Assessing the Impact of Home Environmental Exposures on Allergic Rhinitis using Real-Time Air Quality Monitoring and Symptom Assessment: An Observational Feasibility Study

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Abstract

Background: Rhinitis is the most common sinonasal condition and poses a significant cost burden. Rhinitis symptom control is associated with exposure to environmental triggers (e.g. aeroallergens, pollutants, irritants). While people spend much of their time at home, studies examining the association of rhinitis symptoms with home environmental exposures, especially in low-income, urban racial/ethnic minorities, are limited.

Objective: To determine the feasibility and usability of daily and triggered EMA (Ecological Monitoring Assessment) paired with an indoor air quality monitor to collect environmental exposure and rhinitis symptom data.

Methods: Participants were recruited from the Allergy and ENT clinics at two urban academic centers. Participants had to have a rhinitis diagnosis with active rhinitis symptoms, be ?18 years old, self-identify as a racial/ethnic minority, live in city limits of Chicago, be able to read and speak English, and have a smartphone. Participants received the Awair Omni® air quality monitor to measure VOCs (volatile organic compounds), PM2.5 (particulate matter), and humidity. EMA data were collected using a personal smartphone using the PiLR Health app. Participants were sent daily scheduled survey, random check-in survey, and air quality event triggered survey EMA notifications to assess rhinitis symptoms, environmental exposures, and mitigation strategies for 14 days. After the 14-day data collection period, participants completed acceptability, appropriateness, and feasibility survey items. Feasibility metrics captured included recruitment/retention, demographic data, rhinitis symptoms, and the usability of the PiLR Health App and Awair Omni® device, Barriers and challenges were identified and captured by study staff. Descriptive statistics were performed using Excel.

Results: Twenty-four participants were approached, 15 participants consented and 12 participants completed the study. Participants received an average of 62.42± 14.26 total surveys during their study period, and of those surveys, an average of 36.83± 22.18 (59.0%) surveys were completed. All 12 participants met the threshold for successful home air monitoring, (?11 days of continuous environmental data assessment). Usability of study components and integration into the overall study was high (SUS?68;), indicating participants considered each of the devices to be usable. Participant feedback on the study was positive yet they did identify areas for improvement including getting air quality data in real-time, providing more detailed instructions for device set up, and doing more frequent check-ins.

Conclusions: A real-time assessment of home environmental exposures and subjective rhinitis symptoms was feasible to conduct. This study will support the development of targeted interventions to address disparities in sinonasal disease care and

outcomes.

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Conclusions

A real-time assessment of home environmental exposures and subjective rhinitis symptoms was feasible to conduct. This study will support the development of targeted interventions to address disparities in sinonasal disease care and outcomes.

Introduction

Allergic rhinitis (AR) is the most common allergic airway disease and is characterized by nasal congestion, runny nose, sneezing, and a reduced sense of smell in response to environmental allergen triggers.[1] The prevalence of this disorder has been rising globally, reaching a range of 12-20 % in developed countries.[2] About 70% of pharmacy customers purchasing nasal treatments were self-medicating for AR without a diagnosis, and only 44.3% of those with AR symptoms had received a clinical diagnosis.[3]

AR has a significant impact on quality of life and is associated with other comorbidities such as asthma, cognitive dysfunction, and depression.[4] Economically, AR poses a significant burden on individuals, health care systems, and society. The direct medical expenditure for AR was estimated to be over $3.4 billion, mostly from clinic visits and prescription medications.[5] AR incurred the highest indirect costs due to absenteeism and presenteeism, with an annual average loss of $593 per employee, surpassing conditions such as arthritis, migraine, diabetes, and depression.[6]

AR is triggered by a range of allergens, most commonly pollen (primarily outdoor), mammal /arthropod-derived allergens, and environmental pollutants, which can be indoor or outdoor.[7] Several studies have shown that indoor air quality (IAQ) in the home is directly associated with the development and severity of AR symptoms.[8,9] The IAQ is determined by factors such as outdoor air infiltration, ventilation systems, and the amount of pollutants generated indoors.[10]

The most common indoor pollutants that trigger AR include volatile organic compounds (VOCs), particulate matter (PM), passive tobacco smoke, carbon monoxide (CO), formaldehyde, and greenhouse gases like ozone (O_3), sulfur dioxide (SO_2), and nitrous oxide (NO_2).[11] These are mostly generated from daily household activities including sanitizing, heating, cooking, burning candles, and smoking[12,13,14].

The United States (U.S.) Environmental Protection Agency (EPA) estimates that U.S. residents aged 18-65 spend an average of 80% of the day indoors. A large portion of this indoor time is spent at home.[15] To develop targeted strategies and therapeutic measures to control these environmental factors, it will be vital to analyze them, and how they influence the development and exacerbation of AR.

The predominant methods for the assessment of the relationship between home IAQ data and sinonasal symptoms include periodic patient self-reports on home characteristics and the collection of samples from homes. These are subjective, prone to recall bias, and often capital-intensive.[22] More so, they have no room for real-time evaluation of adjustable home environmental factors and provision of interventions that may reduce exposure to triggers.

Ecological momentary assessment (EMA), also called experience sampling, is a data collection technique where people provide real-time reports on their experience, including their symptoms, actions, and environment[23]. This method usually involves multiple, frequent measurements across a period of time, offering an opportunity for real-time collection of longitudinal data.[23] EMA can inform understanding of the real time relationship between environment and symptoms of sinonasal disease. EMA initially used handwritten logs but has since evolved with technology to employ automated logs in mobile devices leading to an increased utilization of EMA in the study of diseases affected by environmental exposures.[24, 25] Our prior study, however, showed that its adoption in rhinology studies remains limited.[26] Furthermore, the advent of commercial air monitoring devices, such as the Awair® system, present an opportunity to supplement the EMA symptoms data with continuous home IAQ data. Despite the availability of these tools for real-time assessment of home environmental exposure, no studies have applied them to assess the relationship between home

environmental exposures and AR symptoms.

Objectives and Aims

The aims of this study were to determine the feasibility and usability of (1) EMA to assess self-reported home environmental exposures (e.g., aeroallergens/irritants) and rhinitis symptoms (sneezing, itching, nasal congestion/drainage), and (2) real-time objective measures of home environmental exposures (VOCs, $PM_{2.5}$, humidity) using a home air quality monitor (Awair®) over a 2-week study period. We assessed the feasibility of using the Awair Omni® monitors to collect measures of IAQ such as humidity, VOCs, and $PM_{2.5}$ in real time. This multifaceted approach enables us to notify participants of elevated indoor environmental pollutants while simultaneously gathering real-time data on IAQ and AR symptoms. This paper outlines the feasibility and usability results of this study.

Methods

Ethics Approval

All studies were conducted in accordance with the Declaration of Helsinki and the International Conference on the Harmonization Good Clinical Practice guidelines and approved by the relevant institutional review boards at the University of Chicago (IRB #22-1469) and University of Illinois Chicago (IRB #2022-0361).

Study Components

The Awair Omni Indoor Air Quality Monitor® continuously monitors about 1000 square feet of indoor air for 7 air quality indicators: total VOC, $PM_{2.5}$, temperature, humidity, carbon dioxide, ambient light, and ambient noise. This study only focused on humidity, VOCs, and $PM_{2.5}$ levels because of its known associations with rhinitis symptoms. The Awair Omni® device measures about

4 x 4 x 1.3 inches, is Wi-Fi and Bluetooth-enabled, plugs into a standard alternating current (AC) outlet, and includes an 8-hour battery backup. An air quality reading was taken every 10 seconds and real-time data was uploaded to a dashboard accessed only by research personnel. The Awair Omni® proprietary dashboard provided secure communication between the Awair Omni® and its dashboard. Data was exported from the dashboard as a .csv file.

Table 1. Type and range of air quality measures.

Exposure	Sensor	Detectable range/accuracy	Optimal range
VOCs[a]	Multipixel metal-oxide gas	0-60,000 ppb/±10%	<333 ppb
$PM_{2.5}$[b]	Laser-based light scattering	0-1,000 $\mu g/m^3$/±15 $\mu g/m^3$ or 15%	<15 $\mu g/m^3$
Humidity	Complementary metal-oxide semiconductor	0% to 100% /±2% RH	>30% and <60%

[a]VOC: volatile organic compound. [b]$PM_{2.5}$: fine particulate matter.

EMA data was collected electronically using the PiLR EMA Health software platform, which was installed on the participant's personal smartphone (iOS or Android). Data captured was transmitted to the PiLR EMA platform and stored in a secure database. Participants received three scheduled surveys on their smartphone each day. The first scheduled survey was the daily rhinitis survey that was sent once daily at 9:00am. The next scheduled survey was the rhinitis check-in survey, which was sent two times per day, once in the mid-late morning and once in the afternoon. In addition to the scheduled surveys, participants received at least two triggered surveys when the air quality monitor values would go outside of acceptable thresholds. The first was the triggered air quality survey that was sent at the time of the event, and the second survey was the air quality follow-up survey and was sent 45 minutes after the event. The surveys were available for a limited period of time, with the daily rhinitis survey available for 120 minutes, the random rhinitis check-in surveys available for 60 minutes, the initial triggered air quality survey available for 45 minutes and the air

quality follow-up survey for 60 minutes (Table 2). To reduce the burden of surveys sent, all components of air quality had to return to the recommended thresholds before another air quality survey was triggered.

Table 2. EMA surveys sent to participants.

Survey Title	Per day, length available	Duration of Availability
Daily Rhinitis Survey	1	120 minutes
Rhinitis Check-in Survey	2	60 minutes each
Triggered Air Quality Survey	Per event	45 minutes each
Follow-up Air Quality Survey	Per event	60 minutes each

Researchers were able to access the PiLR dashboard to monitor participants' use of the EMA app and review their data. Data was exported from the dashboard as a .csv file.

After the 14-day study period participants were asked to complete an adapted Survey Usability Scale (SUS) on the Awair Omni®, the PiLR EMA Health app and integration of the two systems. Due to an error, usability of the PiLR EMA Health app and integration of the two systems was collected in only half of the participants. The SUS scores were recoded then analyzed by calculating the mean scores for the individual scales where the scheme assumed 1 = strongly agree and 5 = strongly disagree. These scores were then corrected so the highest potential score would be 100 and the lowest potential score would be zero.

Participants

Participants were recruited from a convenience sample of patients attending a clinican encounter in the Allergy and/or ENT clinics at the University of Chicago Medical Center or the University of Illinois Hospital & Health System. Participants had to have a diagnosis of rhinitis with active symptoms (sneezing, itching, nasal congestion, nasal drainage), be ≥18 years old, self-identified as

being from racial/ethnic minority groups (Hispanic, Black, American Indian, Alaskan Native, Asian, Pacific Islander, Native Hawaiian, Arab, or mixed race), live in the city limits of Chicago, be able to read and speak English, and have a smartphone. Participants who had comorbid sinonasal conditions, a sinus tumor, or had a terminal illness or immune dysfunction were excluded.

Recruitment

Potential participants were prescreened by looking through electronic health record and looking for age, race, diagnosis of rhinitis, and no history of co-morbid sinonasal conditions. Study staff approached a patient, after receiving approval from the clinician, and gave a brief overview of the study. Patients that expressed interest completed a REDCap survey that collected current contact information and verified eligibility. Eligible patients were consented onsite after completing the eligibility survey.

Feasibility Measures (Table 3)

Table 3. Feasibility Metrics
Secondary Outcomes
Age, Race, Sex, Primary Language, Household Income (REDCap)
Rhinitis control assessment test and Sinonasal outcome test (Baseline, Day 14; REDCap)
Recruitment Rate and Eligibility Criteria
Number of people approached, screened, eligible, ineligible (REDCap)
Participant Retention
Number of participants recruited (REDCap)
Number of participants who completed 14 days of data collection (REDCap)
Fidelity
Mean ± SD number of EMA surveys sent and completed (PiLR Health Dashboard)
Mean ± SD number of Awair Omni® days with data (Awair Dashboard)
Overall Usability
Day 14 Awair Omni® SUS*(REDCap)
Day 14 Ecological Momentary Assessment SUS* (REDCap)
Day 14 Platform Integration (REDCap)
Overall acceptability
Day 14 Interview Data (REDCap)
Challenges
Day 14 Interview, Study Staff Notes (REDCap)

*System Usability Scale

To assess the feasibility of our study, we collected measures related to recruitment and retention. Recruitment and retention were determined by the number of participants recruited and the percentage of participants who completed the study after consenting, respectively. Sociodemographic information, including race and ethnicity, education level, occupation, yearly household income, health insurance, were collected at baseline using a REDCap form that the participant completed after consent was completed. A 6-item survey called the Rhinitis Control Assessment Test (RCAT) and a 22-item survey called the Sino-Nasal Outcome Test (SNOT-22) were collected to evaluate different aspects of rhinitis control.[31,32] These were completed at baseline and at the end of the study period in REDCap.

Fidelity

Reports were downloaded from the PiLR EMA Health app to determine how many surveys were sent to participants and how many surveys were completed. Additionally, reports were downloaded from Awair dashboard to assess the number of days the devices were online.

Usability Assessment

After the 14-day data collection period, participants were asked to complete a short REDCap survey assessing usability (System Usability Scale)[35]. The SUS asked about participants' experience with the Awair Omni® indoor air quality monitor (10 items), the PiLR EMA Health app the Awair and integration of the two types of technology. (See SUS in appendix) The responses ranged from 1 (strongly agree) to 5 (strongly disagree). After each section, there was an open-ended item for participants to comment on what they liked or did not like about both study tools.

Acceptability assessment

Adherence to the EMA prompts was measured by the frequency of responses to EMA prompts over

the entire study period. This includes the percentage of complete and incomplete responses to prompts out of the total number of prompts. Adherence to the Awair Omni® air-monitor was considered successful if participants achieved a minimum of 11 days of continued environment data assessment through Awair® by keeping the device on and connected to Wi-Fi.

At the end of the study period, study staff scheduled a time to contact participants via phone or Zoom to discuss their experience with the study and go over the close out procedures. Participants were asked open-ended questions about what they liked about the study, what they disliked about the study, and suggestions for future studies. The study staff member would probe if the participant did not answer a question.

Barriers and Challenges

During follow-up calls between participants and study staff, participants were asked questions about difficulties they have been experiencing with the air monitor or the PiLR EMA Health app. These difficulties were documented by study staff and acknowledged or addressed during larger team meetings. Study staff also encountered difficulties when setting up the device or app or while attempting to collect data. These were also documented.

Results

Participant Characteristics

Participant characteristics are listed in Table 4. Participants were on average 37.2±10.7 years of age (range: 20-57 years) and predominantly female (66.7%; Table 3). Participants self-identified as Black (46.7%), Hispanic White (20%), Asian (13.3%), Native American (6.7%), or more than one race (13.3%). At baseline, almost all participants reported uncontrolled rhinitis symptoms (91.6%) and/or severe sinonasal disease (91.6%) based on their RCAT (<21) and SNOT scores (≥50), respectively.

Table 4. Participant Characteristics at Baseline

Age in years, (mean±SD)	37.2±10.7
Sex, n (% female)	8 (66.7%)
Race/Ethnicity, n (%)	
Hispanic White	3 (20.0%)
Black or African American	7 (46.7%)
American Indian or Alaskan Native	1 (6.7%)
Asian	2 (13.3%)
More than one race	2 (13.3%)
Language Most Comfortable Speaking, n (%)	
English	14 (93.3%)
Spanish	1 (6.7%)
Yearly Household Income, n (%)	
<$30,000/year	3 (20%)
$30,001-$90,000/year	4 (26.7%)
>$90,000/year	3 (20%)
Did not answer	5 (33.3%)
RCAT (mean+/- SD)	16.6±4.7
SNOT-22 (mean+/- SD)	51.8±21.6

Participant Recruitment and Retention

Figure 1 diagrams study participant flow. Twenty-four patients were approached in the Allergy and ENT clinics. Eighteen patients were identified through pre-screening of clinic schedules and 6 patients were identified through referral from one of the clinic physicians. Of the 24 approached, 21 expressed interest and were screened for eligibility by study staff. Sixteen of the screened patients were eligible for the study yet one patient declined to consent due to being too busy to participate. Fifteen participants were consented, 3 participants withdrew from one site (reasons not provided), and 12 participants (6 from each site) completed the study.

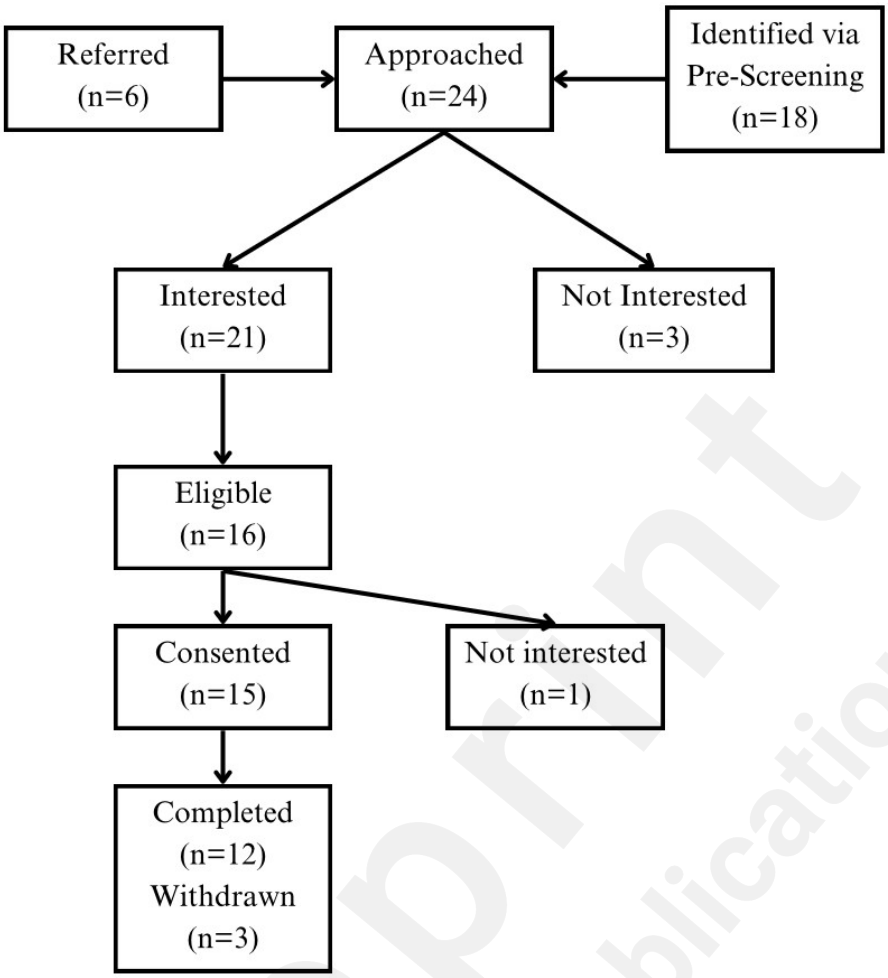


Figure 1. CONSORT Diagram

Fidelity (Table 5)

Adherence to Surveys and Home Air Quality Monitoring

A total of 749 EMA surveys were sent across all participants for the duration of the study. Individually, participants received an average of 62.42± 14.26 total surveys during their study period, approximately 4.0±0.8 per day, and of those surveys, an average of 36.83± 22.18 (59.0%) surveys were completed over the study period. Daily rhinitis (25.1%) and random rhinitis check-in (50.9%) surveys accounted for the majority of surveys sent to the participants. The triggered air quality and air quality follow-up surveys accounted for 11.9% and 12.2% of surveys sent, respectively. The air quality follow-up survey was the most likely to be completed (67.0%). Two participants did not receive any air quality surveys due to user issues with the Awair Omni® air monitor. One participant

received surveys but did not complete any surveys.

Table 5. Number of EMA surveys sent and completed

	Daily Rhinitis Survey	Random Rhinitis Check-In Survey	Triggered Air Quality Survey	Air Quality Follow Up Survey	All Surveys
# (% of Total) Surveys Sent	188 (25.1%)	381 (50.9%)	89 (11.9%)	91 (12.1%)	749 (100%)
Average # Surveys Sent per Participant	15±3	31±6	7±6	7±6	62±14
Average # (%) Surveys Started per Participant	11±5 (67%±25%)	18±10 (56%±25%)	5±6 (66%±34%)	6±6 (74% ±35%)	42±20 (66%±20%)
Average # (%) Surveys Completed per Participant	9±6 (59% ±28%)	17±12 (52%±30%)	5±5 (53%±33%)	5±5 (62% ±39%)	37±22 (58%±26%)

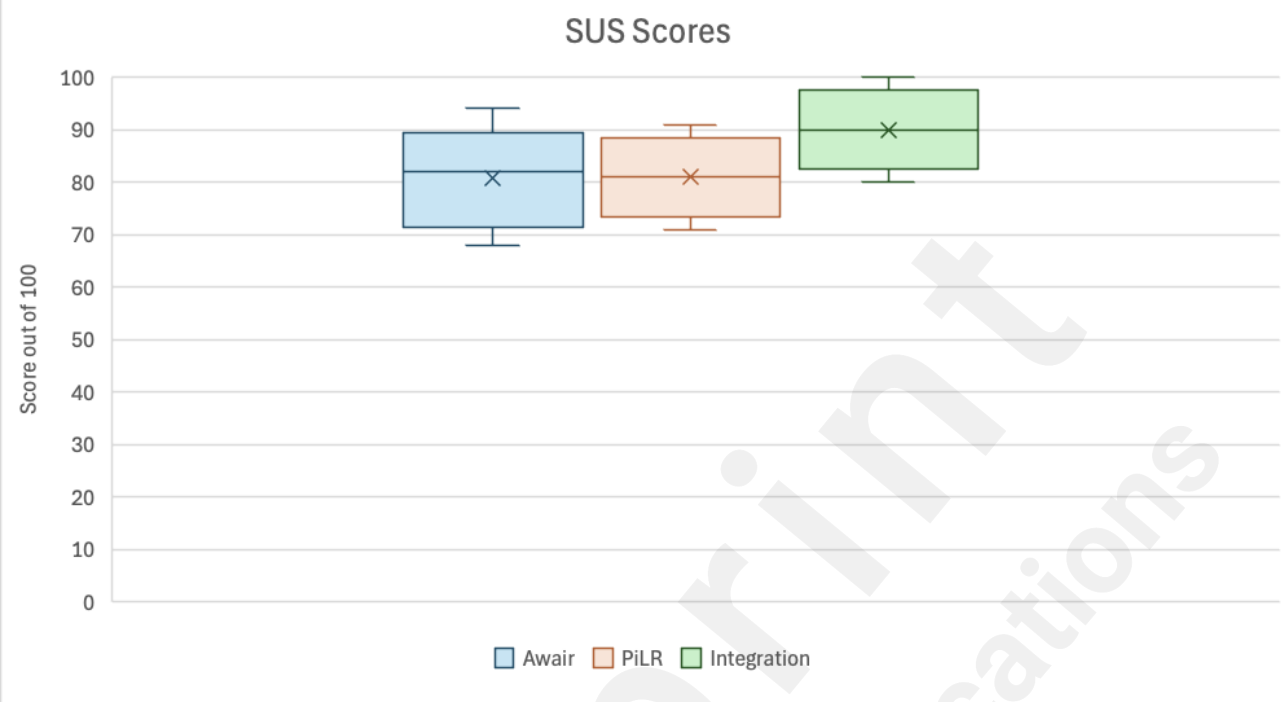
All 12 participants met our threshold for successful home air monitoring, predetermined as a minimum of 11 days of continuous environmental data assessment. Eleven participants (91.7%) had their air monitors operational throughout the entire 14-days of their study period without significant disruption (defined as ≥ 2 hours of interruption) to continuous assessment of home environment data. One participant, however, had their monitor disconnect from Wi Fi for 3 days during their study period. The quantitative data for all participants was successfully downloaded for analysis.

Overall Usability

All 12 participants received and completed the SUS for the Awair but only six participants received and completed the SUS for the PiLR Health App and the overall integration of study components. The mean SUS score for Awair, PiLR Health App and overall integration was high (≥68; Figure 2),

indicating participants considered each of the devices to be usable.

Figure 2. SUS Scores.



Overall acceptability

Study staff notes from the 14-day interview recorded what participants liked and disliked about the study (Table 6). The most common things participants liked about the study was that the device was easy to use and the surveys were short and easy to complete. The most noted dislike by participants was that the PiLR Health App would send “ghost notifications” where the participant would receive a notification or sometimes the survey would not allow them to move forward, followed by participants saying the study or the instructions for setting up the air monitor were too complex for people who were less tech savvy. Suggestions for improvement included getting their air quality data in real-time, providing video instructions for the Awair Omni® device set up, and doing more frequent check-ins.

Table 6. Staff Notes on Participant Study Feedback.

Likes (n)	Dislikes (n)	Suggestions for

• The device was easy to use (3) • Surveys were short, easy to complete (3) • The study was interesting (2) • The consistency of the surveys (2) • The device collecting air quality data (2) • Liked the survey answers (2) • Receiving notifications when the air quality changed (1) • App was simple (1)	• The app was “buggy” (5) • The study/instructions were complex (4) • None (3) • The surveys came at an inconvenient time (3) • Wording of questions was challenging (2) • The Awair Omni® didn’t have enough battery time (1) • The device took up too much space (1) • Surveys were too repetitive (1) • Survey answers were not detailed enough (1)	**improvement (n)** • Seeing the data in real-time or getting results faster (2) • More frequent check-ins (2) • Provide video instructions (1)

Study Challenges

Study challenges were divided into PiLR EMA Health app and the Awair Omni® air monitor. The most common challenge identified was with the PiLR EMA Health App surveys. This primarily included issues with the device assignment logs, which are used to pair the PiLR EMA account to its respective Awair Omni® air monitor. This resulted in a participant not receiving triggered surveys when there was a change in air quality noted by the Awair Omni®. These issues were resolved by contacting the vendor and collecting information that had been overlooked previously. For the Awair Omni® air monitor, the main challenge was in regard to the device shutting down temporarily or

disconnecting from Wi-Fi. In one instance, a participant had changed their WiFi password and had made their device disconnect from WiFi. Most situations were resolved by trouble shooting with participants to determine why their device went offline.

To address these challenges, study staff worked with vendors to troubleshoot issues, then relayed fixes to participants. Study staff contacted and helped participants correct issues with the devices and provided information to prevent future issues. If there was significant time of data being lost, determined by the study staff, the study period for the participant was extended to ensure that 14-days of data were collected. These barriers were recorded and modifications to our manual of operations were made to be utilized in future, adequately powered studies.

Discussion

This study aimed to assess the feasibility of an air quality monitor and EMA app used simultaneously in a study exploring real-time residential Total VOC and $PM_{2.5}$ exposures and real-time rhinitis symptoms in minoritized adults. We were able to recruit and retain participants in the study and found both the air quality monitor and EMA surveys feasible to implement with all participants keeping the air quality monitor active during the study period and ~ two-thirds of participants completing the surveys. Additionally, while we did identify some technical challenges in the pilot study, we were able to develop solutions to address the challenges and are prepared to conduct a larger, appropriately powered observational study to collect further information on rhinitis symptoms.

The field of measuring symptoms and air quality in real-time in rhinitis is a nascent area especially in minoritized populations that often have higher rates of exposures to rhinitis triggers[34]. Prior studies in real-time monitoring and rhinitis reviewed the existing research on EMA as a health monitoring tool and the use of ecological monitoring in understanding rhinitis symptoms and air quality both indoors

and outdoors for individuals with asthma, but none focused on minoritized populations.[26,28] This is the only study to our knowledge that used EMA for real-time rhinitis symptoms and residential air quality monitoring in minoritized adults.

We did encounter technical challenges in regards to the PiLR EMA Health app and Awair Omni® air monitor. Common challenges were participants not receiving triggered air quality surveys and/or the air monitor disconnecting from Wi-Fi. These challenges were technical in nature and were anticipated as this was a system never tested before in this patient population. This may have occurred at a higher rate in our participant population as Black (36.4%) and Hispanic (30.3%) households are less likely to have broadband internet than White households (21.2%).[30]

As research and medical care are leaning into technology more, it is important to acknowledge that there may be challenges in certain populations that could impact their ability to successfully participate in research or get medical care. Although our usability scale showed the Awair Omni® air monitor and the PiLR EMA Health app to be acceptable for our participants, future research should be done that includes older participants, low-income populations, and people in digital deserts.

Limitations to our study include lack of broad generalizability as participants were recruited from a convenience sample of patients from Allergy and ENT clinics in urban academic centers. Further, older adults were not represented in our study sample which may have been due to the heavy technology component to our study and requirement for Wi-Fi and a smartphone. Future studies should offer Wi-Fi and/or smartphone for those that do not have access to these and provide additional technology training to those requesting assistance.

This was the first study to utilize EMA and air quality monitors to monitor rhinitis symptoms in an

urban and racially minoritized population. The findings from this study will provide insight into developing research using EMA to monitor rhinitis symptoms and using EMA for studies pertaining to low income and racially minoritized populations, or other groups, with low technological literacy.

Reference

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Supplementary Files

Multimedia Appendixes

System Usability Scales.
URL: http://asset.jmir.pub/assets/641c84586a5f5d0d7ab7c72ba52c387c.docx