The Changing COVID-19 Landscape: A Feasibility Study to Capture Momentary Residential Environmental Exposures and Asthma Symptoms in Adults

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SPECIFIC AIMS

The global pandemic of coronavirus 2019 (COVID-19) has rapidly impacted the United States (US) population and is a substantial cause for concern among individuals with chronic respiratory diseases. Asthma is a complex, multi-faceted respiratory disease that affects over 19 million US adults (18 years or older).[1] Further, it is estimated that more than 60% of US adults with asthma have uncontrolled symptoms.[2] This represents a substantial health and economic impact; uncontrolled asthma in the US results in the loss of approximately 15 million quality-adjusted life years among adults and a total economic burden (both direct and indirect costs) of greater than $960 billion over a 20-year span.[3] In addition, adults appear to be nearly five times more likely to die from asthma than children and the asthma-related death rate is highest among those 65 years and older.[2] Viral infections are a prominent risk factor for asthma exacerbation[4] and, thus, SARS-CoV-2, the virus responsible for COVID-19, is cause for alarm among those diagnosed with asthma. Sheltering-in-place orders and recommendations, physical distancing, wearing face coverings, hand hygiene, and increased cleaning and disinfecting are primary COVID-19 preventative measures advocated by public health experts.[5] What is not known are the effects of these preventive measures, specifically increased residential exposure to cleaning/disinfecting agents and other environmental exposures on adults with asthma.

As individuals are sheltering at home for longer periods of time, those with asthma may increasingly contend with household asthma triggers and new chemical exposures as they sanitize their home environments to prevent COVID-19. Household asthma triggers may include air pollutants[6,7] such as air particulate matter in the form of combustible pollutants such as secondhand smoke[8] and use of different chemical cleaning/disinfecting products.[9,10] Tight housing construction results in less well-ventilated homes and enhanced exposure to household air pollutants. Ordinarily, adults can spend as many as 15 hours per day indoors[11,12] which further contributes to their risk for environmental exposures. The current COVID-19 crisis has altered usual cleaning practices and amount of time spent at home. It is unknown how these changes impact adults with asthma.

We will assess the feasibility and usability of ecological momentary assessment (EMA) to capture the context of real time behaviors and environmental exposures that impact indoor environments. In addition, we will assess the feasibility and usability of providing participants with a readily available indoor air quality monitor (Awair Omni®) to continuously capture total volatile organic compounds (VOCs) and particulates ($PM_{2.5}$). This design will allow us to alert participants of high levels and collect real time data on exposures and asthma symptoms. Daily and exposure-related lung function will be measured with a low-cost home spirometer. Finally, we will examine the effect of residential environmental exposures that may be related to increased time spent at home due to COVID-19 and the associations between these exposures and asthma control.

Our team is comprised of three nurse-scientists and a physician-scientist, each of whom have research focused on asthma experienced in a range of age groups from adolescent to older adult. Our team has established community partners (Chicago Asthma Consortium) and our research team members are situated in three different midwestern US areas. Our long-term goal is to characterize the impact of COVID-19 on existing asthma risk factors so as to develop tailored, home-based asthma interventions that takes into account COVID-19 and are responsive to the changing home environment and change in home routines resulting from this pandemic. For adults with sub-optimally controlled asthma, this study will:

Aim 1. Determine the feasibility and usability of (1) EMA to assess self-report residential environmental exposures and asthma symptoms, (2) home monitoring of environmental exposures (VOCs, $PM_{2.5}$), and lung function (home spirometry, FEV_1% predicted).

Aim 2a. Assess the frequency and degree of residential environmental exposures (e.g., disinfectants/ cleaners, second-hand smoke) via (1) self-reported data, and (2) home monitoring objective measures.

Aim 2b. Assess the level of asthma control as indicated by self-reported asthma symptoms and lung function.

Aim 3. Explore associations of self-reported and objective measures of residential environmental exposures with self-reported and objective measures of asthma control.

Findings from this study will provide preliminary data for a powered study to develop innovative intervention strategies for those with asthma addressing the impact of changes in environmental exposures related to COVID-19 and enhancing our preparedness for future infectious disease outbreaks. This has implications for risk reduction in individuals with asthma to help improve asthma self-management using personal monitors and sensors for individually tailored exposure profiles.

SIGNIFICANCE

Asthma is a disease of chronic airway inflammation and affects 1 in 12 adults in the US.[1] Despite effective treatments for asthma, it is estimated that more than 60% of adults with asthma have uncontrolled symptoms.[2] Poorly controlled asthma increases the risks of severe asthma exacerbations which may result in missed work days, emergency room visits, and hospitalizations.[13] The 20 year direct costs related to uncontrolled asthma exceed $300 billion thus the burden of uncontrolled asthma is substantial.[3]

Presenting to a healthcare facility with symptoms of wheezing and shortness of breath can initially complicate diagnosis and treatment for asthma exacerbation or COVID-19.[4] Currently, the available case study evidence is unclear whether those with asthma are at greater risk or overrepresented among cases with severe COVID-19 outcomes.[14-17] Recent US data has shown higher rates of asthma in hospitalized COVID-19 patients compared to COVID-19 patients in the ambulatory setting.[18] Further, in one US cohort study, asthma was the second most common co-morbidity after obesity among those 18-49 years old with COVID-19.[19] It is also unclear if individuals with asthma are overrepresented among those currently seeking testing for COVID-19 across the nation. While cardiovascular disease, kidney disease, and diabetes have been associated with greater COVID-19, mortality[20] pulmonary conditions such as asthma, which is exacerbated by respiratory viruses, have not been well studied in COVID-19.

Residential asthma triggers. Adults ordinarily spend about 15 hours/day indoors[11,12] and since COVID-19, those hours have largely been spent in their homes. Environmental asthma triggers in residential settings include dust mites, animal dander, mold, moisture, tobacco smoke, particulates, cockroach allergen, mouse/rat allergens, VOCs, and nitrogen dioxide.[13,21,22] Indoor residential air quality has been associated with decreased general health, asthma symptoms, airway inflammation, asthma exacerbations and decreased lung function in adults with asthma.[23-26] We will focus on residential VOCs, specifically disinfectants/cleaners, and particulates as potential asthma environmental triggers exposures increased during the COVID-19 pandemic.

Disinfectants. The CDC recommends initially cleaning residential surfaces with soap and water followed by disinfecting surfaces with an EPA-registered household disinfectant.[5] As of August, 2020 the EPA includes 482 products that meet the EPA criteria for use against SARS CoV-2 virus. Information listed by the EPA includes product name, active ingredients, contact times required, formulation types (e.g., ready-to-use, wipes, dilatable), and use sites (residential, institutional, healthcare). There are 305 products listed for use in any setting, 16 products listed only for residential use, 33 for institutional/residential use, and 4 for healthcare/residential use. Many of the products listed as appropriate for residential use have active ingredients shown to be asthmagenic such as quaternary ammonium (195 products) and sodium hypochlorite (56 products).[27] The EPA list provides no guidance regarding potential respiratory impacts of these products.

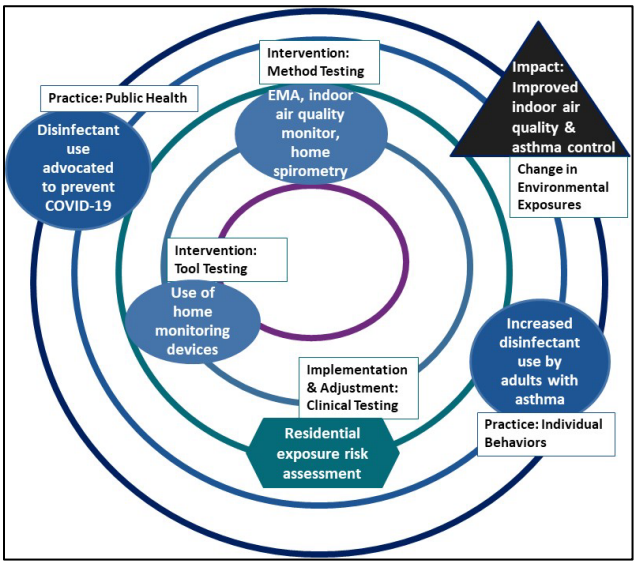
The effects of disinfectants on adults with asthma have been widely explored in the occupational context; research specific to residential exposures and disinfecting/cleaning products is limited. Exposure to cleaning agents, disinfectants, and hand sanitizers at worksites has been shown to increase asthma related symptoms and exacerbations.[28-36] In residential settings, weekly use of spray cleaners was associated with asthma in adults[9,37,38] and with decreased FEV_1 and FVC in European adults.[39] The odds of current asthma for women using bleach 4-7 times per week were 3.0 (1.5-7.1) compared to never using bleach.[10] Specific chemicals in cleaning/disinfecting products shown to impact asthma include d-limonene [40] terpenes, formaldehyde,[41,42] chloroform,[43] quaternary ammonium compounds,[31,44] amine compounds, and aldehydes.[45] Other VOCs commonly found in cleaners/disinfectants include ethanol, acetone, propanol, and a-pinene.[46] Our work in asthma and older adults revealed that, compared to those with well controlled asthma, participants with very poorly controlled asthma cleaned their bathrooms more often with products determined to have respiratory impact (p=002).[47] While cleaners and disinfectants are known asthma triggers, the extent asthma is impacted when use is increased during a pandemic is unknown.

Gharpure et al.[48] reported that since the COVID-19 pandemic, 60% of respondents to an online US survey had increased cleaning/disinfecting since the pandemic. Over a third of survey respondents indicated they had engaged in at least one high-risk practice involving a disinfectant such as bleaching food, using a household disinfectant on their hands, or misting themselves with a cleaner/disinfectant.[48] What is not known is the extent that adults with asthma engage in these types of practices, how often they clean/disinfect, and what impact these practices have on their asthma.

Particulates. Particulate matter (PM) are small particles/liquid droplets that include acids, organic chemicals, metals, soils, dust, and allergens.[49] Common indoor sources of particulates include outdoor sources, vacuum cleaner bags, printers, cooking, secondhand smoke, wood combustion in fireplaces/stoves, dust, pet hair, mold, candles, and biological sources.[25,50] $PM_{2.5}$ concentrations were found to be highest indoors

in homes (vs. outdoors or in offices) on weekends when participants wearing personal air quality monitors were home for longer periods,[51] thus supporting the increased potential exposure to particulates during the COVID-19 pandemic. $PM_{2.5}$, or particulates less than 2.5 micrometers, have been shown to affect cardiovascular health, anxiety, cognitive function, and respiratory health.[50] The effects of $PM_{2.5}$ on asthma are unclear. When nighttime particulates were monitored for 12 weeks in individuals with asthma sensitized to house dust mites (N=26), no consistent relationship was found between PM exposure and daily clinical outcomes (peak expiratory flow, FeNO, symptoms).[52] In contrast, increased indoor particulates were significantly related to reduced lung function, specifically with candle burning.[25] Increased frequency and severity of asthma exacerbations, asthma symptoms, hospitalizations, and asthma mortality were associated with increased ambient $PM_{2.5}$.[53-56] Polivka et al.,[57] found that older adults with poorly controlled asthma had significantly greater maximum $PM_{2.5}$ counts over a 24-hour period (p=.03).

In summary, the impact of home disinfectant use and particulate matter on adult asthma outcomes, particularly during the COVID-19 pandemic, demands further investigation. The home environment is an unregulated space where individuals and families make unique purchasing and cleaning decisions driven by tradition, finances, social and media influences. Existing research on VOCs and particulate matter provides a strong scientific premise for further exploration of these exposures in the home as the COVID-19 pandemic continues to actively unfold. This research can provide evidence-based guidance for home disinfectant use during a pandemic for those with asthma. Research efforts focused on indoor home environments are essential to understand the possible extent of exposures that can impact asthma outcomes in a time when home and healthcare resources (social and financial) continue to be strained. To describe our research trajectory, we illustrate the goals of our feasibility study and the impacts we intend to accomplish using the Translational Research Framework.[58,59] This feasibility study will assess residential exposures of disinfectants and particulates with the goal of reducing exposures and improving asthma outcomes (Figure 1).

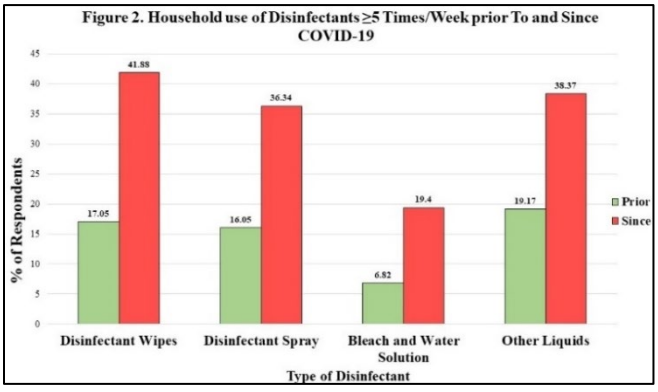


INNOVATION

The proposed feasibility study is innovative in several ways. First, the study addresses how increased cleaning and disinfecting practices associated with a novel virus could impact asthma control in those with asthma. Second, we uniquely use EMA to examine the effects of environmental triggers on adult asthma symptoms in real time, allowing us to capture participant engagement in their own home environment. Third, we will use and integrate innovative technologies to collect self-report and objective residential exposure data (VOCs, $PM_{2.5}$) in real time and link these data with self-report (EMA) and objective data on asthma control (spirometer). Fourth, this study focuses on adults with sub-optimal asthma control, a population also at higher risk for complications from COVID-19.

APPROACH

Preliminary work - Global COVID-19 and Asthma Study (GCAS). The proposed study builds on data collected from the GCAS, an ongoing cross-sectional online survey we launched in May 2020 to examine how the COVID-19 pandemic affected the prevalence of disinfectant use among adults with asthma and to assess the associations of the frequency of disinfectant use with asthma control as measured by the Asthma Control Test (ACT). To date, over 1000 individuals have responded. Of those, 92% are based in the US, 80% are female, about 21% indicated minority race/ethnicity, and 625 agreed to be contacted for follow-up research. Of those willing to be contacted about, 40% had ACT≤19. About 95% of respondents reported increased hand washing, 88% increased use of alcohol-based hand sanitizer since the



COVID-19 pandemic (Figure 2); about one-third noted increased smoking behaviors by household members. The percentage of participants reporting household use of disinfectant wipes, disinfectant sprays, and a bleach and water solution to disinfect objects ≥5 times per week more than doubled since COVID-19. We observed statistically significant associations of the increased frequency of household disinfectants use since COVID-19 with reduced asthma control (ACT score ≤19).

Chicago Asthma Consortium (CAC) was formed in 1996 by American College of Chest Physicians and Respiratory Health Association to coordinate the activities of the asthma community in Chicago. One priority of the CAC is the coordination of the Community Advisory Board (CAB), which was formed in 2014 with support from several grants. The CAB is comprised of community health workers, parents, patients, and pastors from the communities that have the highest asthma rates in Chicago. The research team met with the 5 members of CAC on Wednesday August 5, 2020. The study was briefly explained to CAC members and feedback was received related to all aspects of the proposed protocol including adding an instructional video, reducing the routine EMA notifications from 3 to 2X/day, the 14-day data collection length, and assuring a research team member was available for troubleshooting. Suggestions were incorporated into the study procedures. Once funded, we will meet with the CAC semi-annually for input and feedback on study protocols, measures, recruitment, and interpretation of findings.

Research Design. This study will evaluate the feasibility and usability of assessing real-time residential environmental exposures (VOCs/$PM_{2.5}$), asthma symptoms, and lung function using an innovative combination of commercially available technology (Aim 1).[60] In addition, we will use observational design to explore the unintended effects of these residential environmental exposures on adults with poorly controlled asthma in the era of COVID-19 (Aims 2 & 3).

Sample. Eligibility criteria include GCAS participants who: (1) indicated willingness to be contacted for future research, (2) reported high use of disinfectant/cleaning products since COVID-19 (≥5 per week), and current ACT≤19. Non-US residents and non-English speakers will be excluded. We will strive to have at least 20% of the sample representing minority populations. Fifty individuals meeting these criteria will be randomly selected and invited to participate in this study using their preferred contact method (94% indicated email). Interested individuals will be directed to a REDCap survey link to confirm willingness to participate, verify eligibility, and provide current contact information. We will randomly select replacements if no response is received after 2 contact attempts over two weeks or lack of interest is indicated.

Data collection methods. Three innovative data collection methods will be integrated in this feasibility study: Ecological Momentary Assessment (EMA) downloaded to participants' smartphone, Awair Omni Indoor Air Quality Monitor®, and Zephyr$_x$ Spirometer.

EMA is a survey approach which uses repeated sampling of participants to capture behaviors and experiences in a real time context. This methodological approach maintains the ecological validity of reported behaviors and decreases the impact of recall bias as surveys are sent periodically to participants through electronic devices.[61] EMA is particularly useful when trying to understand the context around symptoms or behaviors. Available literature that combines the EMA methodology with asthma research focuses primarily on asthma-related outcomes such as symptoms, control, quality of life, history, and medication adherence and their relationship with stress (perceived stress, mood, hassles, social support).[62-64] None of the published literature to date pairs EMA with indoor air quality and asthma symptoms. The ability to timestamp behaviors, events, experiences, whether they present a positive or negative health impact, is valuable when seeking to understand the complexity of multiple risk factors and multiple environmental and behavioral interactions.

Exposure	Sensor	Range/ Accuracy	Optimal range
VOCs	Multi-pixel metal oxide semiconductor gas sensor	0-60,000 ppb/ ±10%	<333ppb
$PM_{2.5}$	Laser-based light scattering particle sensor	0-1,000µg/m^3/±15 µg/m^3 or 15%	<15 µg/m^3

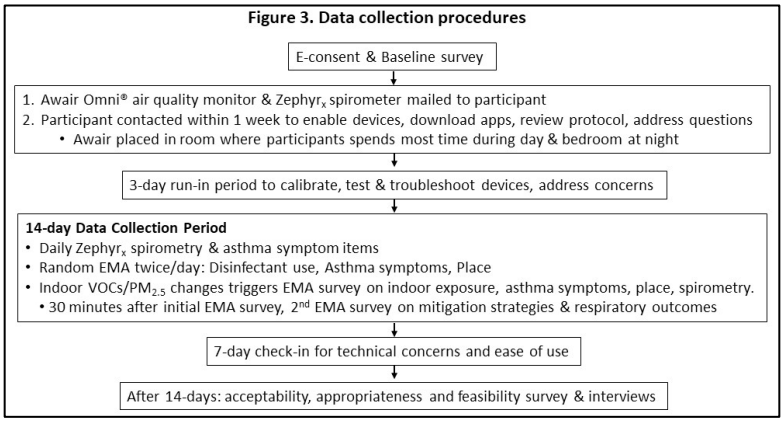
Awair Omni Indoor Air Quality Monitor® continuously monitors about 1,000 square feet of indoor air for 7 air quality factors: total VOC, $PM_{2.5}$, temperature, humidity, CO_2, ambient light, and ambient noise. This feasibility study will only focus on VOCs and $PM_{2.5}$ levels (Table 1). The Awair Omni measures about 4"X4"X1.3", is wi-fi and Bluetooth enabled, plugs into a standard AC outlet, and includes an 8-hour battery back-up. An air quality reading is taken every 10 seconds and real-time data are uploaded to a dashboard accessed only by research personnel. The display on the Awair Omni will be limited to VOCs and $PM_{2.5}$ data. Our preliminary work with Awair indoor air quality monitors indicates that increased VOC levels are detected when disinfectants are used and increased $PM_{2.5}$ levels are detected when vacuuming without a

HEPA filter. The Awair proprietary dashboard provides secure communication between the Awair Omni and its dashboard. Data will be exported from the dashboard to a .CSV file.[65-71]

Zephyr$_x$ Spirometer[72] system allows for laboratory quality pulmonary function tests (PFTs) at home (FVS-forced vital capacity, FEV_1-forced expiratory volume in 1 second, FEV_1/FVC, flow-volume loop). The system consists of an FDA approved handheld Bluetooth spirometer (MIR Spirobank Smart), and a mobile application that works on a smartphone or tablet device. The MIR Spirobank bank measures 49x109x21 mm and weighs 60.7 g. Participants share PFT results through their app and researcher team members will access a HIPAA compliant portal to view participants' PFT results in real time. An in-App video coaching feature guides the participant through the PFT maneuver. Each maneuver conducted by the participant creates a time and date stamped American Thoracic Society standard PFT report accessible through the portal. Data will be exported from the dashboard to a .CSV file.

Procedures (Figure 3)

1. Randomly selected individuals from the CGAS study who meet eligibility criteria will be invited to participate in the current study. Those interested will be directed to a REDCap link to complete an E-consent form and baseline questionnaire.



2. An Awair Indoor Air Quality Monitor and a Zephyr$_X$ Spirometer will be mailed to each participant along with a quick start guide, written instructions with a link to an instructional video, and research team contact information. Once received, a research team member will conduct a live chat with each participant to enable the devices, download apps (EMA, Zephyr$_X$), setup and test the devices and apps, review the protocol, and address questions. Participants will be instructed to place the portable Awair air quality monitor in the room where they spend the most time during the day and at night where they sleep.
3. A 3-day run-in period will be completed during which the participants will become familiar with the devices and troubleshoot issues (Awair requires 24-48 hours to calibrate VOC sensors). Study personnel will be available to answer questions/address technical issues. After the run-in period, a research team member will contact the participant to launch the 14-day data collection period.
4. During the 14-day data collection period, data from the EMA will be collected using EMA software platform on a personal smartphone (iOS or Android) and EMA software platform.[73] Each morning, participants will receive an EMA survey concerning asthma symptoms and a reminder to use their spirometer. Additionally, EMA surveys addressing disinfectant use, asthma symptoms, and spirometry will occur randomly twice/day (6am – 10pm) or tailored for those working off hours (Appendix).
5. A custom interface between the EMA platform and the Awair indoor air quality monitor will alert participants when levels of indoor VOCs or particulates are detected outside the optimal range (Table 1). The air quality monitor will communicate with the EMA platform using publicly available application programming interface (api). Upon notification from the Awair, the EMA will signal the participant to complete a brief survey on disinfectant use/air particulate exposure (depending on the alert), current asthma symptoms, and proximity to the Awair (Appendix). The EMA will then direct participants to use the spirometer. Participants experiencing symptoms will be guided to follow their asthma action plan/provider instructions.
6. Thirty minutes after VOC/$PM_{2.5}$ notification, a second EMA notification will be sent for participants to complete a survey on mitigation strategies, respiratory outcomes, and spirometry use if not already completed (Figure 4).
7. Research personnel will monitor use of these devices/apps and contact participants if a 24-hour gap in data is noted to address concerns and determine acceptability. Research team members will check-in with each participant at about the 7-day mark to address technical concerns and ease of use.

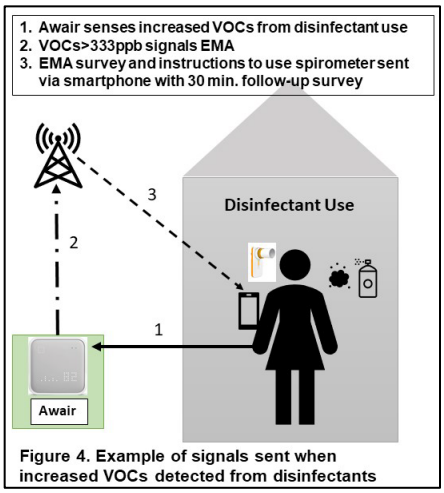


Figure 4. Example of signals sent when increased VOCs detected from disinfectants

8. At the end of the 14 days, participants will complete a short acceptability, appropriateness, and feasibility REDCap survey. A random sample of 20 participants will be interviewed to provide further insights.
9. Participants will be asked to return the Awair in the provided mailer. The Awair will be fully disinfected per manufacturer's directions. Participants will keep the Zephyr$_X$ spirometer as an incentive.

Baseline Measures

The following measures will be administered at baseline via REDCap:

1. *Adult Asthma History* includes 5 items adapted from the Behavioral Risk Factor Surveillance System Survey.[74] Four items address participants' recent contact with healthcare professionals for asthma since COVID-19. The final item addresses changes in routine work/activities due to asthma since COVID-19.
2. *Asthma Control Test (ACT).* The ACT includes 5 items addressing: asthma symptoms, use of rescue medications, and effect of asthma on daily functioning. Responses are summed for total ACT score.[75,76]
3. *Airborne Exposures.* The 7 items from the PROMIS℠ Pool V1.0 Dyspnea Airborne Exposure address airborne allergens, pollutants, smoke, pets, and use of pesticides using Yes:No response options.[77]
4. *Adult Asthma Adherence Questionnaire,*™ includes 5 items on following their prescribed asthma medication plan and barriers to following that plan.[78]
5. *Health and Demographics* includes items such as self-rated physical health, comorbidities, height/weight, age, education, ZIP code, smoking status, and COVID-19 prevention practices, and COVID-19 exposure/infection status.
6. *Home Environmental Exposure* data will be gathered including home type, # of occupants, vacuum with HEPA filter, cleaning practices, cleaning products, air filter, heating, ventilation, smoke exposures, hand washing practices, pests, hobbies, odors, indoor plants, printers, flooring, and stove type.[79,80]

We will also measure the following psychometrically valid measures as potential confounders:

7. *Emotional Distress-Anxiety and Depression PROMIS Short Forms 4a* assess anxiety and depression levels within the last 7 days (4 items). Higher scores indicate higher severity of anxiety or depression.[81,82]
8. *Emotional Support,* PROMIS_SF_V2 Short Form 4A measures perceived feelings of support. being cared for and valued (4 items).[83] Higher score indicating a higher perceived emotional support.
9. *Perceived stress scale* includes 4 items measuring the degree to which situations in one's life are appraised as stressful.[84-86] Higher scores indicate an increased level of perceived stress.

EMA survey items (See Appendix).

- *Asthma symptoms* (trouble breathing, wheezing, coughing, other symptoms [Yes:No]) assessed each time participants are asked to complete an EMA survey.
- *Random EMA surveys (twice/day)* assess use of disinfectants/cleaners in last 2 hours (Yes:No) if Yes, the type, brand, and asthma symptoms are queried.
- *EMA survey triggered by VOCs/$PM_{2.5}$ greater than optimal range as detected by the Awair* will query asthma symptoms, lists of probable sources of elevated VOCs or $PM_{2.5}$.
- *EMA survey 30-minutes after Awair air quality notification* queries mitigation strategies used (from lists) and asthma symptoms.
- *Home spirometer use* (Yes:No) queried in each EMA survey

Home spirometer. FEV_1% predicted– a standard metric of lung function for those with asthma.

Seven-Day check-in. Open-ended questions to identify any trouble-shooting areas, determine if adjustments need to be made, and assess ease of use of the app/devices. Interactions will be recorded and reviewed by the research team for patterns and to identify any adjustments that are needed.

Participant feasibility assessment. At the end of the 14-day data collection period, participants will be asked to respond to a short REDCap survey assessing acceptability, appropriateness, and feasibility of the indoor air quality monitor, EMA notifications, and the home spirometer with response ranging from 1=completely disagree to 5=completely agree. A random sample of 20 participants will be interviewed to further explore these factors using open-ended questions such as "Tell us what you liked/didn't like about the indoor air quality monitor", "Describe the strengths/concerns about the survey you received about your home indoor air quality".

Data Analysis

Each day of observation will be divided into four 4-hour periods between 6 a.m. and 10 p.m. Data from a given period will be considered as follows:

1. Period specific data from all event-contingent EMA prompts [prompts triggered by high indoor air VOC/$PM_{2.5}$ readings] will be analyzed. If multiple event-contingent prompts were answered, data will be averaged across all event-contingent prompts during that period.
2. Data from all answered baseline and random [signal-contingent] EMA prompts will be considered.

Aim 1. For this aim, we will assess:

1. Compliance with the EMA prompts as indicated by the frequency of responses to prompts, specifically:
    a. # of responses (complete:incomplete)/number of prompts
    b. # times spirometer used/number of prompts
    c. # times environment modified/number of event-contingent prompts
2. Compliance as described in 1a-1c by 4-hr each period.

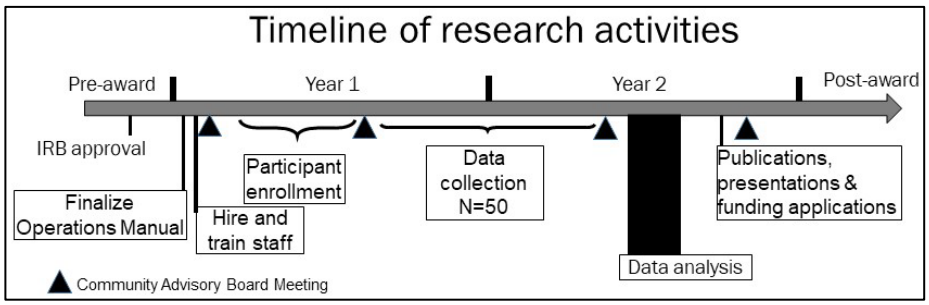
We will also assess the duration the indoor air quality monitor is used by each participant. The quantitative participant feasibility assessment of acceptability, appropriateness, and feasibility will be analyzed descriptively. In addition, we will examine differences in use/acceptance by participant characteristics (e.g., age, asthma symptoms, overall health, education, etc). Qualitative interview data will be transcribed, uploaded into Dedoose qualitative analysis software for content analysis.

Aim 2a: We will collect baseline data on the current frequency and degree of disinfectants/cleaners and exposure to environmental triggers (e.g., secondhand smoke). We will capture real-time self-reported data on disinfectant use throughout the study period. We will determine the prevalence of disinfectant/cleaner use and frequency (% EMA prompts at which disinfectant/cleaner use is reported). We will obtain data from the Awair dashboard to determine the number of times VOCs and $PM_{2.5}$ levels exceed optimal levels, average daily levels, average levels per time period, and fluctuations in VOC and $PM_{2.5}$. We will identify possible environmental triggers that contribute to high levels of VOCs and $PM_{2.5}$ leading to event-contingent prompts.

Aim 2b: We will determine baseline level of asthma control as measured by the ACT. We will use EMA to determine the level of asthma control over the study period as indicated by (a) asthma symptoms reported at each prompt and over the 14 days; (b) number of time-periods during which an EMA prompt is sent and participants report asthma symptoms; and (c) lung function as measured by FEV_1% predicted at each prompt. Asthma control will also be evaluated using EMA by exploring differences in variability in lung function.

Aim 3: Data collected using the EMA approach are multilevel with time windows (level 1) nested with individuals (level 2). The exposure variables will include: (1) Baseline self-reported use and frequency of disinfectant/cleaner use and $PM_{2.5}$ exposures; (2) Number of times VOC and $PM_{2.5}$ levels exceed the threshold for the optimal readings per week; and (3) Average scores of VOC and $PM_{2.5}$ levels in the time windows considered in the analysis. The outcome variables we will consider include occurrence of any asthma symptoms, inhaler use, and FEV_1% predicted (within 30 minutes of each EMA prompt).

We will use multi-level binary logistic regression to examine the associations of the exposure variables with the binary outcome variables. We will use multilevel linear regression to examine the associations of the exposure variables with FEV_1% predicted. We will control for level 1 variables (time of day, day of week) and level 2 variables (baseline asthma symptoms, demographic characteristics, and psychosocial characteristics). Using available time stamps from the indoor air quality monitor, EMA, and the spirometer, we will also explore average lag time between an event-contingent prompt and self-reported asthma symptoms using multilevel survival analyses.



Summary

The proposed study has several strengths. First, our study is innovatively addressing the increased use of disinfectants during COVID-19 in adults with asthma. The study builds on an ongoing study and will be conducted with individuals who have agreed to be recruited for future studies and facilitate recruitment. Furthermore, participants will be drawn from a wide geographic area in the US which increases broad representation of participants. Moreover, we will uniquely gather real time environmental exposure data and indicators of asthma control in unregulated indoor residential space without actual in-person contact. Finally, findings from this study have the potential to impact recommendations for indoor use of disinfectants/cleaners for those with asthma and will guide further research.

References

1. Center for Disease Control and Prevention. Asthma. FastStats web site. https://www.cdc.gov/nchs/fastats/asthma.htm. Published 2018. Accessed Date.
2. Center for Disease Control and Prevention. AsthmaStats. https://www.cdc.gov/asthma/asthma_stats/default.htm. Published 2020. Accessed Date.
3. Yaghoubi M, Adibi A, Safari A, FitzGerald JM, Sadatsafavi M. The projected economic and health burden of uncontrolled asthma in the United States. *Am J Respir Crit Care.* 2019;200(9):1102-1112.
4. Abrams EM, Geert WJ, Yang CL. Asthma and COVID-19. *Can Med Assoc J.* 2020;19(20):E551.
5. Center for Disease Control and Prevention. Coronavirus (COVID-19). https://www.cdc.gov/coronavirus/2019-nCoV/index.html. Published 2020. Accessed Date.
6. Castner J, Barnett R, Huntington-Moskos L, Folz RJ, Polivka B. Home environment allergen exposure scale in older adult cohort with asthma. *Can J Public Health.* 2020:1-10.
7. Leynaert B, Le Moual N, Neukirch C, Siroux V, Varraso R. Environmental risk factors for asthma developement. *Presse Med.* 2019;48(3 Pt 1):262-273.
8. Chan T-C, Hu T-H, Chu Y-H, Hwang J-S. Assessing effects of personal behaviors and environmental exposure on asthma episodes: a diary-based approach. *BMC Pulm Med.* 2019;19(1):231.
9. Bedard A, Varraso R, Sanchez M, et al. Cleaning sprays, household help and asthma among elderly women. *Respir med.* 2014;108(1):171-180.
10. Matulonga B, Rava M, Siroux V, et al. Women using bleach for home cleaning are at increased risk of non-allergic asthma. *Respir med.* 2016;117:264-271.
11. Baker M, Keall M, Au EL, Howden-Chapman P. Home is where the heart is--most of the time. *N Z Med J (Online). .* 2007;120(1264).
12. U.S. Environmental Protection Agency. Exposure Factors Handbook. https://www.epa.gov/expobox/about-exposure-factors-handbook. Published 2011. Accessed Date.
13. National Asthma Education Prevention Program. Third expert panel on the diagnosis and management of asthma. Expert panel report 3: Guidelines for the diagnosis and management of asthma. National Heart, Lung, and Blood Institute. https://www.ncbi.nlm.nih.gov/books/NBK7232/. Published 2007. Accessed Date.
14. Dong X, Cao Yy, Lu Xx, et al. Eleven faces of coronavirus disease 2019. *Allergy.* 2020:1-11.
15. Goyal P, Choi JJ, Pinheiro LC, et al. Clinical characteristics of Covid-19 in New York City. *N Engl J Med.* 2020;382::2372-2374.
16. Chhiba KD, Patel GB, Vu THT, et al. Prevalence and characterization of asthma in hospitalized and non-hospitalized patients with COVID-19. *J Allergy Clin Immunol.* 2020;146(2):307-314.
17. Lieberman-Cribbin W, Rapp J, Alpert N, Tuminello S, Taioli E. The Impact of Asthma on Mortality in Patients With COVID-19. *Chest.* 2020. In press.
18. Tenforde MW, Rose EB, Lindsell CJ, et al. Characteristics of adult outpatients and inpatients with COVID-19—11 academic medical centers, United States, March–May 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(26):841-846.
19. Garg S, Kim L, Whitaker M, et al. Hospitalization Rates and Characteristics of Patients Hospitalized with Laboratory-Confirmed Coronavirus Disease 2019 - COVID-NET, 14 States, March 1-30, 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(15):458-464.
20. Wortham JM. Characteristics of Persons Who Died with COVID-19—United States, February 12–May 18, 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(28):923-929.
21. Crocker DD, Kinyota S, Dumitru GG, et al. Effectiveness of home-based, multi-trigger, multicomponent interventions with an environmental focus for reducing asthma morbidity: A community guide systematic review. *Am J Prev Med.* 2011;41(2 SUPPL. 1):S5-S32.
22. Richardson G, Eick S, Jones R. How is the indoor environment related to asthma?: literature review. *JAdv Nurs.* 2005;52(3):328-339.
23. Billionnet C, Gay E, Kirchner S, Leynaert B, Annesi-Maesano I. Quantitative assessments of indoor air pollution and respiratory health in a population-based sample of French dwellings. *Environ Res.* 2011;111(3):425-434.
24. Blanc PD, Eisner MD, Katz PP, et al. Impact of the home indoor environment on adult asthma and rhinitis. *J Occup Environ Med.* 2005;47(4):362-372.

25. Karottki DG, Bekö G, Clausen G, et al. Cardiovascular and lung function in relation to outdoor and indoor exposure to fine and ultrafine particulate matter in middle-aged subjects. *Environ Int.* 2014;73:372-381.
26. Sennes V, Felonneau M-L, Gombert-Courvoisier S, Ribeyre F. How do households perceive risks at the scale of the environment in their own home? *Indoor and Built Environ.* 2013;22(2):422-432.
27. U.S. Environmental Protection Agency. List N: Disinfectants for use against SARS-CoV-2 (COVID-19). https://www.epa.gov/pesticide-registration/list-n-disinfectants-use-against-sars-cov-2-covid-19. Published 2020. Accessed Date.
28. Arif AA, Delclos GL. Association between cleaning-related chemicals and work-related asthma and asthma symptoms among healthcare professionals. *Occup Environ Med.* 2012;69(1):35-40.
29. Dumas O, Varraso R, Boggs KM, et al. Association of hand and arm disinfection with asthma control in US nurses. *Occup Environ Med.* 2018;75(5):378-381.
30. Dumas O, Wiley AS, Quinot C, et al. Occupational exposure to disinfectants and asthma control in US nurses. *Eur Respir J.* 2017;50(4).
31. Folletti I, Siracusa A, Paolocci G. Update on asthma and cleaning agents. *Curr Opin Allergy Clin Immunol.* 2017;17(2):90-95.
32. Gonzalez M, Jegu J, Kopferschmitt MC, et al. Asthma among workers in healthcare settings: role of disinfection with quaternary ammonium compounds. *Clin Exp Allergy.* 2014;44(3):393-406.
33. Lipinska-Ojrzanowska AA, Wiszniewska M, Walusiak-Skorupa JM. Work-related asthma among professional cleaning women. *Arch EnvironOccup Health.* 2017;72(1):53-60.
34. Su FC, Friesen MC, Humann M, et al. Clustering asthma symptoms and cleaning and disinfecting activities and evaluating their associations among healthcare workers. *Int J Hyg EnvirHealth.* 2019;222(5):873-883.
35. Siracusa A, De Blay F, Folletti I, et al. Asthma and exposure to cleaning products - a European Academy of Allergy and Clinical Immunology task force consensus statement. *Allergy.* 2013;68(12):1532-1545.
36. Vizcaya D, Mirabelli MC, Anto JM, et al. A workforce-based study of occupational exposures and asthma symptoms in cleaning workers. *Occup Environ Med.* 2011;68(12):914-919.
37. Le Moual N, Varraso R, Siroux V, et al. Domestic use of cleaning sprays and asthma activity in females. *Eur Resp J.* 2012;40(6):1381-1389.
38. Zock J-P, Plana E, Jarvis D, et al. The use of household cleaning sprays and adult asthma: an international longitudinal study. *Am J Rrespir Crit Care Med.* 2007;176(8):735-741.
39. Svanes O, Bertelsen RJ, Lygre SHL, et al. Cleaning at Home and at Work in Relation to Lung Function Decline and Airway Obstruction. *Am J Respir Crit Care Med.* 2018;197(9):1157-1163.
40. Dales RE, Cakmak S. Is residential ambient air limonene associated with asthma? Findings from the Canadian Health Measures Survey. *Environ Pollut.* 2019;244:966-970.
41. Dannemiller KC, Murphy JS, Dixon SL, et al. Formaldehyde concentrations in household air of asthma patients determined using colorimetric detector tubes. *Indoor Air.* 2013;23(4):285-294.
42. Yu L, Wang B, Cheng M, et al. Association between indoor formaldehyde exposure and asthma: A systematic review and meta-analysis of observational studies. *Indoor Air.* 2020;30(4):682-690
43. Zock J-P, Vizcaya D, Le Moual N. Update on asthma and cleaners. *Curr Opin Allergy and Clin Immunol.* 2010;10(2):114.
44. Vandenplas O, D'Alpaos V, Evrard G, et al. Asthma related to cleaning agents: a clinical insight. *BMJ Open.* 2013;3(9):e003568.
45. Quirce S, Barranco P. Cleaning agents and asthma. *J Investig Allergol Clin Immunol.* 2010;20(7):542-550; quiz 542p following 550.
46. Su F-C, Friesen MC, Stefaniak AB, et al. Exposures to volatile organic compounds among healthcare workers: modeling the effects of cleaning tasks and product use. *Ann Work Expos health.* 2018;62(7):852-870.
47. Polivka B, Folz R, Barnett R, Endicott D, Norton C. Home environments and asthma control in older adults. Oral presentation? at: Association of Commuity Health Nurse Educators; June, 2020; Virtual conference.
48. Gharpure R. Knowledge and Practices Regarding Safe Household Cleaning and Disinfection for COVID-19 Prevention—United States, May 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(23):705-709.

49. U.S. Environmental Protection Agency. Particulate Matter (PM) Basics. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics. Published 2018. Accessed Date.
50. National Academies of Sciences, Engineering, Medicine. *Health Risks of Indoor Exposure to Particulate Matter: Workshop Summary.* National Academies Press; 2016.
51. Mazaheri M, Clifford S, Yeganeh B, et al. Investigations into factors affecting personal exposure to particles in urban microenvironments using low-cost sensors. *Environ Int.* 2018;120:496-504.
52. Hussain S, Parker S, Edwards K, et al. Effects of indoor particulate matter exposure on daily asthma control. *Ann Allergy Asthma Immunol.* 2019;123(4):375-380.e373.
53. James KA, Strand M, Hamer MK, Cicutto L. Health services utilization in asthma exacerbations and PM10 levels in rural Colorado. *Ann Am Thorac Soc.* 2018;15(8):947-954.
54. Kim KH, Jahan SA, Kabir E. A review on human health perspective of air pollution with respect to allergies and asthma. *Environ Int.* 2013;59:41-52.
55. Liu Y, Pan J, Zhang H, et al. Short-term exposure to ambient air pollution and asthma mortality. *AmJRespirCritCare Med.* 2019;200(1):24-32.
56. Mirabelli MC, Vaidyanathan A, Flanders WD, Qin X, Garbe P. Outdoor PM2. 5, ambient air temperature, and asthma symptoms in the past 14 days among adults with active asthma. *Environ Health Persp.* 2016;124(12):1882-1890.
57. Polivka B, Folz R, Barnett R, Myers J. Home environmental exposure clusters in older adults with asthma. Oral presentation? at: Midwest Nursing Research Society Annual Conference; March, 2019; Kansas City, Kansas.
58. Pettibone KG, Balshaw DM, Dilworth C, et al. Expanding the concept of translational research: making a place for environmental health sciences. *Environ Health Persp.* 2018;126(7):074501.
59. Castner J, Amiri A, Huntington-Moskos L. Applying the NIEHS translational research framework (NIEHS-TRF) to map clinical environmental health research trajectories. *Nurs Outlook.* 2020;68(3):301-312.
60. Feenstra B, Papapostolou V, Hasheminassab S, et al. Performance evaluation of twelve low-cost PM2.5 sensors at an ambient air monitoring site. *Atmos Environ.* 2019;216.
61. Shiffman S. Conceptualizing analyses of ecological momentary assessment data. *Nicotine Tob Res.* 2014;16 S76-87.
62. Dunton G, Dzubur E, Li M, Huh J, Intille S, McConnell R. Momentary Assessment of Psychosocial Stressors, Context, and Asthma Symptoms in Hispanic Adolescents. *Behav Modif.* 2016;40(1-2):257-280.
63. Kolmodin MacDonell K, Naar S, Gibson-Scipio W, Lam P, Secord E. The Detroit Young Adult Asthma Project: Pilot of a Technology-Based Medication Adherence Intervention for African-American Emerging Adults. *J Adolesc Health.* 2016;59(4):465-471.
64. Smyth JM, Zawadzki MJ, Santuzzi AM, Filipkowski KB. Examining the effects of perceived social support on momentary mood and symptom reports in asthma and arthritis patients. *Psychol Health.* 2014;29(7):813-831.
65. Anonymous. Awair partners with Brown University to study effects of environmental exposures on neurodevelopment in children. BioSpace. https://www.biospace.com/article/releases/awair-partners-with-brown-university-to-study-effects-of-environmental-exposures-on-neurodevelopment-in-children/. Published 2017. Accessed Date.
66. Ansaldo M. Awair Element indoor air-quality monitor review: New look, lower price tag, same accurate readings. TechHive from IDG. https://www.techhive.com/article/3534041/awair-element-review.html. Published 2020. Accessed 2020.
67. Awair Incorporated. Awair Omni Enterprise Essentials. https://www.getawair.com/home/element. Published 2020. Accessed Date.
68. Bamashmoos F, Woznowski P, Tryfonas T. A review of air quality sensing technologies and their potential interfaces with IoT for asthma management. Paper presented at: Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference; 2018.
69. Li J, Mattewal SK, Patel S, Biswas P. Evaluation of nine low-cost-sensor-based particulate matter monitors. *Aerosol Air Qual Res.* 2020;20(2):254-270.
70. Boubekri M, Lee J, MacNaughton P, et al. The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers. *Int J Environ Res Public Health.* 2020;17(9):3219.
71. Eitland ES. The assessment of building interventions on student health. 2020.

72. ZephyRx. ZephyRx spirometer. https://www.zephyrx.com/. Published 2020. Accessed Date.
73. ilumivu Software for Humanity. Ecological momentary assessment. https://ilumivu.com/. Published 2020. Accessed Date.
74. Center for Disease Control and Prevention. Behavioral risk factor surveillance system survey questionnaire. U.S. Department of Health and Human Services. http://www.cdc.gov/brfss/suggestedcitation.htm. Published 2009. Accessed Date.
75. Schatz M, Mosen DM, Kosinski M, et al. Validity of the asthma control test™ completed at home. *Am JManag Care.* 2007;13(12):661-667.
76. Schatz M, Sorkness CA, Li JT, et al. Asthma control test: Reliability, validity, and responsiveness in patients not previously followed by asthma specialists. *J Allergy Clin Immunol.* 2006;117(3):549-556.
77. PROMIS Dyspnea Instruments. 2016.
78. Schatz M, Zeiger RS, Yang S-J, et al. Development and preliminary validation of the adult asthma adherence questionnaireTM. *J Allergy Clin Immunol Prac.* 2013;1(3):280-288.
79. Krieger J, Takaro TK, Song L, Beaudet N, Edwards K. A randomized controlled trial of asthma self-management support comparing clinic-based nurses and in-home community health workers: The Seattle-King County Healthy Homes II Project. *Arch Pediat Adol Med.* 2009;163(2):141-149.
80. Polivka BJ, Folz R, Myers J, et al. Identifying phenotypes and factors impacting outcomes in older adults with asthma: A research protocol and recruitment results. *Res Nurs Health.* 2018;41(4):336-345.
81. Kroenke K, Yu Z, Wu J, Kean J, Monahan PO. Operating characteristics of PROMIS four-item depression and anxiety scales in primary care patients with chronic pain. *Pain Med.* 2014;15(11):1892-1901.
82 Heatlth Measures. PROMIS Health Measures. Northwestern University. https://www.healthmeasures.net/explore-measurement-systems/promis. Published 2020.
83, PROMIS Health Measures. Emotional Support,. A brief guide to the PROMIS Emotional Support Instruments. Health Measures. http://www.healthmeasures.net/images/promis/manuals/PROMIS_Emotional_Support_Scoring_Manual.pdf. Published 2020.
84. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. *J Health Soc Behav.* 1983;24(4):385-396.
85. Karam F, Berard A, Sheehy O, et al. Reliability and validity of the 4-item perceived stress scale among pregnant women: results from the OTIS antidepressants study. *Res Nurs Health.* 2012;35(4):363-375.
86. Lee EH. Review of the psychometric evidence of the perceived stress scale. *Asian Nurs Res (Korean Soc Nurs Sci).* 2012;6(4):121-127.