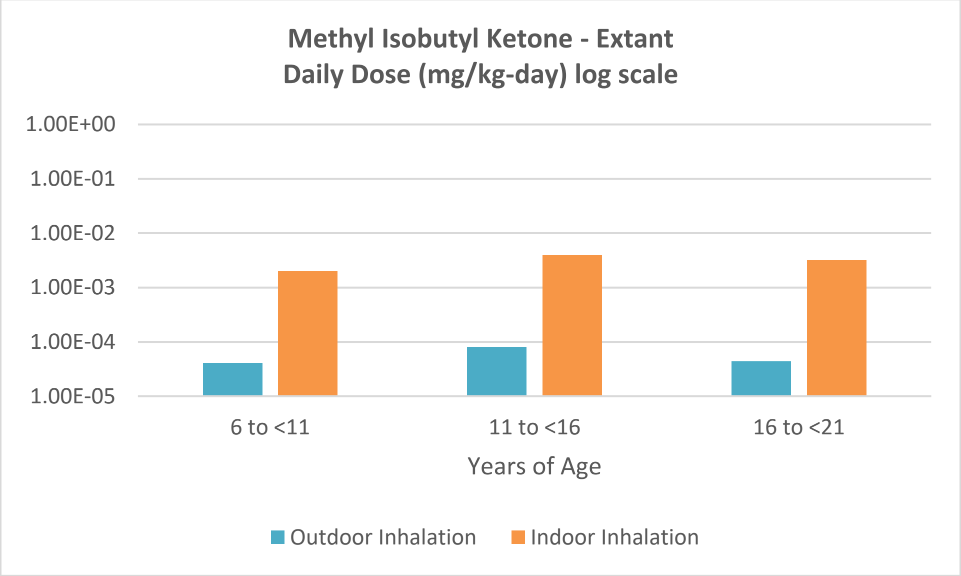


Figure 5-10. Methyl isobutyl ketone inhalation daily dose calculated for three age groups, using extant data.

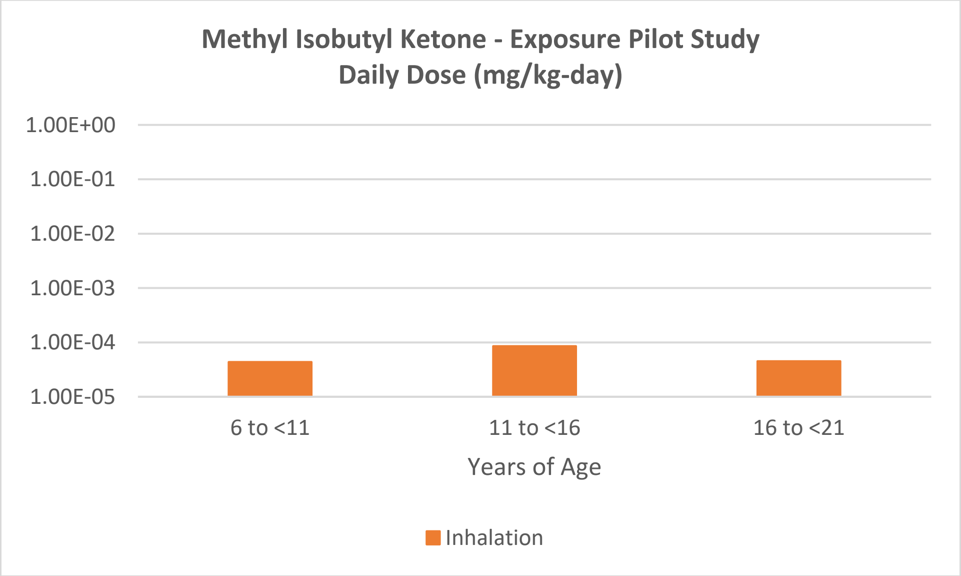


Figure 5-11. Methyl isobutyl ketone inhalation daily dose calculated for three age groups, using exposure pilot study data.

5.2.3.5 Lead Exposure Estimates

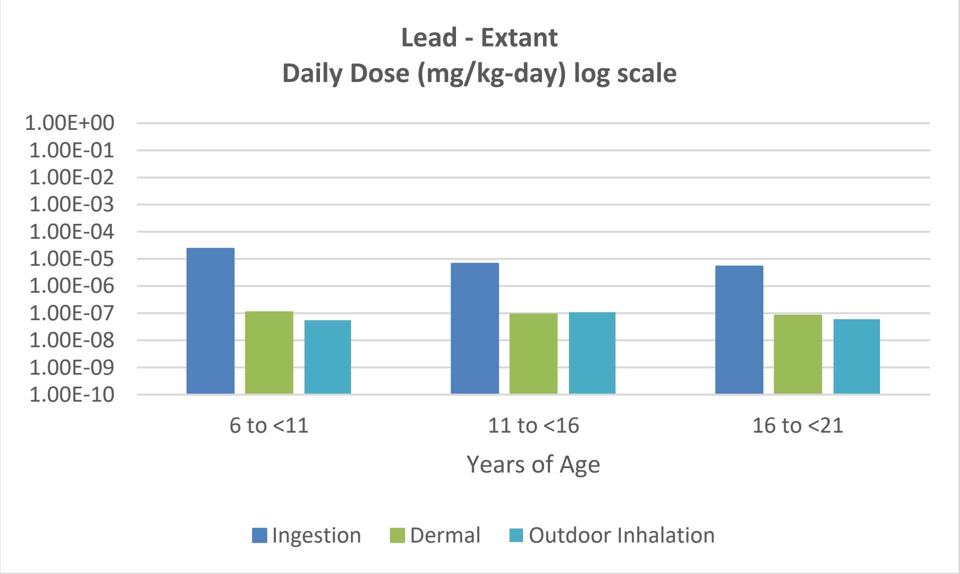


Figure 5-12. Lead daily dose calculated for three age groups, by route of exposure, using extant data.

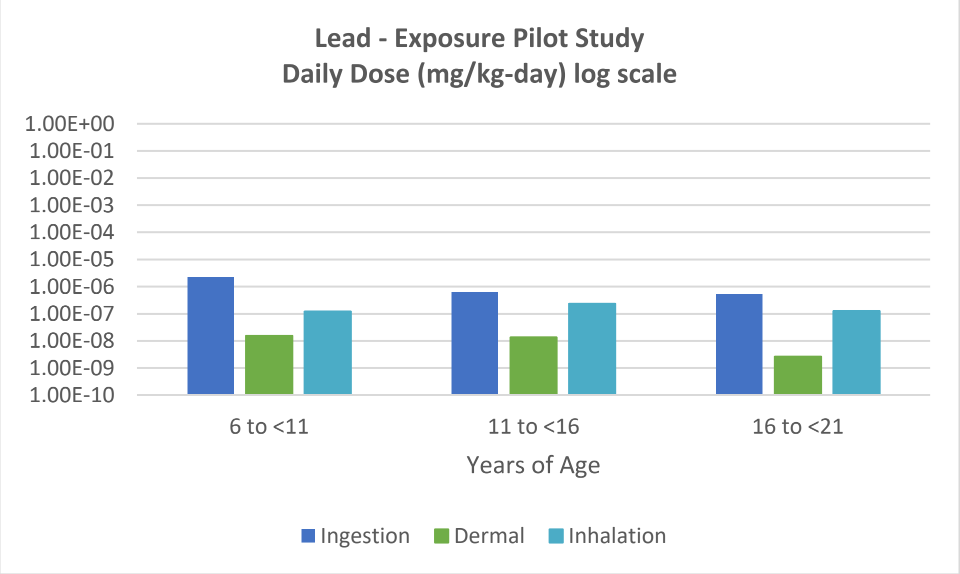


Figure 5-13. Lead daily dose calculated for three age groups, by route of exposure, using exposure pilot study data.

5.2.3.6 Zinc Exposure Estimates

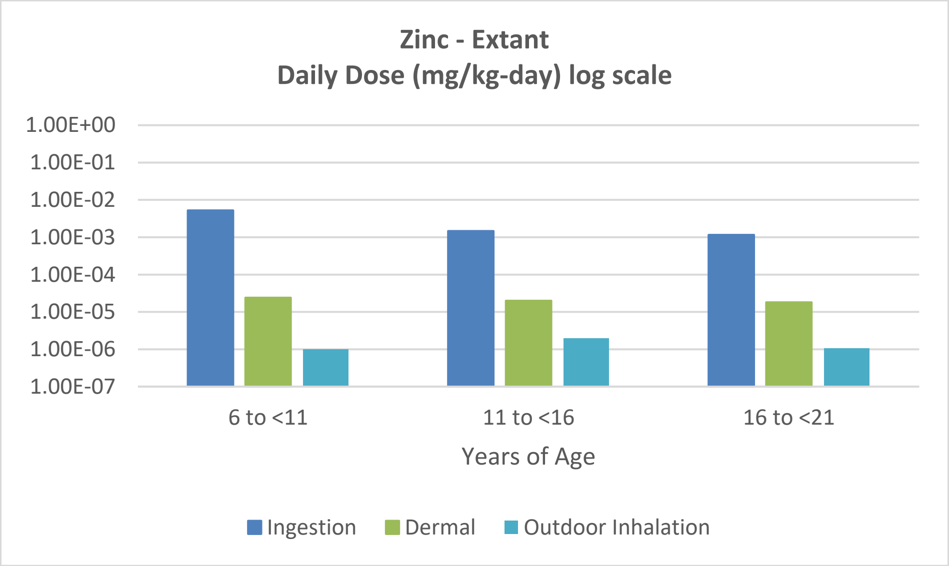


Figure 5-14. Zinc daily dose calculated for three age groups, by route of exposure, using extant data.

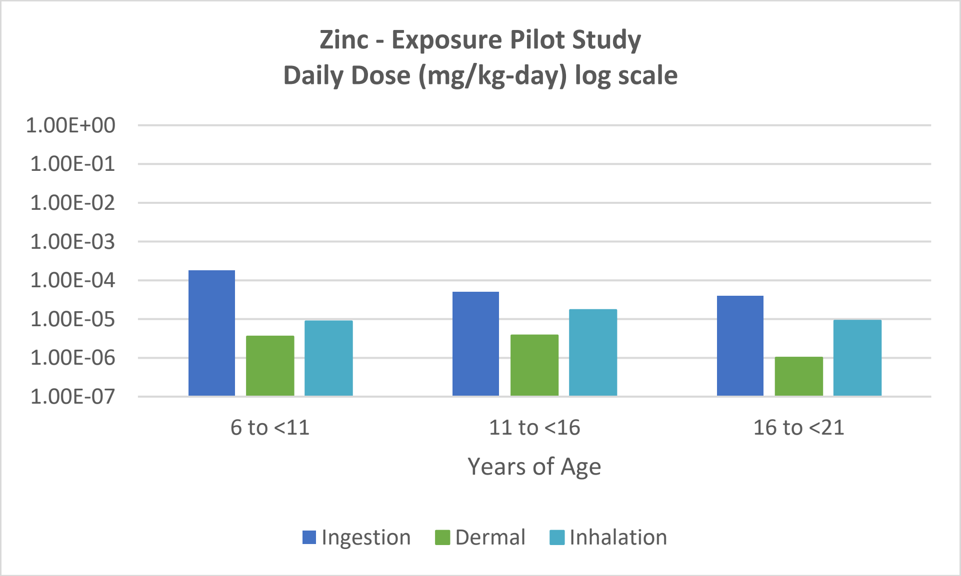


Figure 5-15. Zinc daily dose calculated for three age groups, by route of exposure, using exposure pilot study data.

5.2.4 Background Exposure Estimation Results from Residential and Dietary Sources

Daily residential plus dietary dose rate estimates for inhalation, dietary and non-dietary ingestion, and dermal absorption were calculated for three age groups (Table 5-15). Dietary and non-dietary ingestion are summed as "Total Ingestion," and inhalation, total ingestion, and dermal absorption are summed as "Total Estimated Daily Dose." Estimates are missing where no media-specific background data could be located; for example, no values were found through a literature search for benzothiazole concentrations in food or dust/soil, so no dietary or non-dietary ingestion or dermal absorption intake rates could be estimated. "Total Estimated Daily Dose" represents the summation of all available estimates, assuming zero for any missing route-specific estimates.

In general, route-specific and total estimated doses are highest for the youngest age group and lowest for adults. Total estimated dose largely reflects ingestion, with dietary ingestion dominating for some chemicals substances and non-dietary ingestion dominating for others. This result is not surprising since the highest dust/soil ingestion rates and the highest dietary consumption rates per unit body weight are for the youngest age group.

Table 5-15. Estimated Residential Plus Dietary Daily Dose for Chemicals of Interest, by Age Group[a]

Age (years)	Chemical Substance	Daily Dose - Inhalation (mg/kg-day)	Daily Dose - Dietary Ingestion (mg/kg-day)	Daily Dose - Non-Dietary Ingestion (mg/kg-day)	Daily Dose - Total Ingestion (mg/kg-day)	Daily Dose - Dermal (mg/kg-day)	Total Estimated Daily Dose[b] (mg/kg-day)
6 to <11	Benzo[a]pyrene	5.18E-08	7.86E-07	2.09E-06	2.88E-06	3.83E-08	2.97E-06
6 to <11	Pyrene	4.39E-07	7.03E-06	4.06E-07	7.44E-06	2.07E-08	7.90E-06
6 to <11	Benzothiazole	9.62E-06	NC	NC	NC	NC	9.62E-06
6 to <11	Methyl isobutyl ketone	1.80E-05	3.14E-05	NC	3.14E-05	NC	4.95E-05
6 to <11	Lead	3.33E-06	7.50E-05	2.62E-04	3.37E-04	2.23E-06	3.43E-04
6 to <11	Zinc	NC	6.60E-02	4.72E-04	6.65E-02	4.02E-06	6.65E-02
11 to <16	Benzo[a]pyrene	3.65E-08	4.40E-07	5.86E-07	1.03E-06	3.17E-08	1.09E-06
11 to <16	Pyrene	3.10E-07	4.26E-06	1.14E-07	4.37E-06	1.72E-08	4.70E-06
11 to <16	Benzothiazole	6.78E-06	NC	NC	NC	NC	6.78E-06
11 to <16	Methyl isobutyl ketone	1.27E-05	1.76E-05	NC	1.76E-05	NC	3.03E-05
11 to <16	Lead	2.35E-06	7.50E-05	7.34E-05	1.48E-04	1.85E-06	1.53E-04
11 to <16	Zinc	NC	6.60E-02	1.32E-04	6.61E-02	3.33E-06	6.61E-02
16 to <21	Benzo[a]pyrene	3.13E-08	3.49E-07	4.65E-07	8.14E-07	2.88E-08	8.74E-07
16 to <21	Pyrene	2.65E-07	3.31E-06	9.01E-08	3.40E-06	1.56E-08	3.68E-06
16 to <21	Benzothiazole	5.81E-06	NC	NC	NC	NC	5.81E-06
16 to <21	Methyl isobutyl ketone	1.09E-05	1.40E-05	NC	1.40E-05	NC	2.49E-05
16 to <21	Lead	2.01E-06	7.50E-05	5.82E-05	1.33E-04	1.68E-06	1.37E-04
16 to <21	Zinc	NC	6.60E-02	1.05E-04	6.61E-02	3.03E-06	6.61E-02

[a] NC = not calculated.

[b] Total estimated daily dose across all exposure pathways incorporates inhaled, total ingested and dermal estimations.

5.3 Comparison of Synthetic Turf Field User Exposure Estimates Using Extant Data and Exposure Pilot Study Data

Using existing measurement data for six chemicals and exposure pathway model parameters that included many values not necessarily developed for these specific chemicals, tire crumb rubber infill material, or synthetic turf field athlete scenarios, we observed the following:

- In general, chemicals of like or similar classifications (i.e., VOCs) followed similar patterns of exposure for each age group.
- Ingestion appears to be the most significant route of exposure for the PAH SVOCs pyrene and benzo[a]pyrene. Estimated exposures were highest for the 6 to <11 age group, with lower exposures for older age groups, as the amount of tire crumb rubber constituents ingested is assumed to decrease with age due to the decrease in hand-to-mouth contact.
- Ingestion is also the dominant route of exposure for the metals lead and zinc and is also highest in the 6 to <11 age group. A decrease in exposure is observed for the other age groups due to an assumed decrease in incidental ingestion of tire crumb rubber with age.
- The predominant exposure pathway for the SVOC benzothiazole appears to be inhalation, with much higher inhalation exposures at indoor fields than outdoor fields (based only on a very small number of indoor field air measurements).
- Dermal exposures are estimated to be lower than ingestion exposures for the metals and PAH SVOCs and much lower than the inhalation exposure for benzothiazole. Dermal exposure was not observed to be the dominant route of exposure for any of the compounds of interest; however, there are large uncertainties in the model adherence and dermal absorption parameters.

Using measurements of bioaccessibility of metals in tire crumb rubber and exposure-related measurement data from this exposure pilot study (including measurements of chemical substances in field dust and on dermal wipes), the exposure pathway models were re-run. We observed the following using the data from this study:

- There was no change in the dominant route of exposure for each chemical substance, and trends were consistent with each age group.
- Estimates for ingested dose using data from the exposure pilot study were lower than dose estimates using extant measurements, based on lower metal and PAH SVOC levels in field dust compared to tire crumb rubber and lower exposure pilot study ingestion absorption for metals based on the bioaccessibility (biological sample) results.
- There are no objective data for assessing incidental ingestion of tire crumb rubber or synthetic turf field dust for synthetic field turf scenarios, leaving ingestion exposure estimates still highly uncertain.
- Direct dermal loading measurements in the exposure pilot study provided the ability to calculate the amount of chemical directly in contact with the exposed skin, avoiding more uncertain adherence assumptions concerning adherence of crumb to skin. Exposure pilot study dermal estimates for metals were lower than results obtained using extant measurement data together with assumed tire crumb rubber dermal adherence values.
- Exposure via the dermal route was relatively low for each chemical substance, especially for lead and zinc, when this exposure pilot study's bioaccessibility measurements

replaced the more conservative (i.e., higher) dermal absorption estimates for metals using extant data.

The following observations were made regarding potential improvements in exposure estimates based on additional data collected in the exposure pilot study:

- Laboratory bioaccessibility measurements for lead and zinc reduced uncertainty from assumptions concerning the amount of the metal available to be absorbed.
- Dermal wipe measurements reduced uncertainty from assumptions concerning the amount of chemical substances (excluding methyl isobutyl ketone) transferred from tire crumb directly onto skin.
- In the absence of dermal wipe measurements, measurements of chemical substances in crumb rubber field dust (instead of in the larger crumb rubber granules) is likely to provide better estimates of the amount of chemical substances likely to transfer to skin.
- Measurements from field dust are also likely to provide better estimates of exposure through ingestion, compared to measurements from the larger granules.

Even with the data from the exposure pilot study, several limitations remain. These include the following:

- The exposure pilot study field measurements were not able to provide any measurements of methyl isobutyl ketone in tire crumb rubber granules or dust or on field surfaces.
- No additional pathways could be completed for methyl isobutyl ketone based on new data collected during the exposure pilot study.
- Both extant data and exposure pilot study field data ignore the contribution of dietary intake from off-field activities to the total intake for relevant chemical substances.
- Small sample size of the exposure pilot study necessitated the combining of measurements from indoor and outdoor fields, limiting the scope of the modeling effort.
- A lack of data on bioaccessibility for chemical substances in crumb rubber field dust serves to increase the uncertainty of the route-specific exposure estimates for all three routes (see Figure 5-2).

5.4 Comparisons Between Synthetic Turf Field and Background Exposure Estimates

Total daily dose estimates calculated from residential plus dietary concentrations, from extant synthetic turf field data from the literature, and from the synthetic turf field data collected in this exposure pilot study are presented in Table 5-16. The table includes daily dose estimates for all three age groups in the exposure pilot study. Dose estimates for benzothiazole are not shown due to scarcity of data. Daily residential plus dietary dose estimates for benzo[a]pyrene are similar to estimates using extant synthetic turf field data and associated model parameters, but higher than estimates for synthetic turf field users based on data from this exposure pilot study. Daily residential plus dietary dose estimates for pyrene are slightly lower than estimates using extant synthetic turf field data but higher than estimates for synthetic turf field users based on data from this study. For lead and zinc, the total estimated daily doses are substantially higher for residential plus dietary than for synthetic turf fields. The differences among the three sets of results (residential plus dietary background, extant synthetic turf, and measurements in the exposure pilot study) are illustrated for benzo[a]pyrene, pyrene, lead, and zinc in Figures 5-16 through 5-19, respectively.

Table 5-16. Total Estimated Daily Dose Across all Pathways by Age Group[a]

Age (years)	Chemical Substance	Estimated Total Daily Dose – Residential Plus Dietary Background (mg/kg-day)	Estimated Total Daily Dose – Synthetic Field, Extant Data (mg/kg-day)	Estimated Total Daily Dose – Synthetic Field, Exposure Pilot Study (mg/kg-day)
6 to <11	Benzo[a]pyrene	2.97E-06	1.64E-06	7.62E-07
6 to <11	Pyrene	7.90E-06	1.32E-05	5.62E-06
6 to <11	Methyl isobutyl ketone	4.95E-05	2.04E-03	4.37E-05
6 to <11	Lead	3.43E-04	2.36E-05	2.43E-06
6 to <11	Zinc	6.65E-02	5.24E-03	1.90E-04
11 to <16	Benzo[a]pyrene	1.09E-06	5.53E-07	2.21E-07
11 to <16	Pyrene	4.70E-06	4.63E-06	1.92E-06
11 to <16	Methyl isobutyl ketone	3.03E-05	3.99E-03	8.55E-05
11 to <16	Lead	1.53E-04	6.74E-06	8.92E-07
11 to <16	Zinc	6.61E-02	1.48E-03	7.08E-05
16 to <21	Benzo[a]pyrene	8.74E-07	4.42E-07	1.52E-07
16 to <21	Pyrene	3.68E-06	3.64E-06	1.37E-06
16 to <21	Methyl isobutyl ketone	2.49E-05	3.21E-03	4.52E-05
16 to <21	Lead	1.37E-04	5.33E-06	6.37E-07
16 to <21	Zinc	6.61E-02	1.18E-03	4.96E-05

[a] Total estimated daily dose across all pathways for each part of the study; benzothiazole comparison not shown due to scarce data.

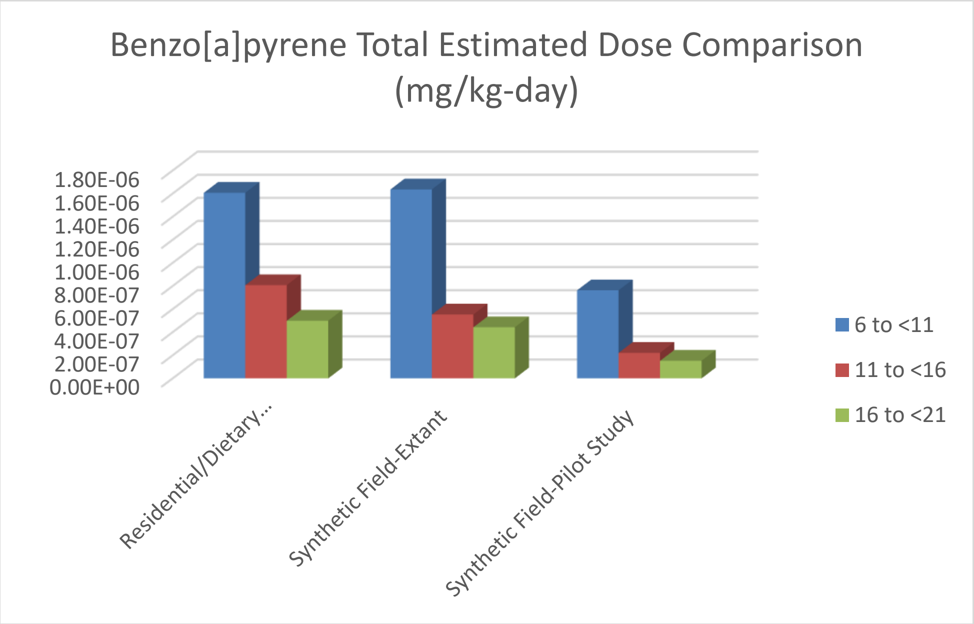


Figure 5-16. Total estimated benzo[a]pyrene background (residential/dietary) and synthetic turf field daily dose rate comparison across all pathways, by age group.

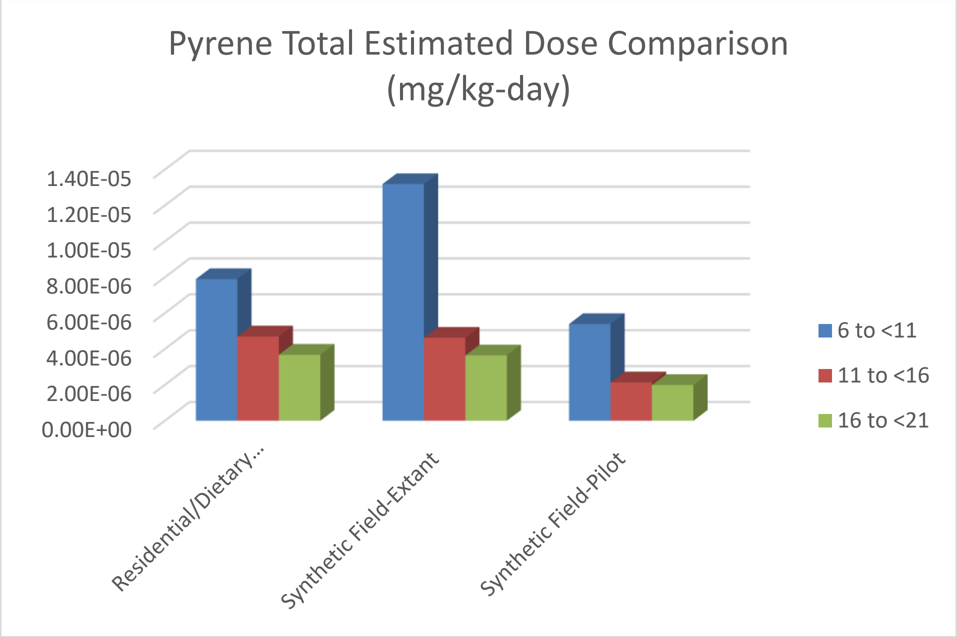


Figure 5-17. Total estimated pyrene background (residential/dietary) and synthetic turf field daily dose rate comparison across all pathways, by age group.

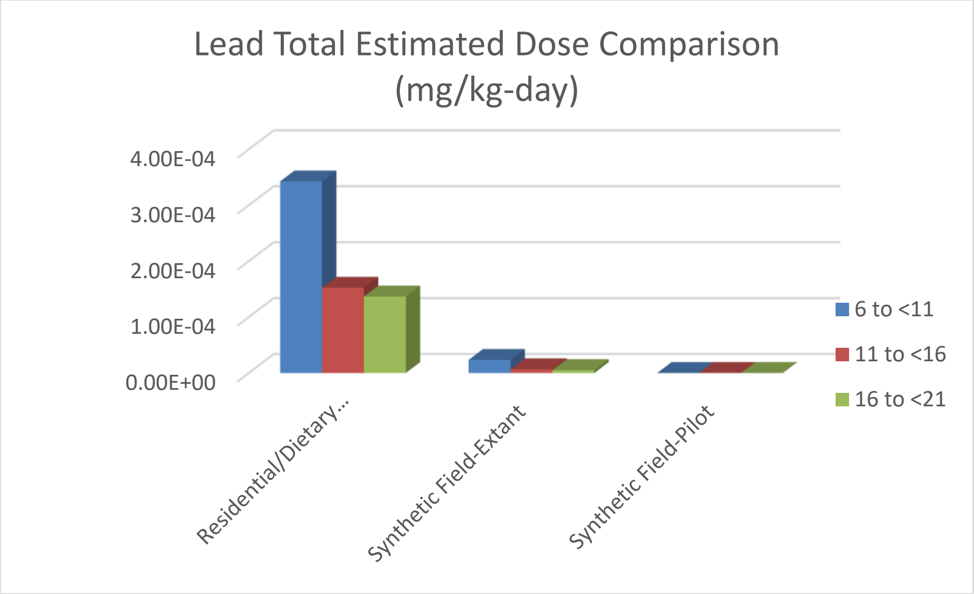


Figure 5-18. Total estimated lead background (residential/dietary) and synthetic turf field daily dose rate comparison across all pathways, by age group.

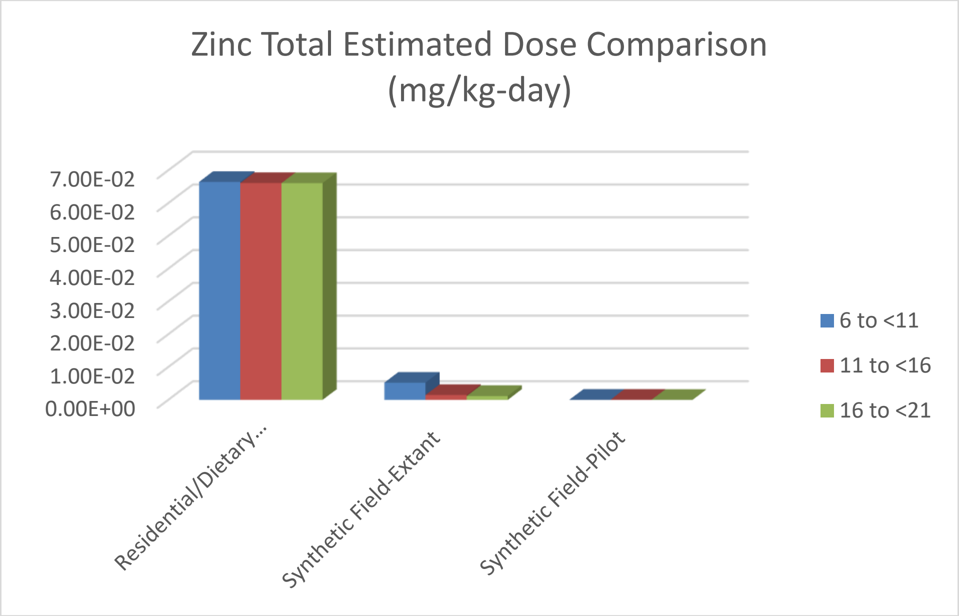


Figure 5-19. Total estimated zinc background (residential/dietary) and synthetic turf field daily dose rate comparison across all pathways, by age group.

Differences between total estimated doses using extant data from synthetic turf fields versus data from the tire crumb rubber characterization portion of the study (U.S. EPA & CDC/ATSDR (2019) and the exposure pilot study can be attributed to several factors, including: a) different concentrations measured in this study, b) the use of dust measurement data in this study instead of tire crumb rubber for ingestion estimates, c) the use of direct dermal measurements in this study instead of an assumed adherence factor for tire crumb rubber, and d) the use of laboratory-measured bioaccessibility of zinc and lead instead of the assumed values used for the extant data.

Measurements of the six compounds of interest in media from environments not known to be impacted by contamination are relatively sparse. In addition, some of the data that were available for U.S. populations were collected almost 20 years ago and may not reflect current exposures in the population. Due to the paucity of background concentration measurements, the total residential plus dietary background daily dose estimates should be considered highly uncertain. Benzothiazole estimates could not be calculated, and methyl isobutyl ketone data were missing for key media, especially residential indoor air and indoor dust measurements. The air concentrations for methyl isobutyl ketone were measured in outdoor air and are not considered a good surrogate of residential indoor air. Zinc was also missing indoor air measurements.

The process of modeling using algorithms that rely on exposure factor parameters required some large assumptions. For example, EPA's Exposure Factors Handbook (U.S. EPA, 2011b) provides no applicable indoor dust adherence rates for adults, and the adherence factor recommended for children had to be used across all age groups.

The six chemical substances evaluated in this comparative analysis are only indicative of a small subset of the chemicals associated with tire crumb rubber; however, due to the limited or unavailable environmental concentration, dietary intake, and bioaccessibility and concentration data available for those chemicals, testing protocols have not been fully developed, and at this time, gathering enough information to apply to modeling residential and dietary exposures is not feasible.

5.5 Conclusions

Based on these modeling exercises, we report the following observations regarding the accuracy and uncertainties in exposure estimates for athletes using synthetic turf fields:

- The data are not adequate to support probabilistic exposure modeling approaches. For many chemicals found to be associated with tire crumb rubber infill on synthetic turf fields, there is a lack of robust data for many exposure media, including air (particularly in athlete breathing zones), field surfaces and field dust, and dermal residue loadings. This lack of robust data likely results in increased uncertainty in exposure estimation.
- Current exposure estimates are somewhat limited by the lack of exposure scenarios that more fully account for actual activity levels and types and frequencies of contact, and their differences among sport types (e.g., football vs. soccer) and specific positions (e.g., goalkeepers) that likely involve higher rates of contact with turf materials.
- There are limited or no data available for some of the important parameters needed to estimate exposures for athletes using synthetic turf fields with tire crumb rubber infill. The lack of parameter data leads to applications of assumed values or values applied from non-equivalent scenarios, both of which can lead to considerable uncertainties in exposure estimates. In some cases, conservative values are applied that may lead to exposure over-estimation but are considered to be protective in assessments for exposed populations. In other cases, important exposure mechanisms may not be correctly accounted for, potentially leading to exposure under-estimation. Some of the important parameters with no or limited data include:
    - Concentration of tire crumb rubber particles of various size fractions in the breathing zones of athletes under different athletic activity conditions
    - Ingestion rates for tire crumb rubber particles of various sizes during athletic activities
    - Skin adherence rates of tire crumb rubber particles of various sizes, for both dry skin and sweaty skin conditions
    - Skin adsorption rates for organic chemicals associated with tire crumb rubber particles of various sizes
    - Respiratory absorption rates for inorganic and organic chemicals associated with tire crumb rubber particles of various sizes
    - Ingestion (gastrointestinal) absorption rates for organic chemicals associated with tire crumb rubber
- There are a large number of chemical substances associated with tire crumb rubber infill that have not been included in most exposure assessments. Lack of certainty in the identification of many of these chemicals and lack of quantitative measurements inhibits a more complete cumulative exposure assessment.

Estimates of “background” exposures to benzo[a]pyrene, pyrene, lead and zinc from residential and dietary sources were calculated and compared to modeled exposure estimates for synthetic turf field users to provide perspective on the magnitude of the exposures estimated for athletes. The following observations were made from that analysis:

- Benzo[a]pyrene and pyrene exposures from residential plus dietary sources were estimated to be 1.5 to 3 times higher than modeled exposure estimates for synthetic turf field users based on data produced in this exposure pilot study.
- When using previously published literature results for synthetic turf fields and somewhat different model parameters (e.g., duration of exposure), benzo[a]pyrene exposures from residential plus dietary sources were similar to those for synthetic turf field users. Pyrene exposures were ≤ 1.5 times higher for synthetic turf field users using extant literature data compared to residential plus dietary sources.
- Lead and zinc exposures from residential plus dietary sources were estimated to be over 100 times higher than modeled exposure estimates for synthetic turf field users based on data produced in this exposure pilot study and over 10 times higher for estimates using extant data from the literature to model exposures for synthetic turf field users.

Previous exposure estimates for athletes have primarily focused on soccer players of various age groups and playing intensities. More work is needed to examine potential exposures for other sport types and for certain positions within sports. For example, football athletes, rugby athletes, and soccer goalies are likely to experience substantially different dermal and ingestion exposures than soccer field players due to their much more frequent contact with turf materials. They may also experience higher particle inhalation due to the nature of their play and more frequent proximity to the turf surface. Players using mouthguards, typically required in football, may also experience higher oral contact rates with residues. More data are needed on activity types and contact rates, along with improved approaches for measuring chemicals in the relevant exposure media, dermal wipes, and biological samples to develop or improve exposure pathway model parameter values for estimating athlete exposures at synthetic turf fields.

Some researchers have developed exposure estimates for non-athletes at synthetic turf fields. More information regarding time and activities by coaches, referees, maintenance workers, parents and young siblings could be beneficial to extending and improving exposure estimation for these groups.

Finally, a large number of inorganic and organic chemical substances have been found to be associated with tire crumb rubber. These chemicals have a large range of chemical and physical properties that affect how they are released from the tire crumb rubber material and absorbed in the body. It remains a challenge to accurately estimate inhalation, dermal and ingestion exposures across this large range of chemicals, and even more of a challenge to estimate potential risks on a cumulative exposure basis. Studies that investigate biomarker identification of chemical substances found in tire crumb rubber can contribute to exposure modeling for a more robust exposure profile. Currently, data are likely to be sparse for estimating background exposures for many of the chemicals associated with tire crumb rubber for comparison with synthetic turf field user exposure estimates.

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7.0 Appendices

The following Appendices can be found in Volume 2 of this report:

A Supplemental Biomonitoring Study
B Quality Assurance and Quality Control
C Standard Operating Procedures (SOP) for Exposure Characterization Research
D Synthetic Field Facility User Questionnaires
E Exposure Characterization Meta-Data Collection Forms
F Blood Metals and Serum Metals Analysis Protocols
G Video Activity Data
H Feasibility Assessment for Silicone Wristband Passive Samplers at Synthetic Turf Fields

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