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Impacts of COVID-19-related social distancing measures on personal environmental sound exposures

Lauren M Smith[1], Linyan Wang[1], Kuba Mazur[2], Michael Carchia[2], Glen DePalma[2], Reza Azimi[2], Samantha Mravca[2] and Richard L Neitzel[1]

[1] Department of Environmental Health Sciences, University of Michigan School of Public Health, 1415, Washington Heights, Ann Arbor, MI 48109-2029, United States of America
[2] Apple Inc., One Apple Park Way, Cupertino, CA 95014, United States of America

E-mail: rneitzel@umich.edu

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Abstract

The COVID-19 pandemic has created substantial and dynamic disruptions in society, personal behavior, and potentially chronic sound exposures, which are associated with hearing loss, cardiovascular disease, and other health impacts. Leveraging preliminary data from our unique nationwide Apple Hearing Study, we explored changes in personal sound exposures resulting from COVID-19-related social distancing. Volunteer participants opted to share environmental sound data from their Apple Watch and headphone sound data from their iPhone. Participants for this analysis were chosen from four states which exhibited diverse responses to COVID-19. Equivalent continuous average sound exposures (in A-weighted decibels, dBA) were computed per person-day and normalized to 8 hour L_{EX8h} exposures. Daily mean L_{EX8h} exposures across two time periods, a baseline period (before the first known US COVID-19 death at the time of analysis) and an intervention period (starting with each state's first COVID-related public health social distancing announcement and ending on April 22, 2020) were defined to assess changes in sound exposure. We modeled sound levels across 5,894 participants and 516,729 monitored days using a linear mixed-effects model with random effects for participant. The overall reduction in LEX8h between baseline and intervention was 2.6 ± 0.05 dBA (mean ± SE). There was a significant day-of-week effect during the baseline period, with the lowest exposures on Monday and the highest on Saturday. This effect was not noted during the intervention period. COVID-19 social distancing measures were associated with an approximately 3 dBA reduction in personal environmental sound exposures; this represents a substantial and meaningful reduction in this harmful exposure. Our analysis demonstrates the utility of everyday use devices in detecting behavior and exposure changes associated with the COVID-19 pandemic, and the usefulness of longitudinal, large-scale characterization of personal exposures and health impacts using wearable technology.

1. Introduction

The COVID-19 pandemic has created unprecedented disruptions in society, personal behavior, and potentially chronic sound exposures, which are associated with hearing loss [1], cardiovascular disease [2], and an increasing number of other health impacts [3]. While point-in-time sound measurements made in public areas, particularly employed in combination with spatial models, can provide general information on broad trends in sound levels [4], longitudinal personal measurements are needed in order to accurately evaluate exposures and health impacts at the individual level [5]. Leveraging preliminary data from our ongoing nationwide Apple Hearing Study, we had a unique, timely opportunity to explore changes in personal sound exposures resulting from COVID-19-related social distancing. Our study also presents an opportunity to demonstrate the utility of scalable, privacy-centric smartphone- and smartwatch-based evaluations of individual-level behaviors and associated exposure impacts resulting from dynamic public health threats. Studies involving the application of these smart technologies will be increasingly common in the future, and represent an unprecedented and invaluable new tool for assessing both personal and population-level impacts of traditional and emerging environmental hazards.

2. Methods

The Apple Hearing Study, conducted as a partnership between the University of Michigan and Apple Inc., is characterizing exposures for English-speaking volunteer participants who enroll in the study and opt to share headphone sound data from an iPhone 6s or later and, for participants who have an Apple Watch Series 4 or later, environmental sound data from the Noise app on the Apple Watch. Additional detail on the methods for our study can be found on https://sph.umich.edu/applehearingstudy/, on ClinicalTrials.gov (NCT04172766), or by downloading the Apple Research app from the App Store. All study procedures were reviewed and approved by a commercial Institutional Review Board (Advarra, approval number Pro00037864).

Participants for this analysis were chosen from four US states: CA, FL, NY, and TX. These states were chosen based on their geographic and cultural diversity, and because of the diversity in the timing and intensity of their responses to the COVID-19 pandemic.

Equivalent continuous average exposures (in A-weighted decibels, dBA) were computed from Apple Watch sound level measurements for each person-day and then normalized to 8 hour L_{EX8h} exposures to allow for direct comparisons of exposures across individuals wearing their watches for differing amounts of time. Two time periods were assessed in this study. A baseline period (8 January–21 February 2020) was used for all states to establish exposures prior to the first known US COVID-19 death (as of 31 March 2020). Each state was assigned a state-specific intervention period that started with the state's first COVID-focused public health social distancing announcement [6], included the issuance of a state-level stay-at-home order [7], and ended on 22 April 2020. Gradual loosening of restrictions across some of these states started in early May, therefore the end date of the intervention period was selected to ensure that any changes due to relaxation of the interventions were not considered in this analysis. Participants were included in this analysis if they contributed ≥10 hours of data per day for ≥5 days during both baseline and intervention periods.

Daily average L_{EX8h} exposures were plotted over time by state to visualize trends. In order to evaluate the specific timing of any changes in sound exposures associated with the COVID-19 responses, a time-series AR(1) model was fit to the daily mean L_{EX8h} exposures to identify change points within states [8].

A linear mixed-effects model [9] was fit to evaluate the relationship between L_{EX8h} and period (i.e. baseline and intervention), state, and day of the week to evaluate the influence of these factors on daily sound exposures. Participant was modeled as a random effect to account for repeated observations within individual.

3. Results

De-identified data from 5894 participants (2937 from CA, 1111 from TX, 973 from New York, 873 from FL) were included. A total of 516 729 daily L_{EX8h} included. Each participant contributed on average 69.6 daily measurements with an average duration of 16.9 hours per day. The age of our participants was 39.6 ± 12.6 years (mean ± SD). Seven hundred seventy-four participants (13.1%) were aged 26 or less, 4459 (75.7%) were aged 26 to less than 56 years, and 661 (11.2%) were aged 56 years or greater.

Although the states were diverse in their COVID-19 responses, the daily mean L_{EX8h} shift detected by the time-series model was March 13th for all states (figure 1). The overall L_{EX8h} reduction between baseline and intervention was 2.6 ± 0.1 dBA (mean ± SE), from 73.2 ± 0.1 dBA to 70.6 ± 0.1 dBA. For comparison, a 3 dBA reduction represents a halving of sound energy. New York experienced the largest reduction (3.1 ± 0.1 dBA) and Florida the smallest (2.4 ± 0.1 dBA). The sound exposure reduction among younger participants (less than 26 years) was 3.6 ± 0.1 dBA compared to just 1.7 ± 0.1 dBA to that of older participants (greater than 56 years).

There was a significant day-of-week effect during the baseline period (as seen by the oscillating pattern in figure 1), with the lowest exposures on Monday and the highest on Saturday. This effect was greatly reduced during the intervention period. The increase from Monday to Saturday was 2.0 ± 0.04 dBA (72.1 to 74.1 dBA) during the baseline period, and only 0.9 ± 0.04 dBA (69.9 to 70.8 dBA) during the intervention period. Overall, more than 99% of participants reduced their time spent above 75 dBA between Friday and Sunday.

L_{EX8h} distribution showed a marked shift of measurements from the 70 to <75 dBA exposure range to 65 to <70 dBA between the baseline and intervention periods (figure 2). Furthermore, 0 to <65 dBA measurements increased from 2.0% (±0.2%) to 8.8% (±0.4%).

4. Discussion

COVID-19 social distancing measures in CA, FL, NY, and TX were associated with an approximately 3 dBA reduction in personal environmental sound exposures. This represents a substantial and health-relevant

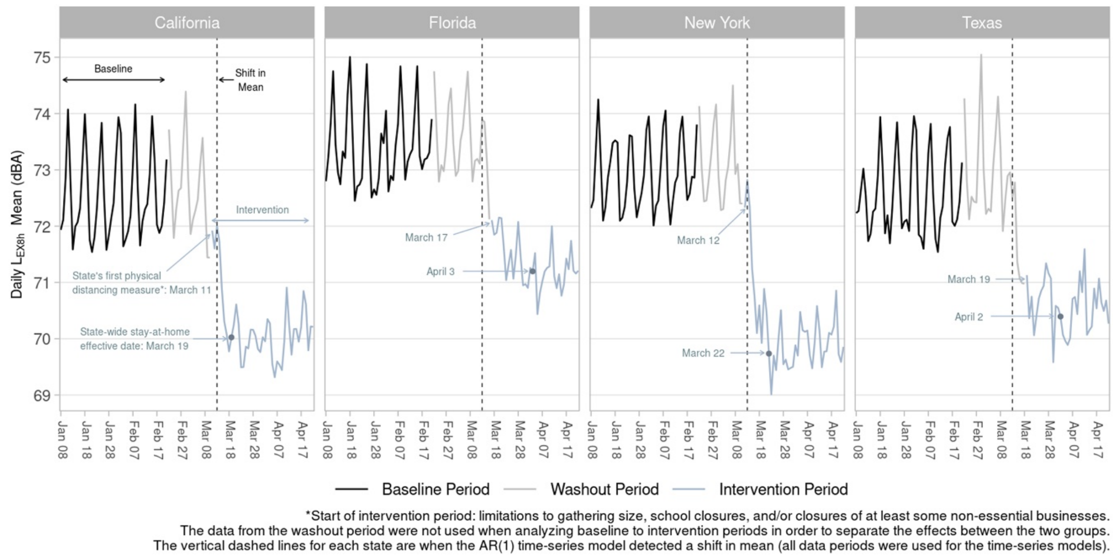

Figure 1. Daily L_{EX8h} over time in California, Florida, New York, and Texas.

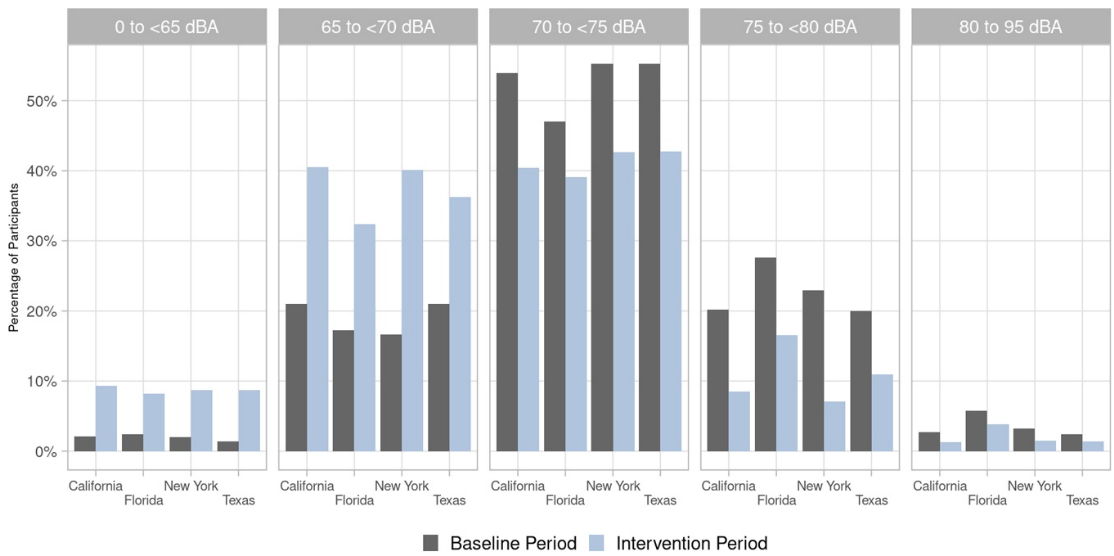

Figure 2. Distribution of participant's daily L_{EX8h} during baseline and intervention periods in California, Florida, New York, and Texas.

reduction in exposure across nearly 6000 participants spread across a large and culturally diverse geographic area of the US. While the impact of a 3 dBA reduction in sound exposure on sound-related health impacts such as ischemic heart disease, hypertension, and cognitive performance has not been sufficiently characterized [3], a 3 dBA reduction in average sound levels over 70 dBA L_{EX8h} is associated with a lower risk of noise-induced hearing loss [10]. Given that the negative impacts of sound on ischemic heart disease, hypertension, and cognitive performance appear to occur at levels well below 70 dBA L_{EX8h} [3], the COVID-related reduction in sound exposures among study participants likely represents a meaningful reduction in overall risk of sound-related health effects [4].

Due to our study inclusion criteria (i.e. a requirement that participants speak English, have an iPhone 6s or later, and, for inclusion in this specific analysis, also have an Apple Watch Series 4 or later) our sample may not be nationally representative. Nevertheless, our analysis demonstrates the utility of everyday use devices in evaluating daily behaviors and exposures. While our study is intended to better understand exposures to music and sound and to evaluate sound-related impacts on hearing and cardiovascular health, the flexibility and utility of the technology the study is based on has allowed us to evaluate changes in exposures and behaviors associated with the COVID-19 pandemic.

While the Apple Hearing Study only launched in November 2019, the amount of data described in this analysis—516 729 daily noise measurements—already represents the largest-ever study of personal noise exposures. Our results suggest that longitudinal, large-scale characterization of personal exposures and health impacts associated with sound and a myriad of other environmental hazards can offer previously-impossible insights into important environmental and social determinants of human health.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Author contributions:

DePalma, Azimi, and Wang had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Smith, Wang, Mazur, Carchia, DePalma, Mravca, Azimi, and Neitzel *Acquisition, analysis, or interpretation of data:* Smith, Wang, Carchia, DePalma, Azimi, and Neitzel

Drafting of the manuscript: Smith, Wang, Carchia, DePalma, Azimi, and Neitzel

Critical revision of the manuscript for important intellectual content: Smith, Carchia, DePalma, Neitzel

Statistical analysis: Wang, DePalma, and Azimi

Obtained funding: Mazur and Neitzel

Administrative, technical, or material support: Smith, Mazur, Mravca, and Neitzel

Supervision: Neitzel

Conflict of interests

None reported.

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Role of the Funder/Sponsor

This study is a result of an equal collaboration between a small team at the University of Michigan and a dedicated team at Apple Inc. All members of each team have been involved in every step of the process including design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, and approval of the manuscript; and decision to submit the manuscript for publication.

ORCID iDs

Lauren M Smith https://orcid.org/0000-0001-5677-2286
Richard L Neitzel https://orcid.org/0000-0001-5500-2589

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