Earwitness to the COVID-19 Pandemic

Yoshimi Hasegawa and Siu-Kit Lau

After the prolonged three-year (2020–2023) fight against the coronavirus disease (COVID-19), the World Health Organization (WHO, 2023a) declared the end of the pandemic as a global health emergency. As a result, most countries have lifted nearly all pandemic-related restrictions and reduced testing and reporting of new COVID-19 cases (WHO, 2023b). People apparently stopped paying attention to the pandemic and merely recalled what happened in the early days of 2020. Many initial restrictions, such as closing schools and workplaces, halting public transportation, and imposing travel bans, were previously inconceivable but had to be implemented for the safety of the public.

From the perspective of the acoustic environment, these initial pandemic restrictions led to the most abrupt change in sound environments that many countries around the world have ever heard. During the initial pandemic outbreak, one remarkable thing that was noticed by many was the silence, which was referred to as *the lockdown acoustics* (Schulte-Fortkamp, 2020). Due to the sudden suspensions of social and commercial activities, cities emptied and were perceived as "dead." Meanwhile, the virus confined people to their homes, limiting the extent of their activities outside and replacing these activities with alternatives inside, which generated more sound at home or exposed people to their previously unnoticed neighbors' sounds. Listening to our everyday surroundings, cities, neighbors, and communities, we were all earwitnesses (one who testifies or can testify to what he or she has heard) to the COVID-19 pandemic (Schafer, 1977).

A large number of studies regarding pandemic acoustics appeared in the literature starting in 2020 and continues to this day. In this article, we explore some of the unprecedented changes in the world's acoustical environments that people observed during the pandemic. In particular, the article is devoted to the human perceptions, experiences, and/or understanding of the sound environments or *soundscapes* (International Organization for Standardization [ISO] 12913-1:2014, 2014) in the context of the COVID-19 pandemic.

Pandemic Soundscape Overview

Starting in the early part of 2020, many scholars explored how different emerging pandemic situations changed various aspects of sound environments. This includes changes in physical noise levels (in decibels) and/or human perceptual changes (e.g., noise annoyance), in the indoor and/or outdoor environments, and in their occurrence from traffic-dominated areas to residential areas. The understanding of these changes and their consequences on inhabitants have been subsequently documented and published (e.g., Hasegawa and Lau, 2022).

The geographical distribution of the research investigations from the scholarly articles and a list of countries by the number of these investigations are shown in **Figure 1**. The majority of investigations (more than 40%) were conducted in Europe (including the United Kingdom), followed by Asia, North America, and South America. Fourteen studies have surveyed multiple countries, and some of them were across different continents (e.g., Europe and Asia). Some multinational or international investigations included countries in West Asia or Africa, yet those regions are underrepresented in the mainstream of acoustic research.

According to their methodologies and procedures, most researchers conducted their investigations, mainly field works including sound measurements and survey administration, during the first year of the pandemic, with the most data collection occurring from March to May. Recall that the WHO declared COVID-19 a worldwide pandemic on March 11, 2020 (Adhanom Ghebreyesus, 2020). Researchers were then urged to quickly respond to the drastic changes in acoustic environments in many countries across the world that resulted from the pandemic.

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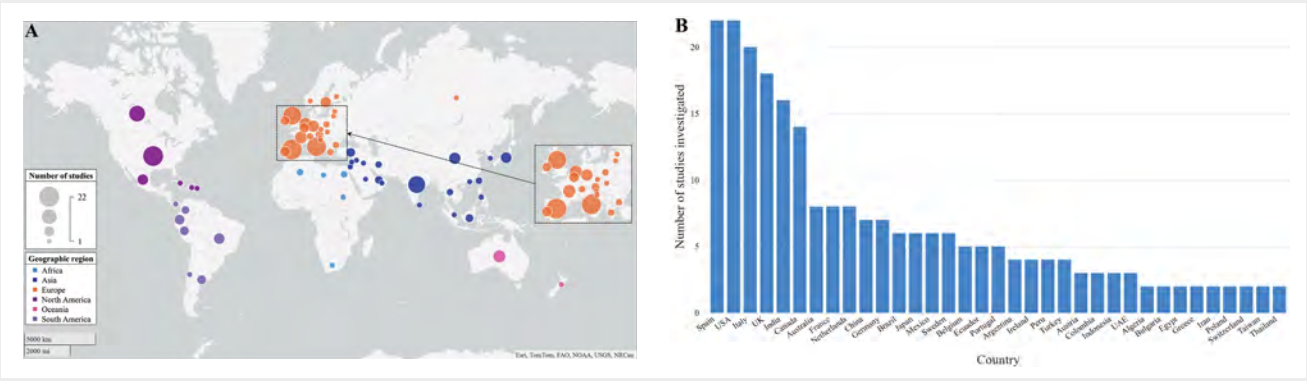


Figure 1. *Geographical distributions of the research investigations regarding sound and COVID-19. Each count is unique and unduplicated by multiple articles sharing the same sample from the same survey.* ***A: circles*** *roughly identify states or provenances where the studies were conducted.* ***Size of the circles*** *represents the number of studies analyzing data from individual countries.* ***Color of marks*** *represents geographical groups. Map generated using MATLAB; Map data sourced from Esri, TomTom, NOAA, FAO, USGS, NRCan.* ***B: number of investigations*** *for countries having at least two investigations. The systematic database search was initially conducted in 2022 (Hasegawa and Lau, 2022) and updated in 2023 (Hasegawa, 2023), resulting in a collection of 175 relevant articles.*

Many researchers collected or externally acquired pre-COVID datasets that had been collected prior to the WHO's pandemic declaration or in previous years (e.g., 2018, 2019). The datasets included those from previous research activities and surveys, other on-going projects that were not initially intended for pandemic-related research, or publicly available databases (e.g., census datasets). Thus, none of those pre-COVID datasets were collected with the thought of using them as pre-/postpandemic comparisons. Yet these comparisons were purposeful and worthwhile in terms of understanding the impacts of the COVID-19 pandemic on soundscapes. There are also 20 unique studies investigating further impacts of the pandemic on soundscapes in 2021 and 2022 (18 and 2 studies, respectively), focusing on subsequent lockdown phases (e.g., the second wave of the pandemic) as well as postpandemic scenarios.

World of the Wrong Silence

Even if people were not aware of their acoustic surroundings before the pandemic, once the pandemic started, many people noticed that many of the sounds normally in their environments were diminished, especially as related to people walking and conversing outdoors or to social or business activities across a neighborhood. The lack of acoustic activities in these soundscapes often induced certain eerie atmospheres in the outdoor environments: the soundscape of the *wrong silence* (Schulte-Fortkamp, 2020; also see a video at bit.ly/48ojCoW for some news about the COVID quietness around the world).

Changes in Outdoor Soundscapes (Noise Level Reduction in Cities)

To scientifically quantify the changes in the soundscape, many acoustic researchers around the world conducted a series of sound measurements in their existing environments. The most common acoustic parameter used in the environmental noise measurements was the equivalent continuous sound pressure level (L_{eq}). The $L_{eq,T}$ is a measure of the sound energy averaged over a given time interval (T) (ISO 1996-1:2016, 2016). For example, $L_{eq,24hr}$ is the sound level averaged over a 24-hour period. Depending on the time interval to which the rating of the sound is referred (i.e., reference time interval), the L_{eq} is recalculated as day (L_{day}), evening ($L_{evening}$), and night (L_{night}) sound levels. The default values (refer to ISO 1996-1:2016, 2016) for each time interval are given in **Table 1**. However, some countries define different reference time intervals, such as L_{day} over the 16 hours from 6 a.m. to 10 p.m. and L_{night} over the 8 hours from 10 p.m. to 6 a.m. (next day) (Government of India, 2000). Furthermore, day-night- (L_{dn}) and day-evening-night- (L_{den}) weighted sound levels are equal to the $L_{eq,24hr}$, obtained after the addition of 10 dB to L_{night} and the addition of both 5 dB to $L_{evening}$ and 10 dB to L_{night}, respectively.

Table 1. *Symbols for day, evening, and night sound levels and default values of their reference time intervals*

Quantity	Symbol	Reference Time Interval
Day sound level	L_{day} (L_d)	Daytime hours: • the 12 hours between 7 a.m. and 7 p.m., or • the 15 hours between 7 a.m. and 10 p.m.
Evening sound level	$L_{evening}$ (L_e)	Evening time hours: • the 4 hours between 7 p.m. and 11 p.m.
Night sound level	L_{night} (L_n)	Nighttime hours: • the 8 hours between 11 p.m. and 7 a.m., or • the 9 hours between 10 p.m. and 7 a.m.

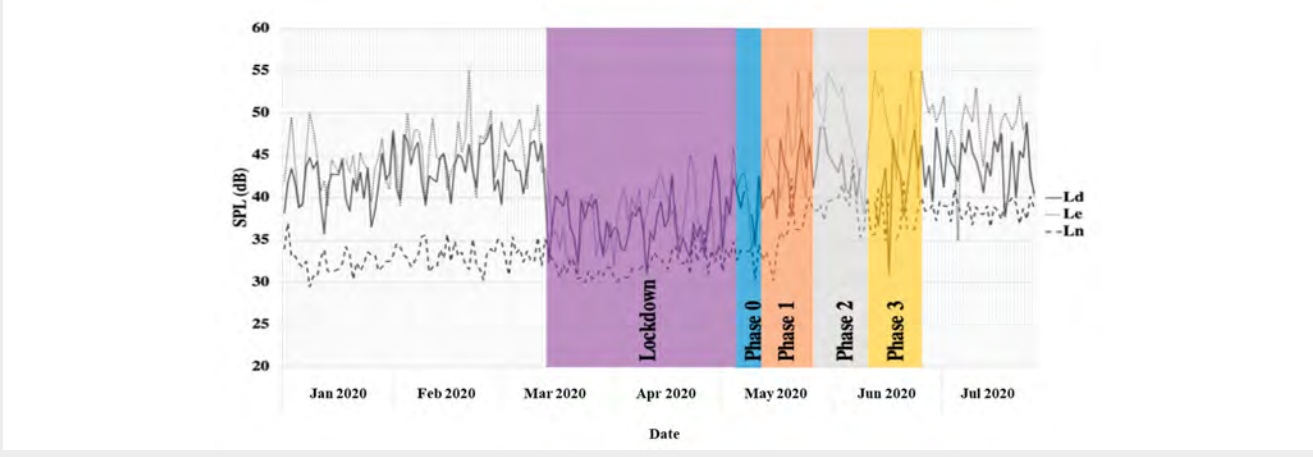
From International Organization for Standardization (ISO) 1996-1:2016, 2016.

In terms of data acquisition, noise-monitoring sensors (e.g., monitoring stations or terminals installed for continuous noise measurements) became one of the most accessible tools for observing changes in environmental noise in cities during the quarantine periods.

Quantitative changes in sound pressure levels during strict pandemic phases clearly differed from their typical prepandemic and postpandemic restriction levels in that the levels dropped in amplitude during restrictive periods (e.g., lockdowns) and reversed after easing the COVID-19 restrictions. This phenomenon is shown in **Figure 2**, which is a time series of the L_{day}, $L_{evening}$, and L_{night} (with the default reference time intervals as provided by **Table 1**) recorded in a high-traffic part of the city of Córdoba, Spain during the pandemic (Redel-Macías et al., 2021). The noise reduction started around the middle of March when the strictest measures were implemented (**Figure 2**, Lockdown). This reduction was especially apparent in the evening and possibly during the day. After the lockdown phase, the noise levels increased, reaching values similar to or higher than before the lockdown by mid-May 2020.

Another example that highlights similar phenomena is the local anthropogenic (human-produced) noise levels measured during the pandemic in New Delhi, India (Mimani and Singh, 2021) (see **Figure 3**). The L_{day} dropped suddenly when the strict lockdown phase 1 was declared. The greatest reduction of 15 dB(A) was observed with respect to the average levels during the prepandemic period as well as the same period in 2019. Subsequently, the levels started to

Figure 2. *Long-term sound pressure level (SPL) recorded throughout all de-escalation phases (i.e., Phases 0-3) and during the lockdown in Córdoba, Spain. The record was provided by the Interlight S. L. Company.* ***Lockdown:*** *citizens were required to stay at home and walks and outdoor sports were not allowed;* ***Phase 0:*** *family walks and individuals' outdoor sports were allowed with limitations.* ***Phase 1:*** *small business activities were resumed.* ***Phase 2:*** *some indoor venues (e.g., cinemas, museums) were reopened with a reduced capacity.* ***Phase 3:*** *capability of stores was increased up to 50%, and mobility between provinces was unrestricted.* L_d*, sound level during the day;* L_e*, sound level in the evening;* L_n*, sound level at night. Adapted (cropped from original and relabeled dates) from Redel-Macías et al. (2021), with permission, used under CC BY 4.0.*



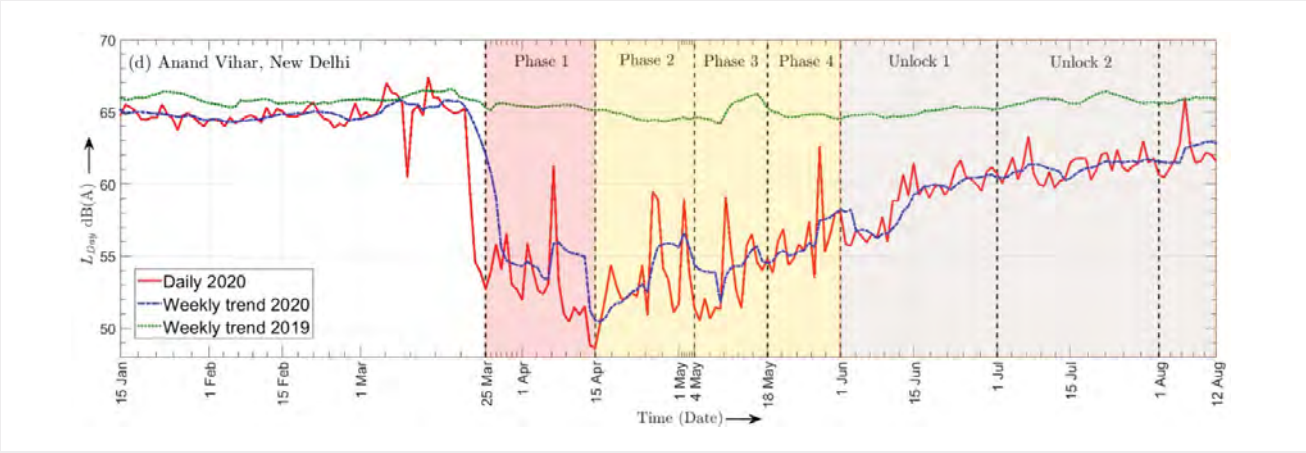


Figure 3. *Daily sound level (L_{Day}) graph for the year 2020 (**red line**) and the weekly trend graph for the years 2020 (**blue line**) and 2019 (**green line**) in Anand Vihar, New Delhi, India. The 24/7 (i.e., 24 hours a day, 7 days a week) ambient-noise levels were recorded by one of the noise-monitoring stations from the National Ambient Noise Monitoring Network (NANMN). **Phase 1:** a complete lockdown was implemented and all transportation services were suspended (the most stringent part). **Phase 2:** almost all the restrictions remained, with some conditional relaxations. **Phase 3:** movement restrictions based on the pandemic situation of different zones were begun. **Phase 4:** it was the least stringent part. **Unlock:** gradual reopening for usual activities. Reproduced from Mimani and Singh (2021), with permission.*

increase from phase 2 onward, slowly reaching close to the prelockdown noise levels. Changes in sounds between prelockdown and during the lockdown in Kolkata, India, are at bit.ly/3t6woZ6 (start at 34 seconds into audio) for reference.

Noise Reductions and Severity Levels

The changes in the temporal variations of noise levels were associated with the adaptation of inhabitants' activity and behavior to the pandemic circumstances (Asensio et al., 2020). Pandemic situations depended on many factors, including the governments' regulations (policies, restrictions, requirements); health care and social systems and capabilities; cultural/social expectations, behaviors, preferences, and attitudes toward the pandemic-related changes; urbanization (urban, suburban, rural) and its morphology of places; and so on. Because our soundscapes are context specific (ISO 12913-1:2014, 2014), it is important to carefully consider the impacts of those pandemic contexts on the world's sound environments.

A significant association between quarantine measures and environmental noise reduction was documented in the early phase of the pandemic (Zambrano-Monserrate et al., 2020). Namely, the more severe the implemented pandemic restriction measures, the greater the resulting noise reduction. To derive global estimates of this association, a meta-analysis was conducted to examine how the noise level reductions varied as a function of the severity levels of such COVID-19 restrictions across many cities worldwide (Hasegawa and Lau, 2022).

Of the acoustic parameters, including 24-hour levels ($L_{eq,24hr}$, L_{den}, L_{dn}) and those in **Table 1**, samples of averaged noise level changes before and after the pandemic restrictions were collected from previously published scholarly articles. A challenge was estimating the strictness of multiple pandemic's precautions and prevention measures imposed by governments from different countries. For consistent estimations, a *stringency index* was collected from the Oxford COVID-19 Government Response Tracker (OxCGRT) (Hale et al., 2021). A stringency index is a composite measure made up of a particular combination of nine policy indicators/response metrics (C1-C8 and H1; see **Figure 4**) and represents the strictness of the "lockdown-style" policies that primarily restrict people's behavior (Hale et al., 2021). It was found that the average noise-level reduction observed during the pandemic varied as a function of the stringency level of the COVID-19 confinement policies imposed by the governments (Hasegawa and Lau, 2022). Clearly, a set of these restrictions had consequences for our total acoustic environment, bringing out an unprecedented silencing on a large scale (Asensio et al., 2022).

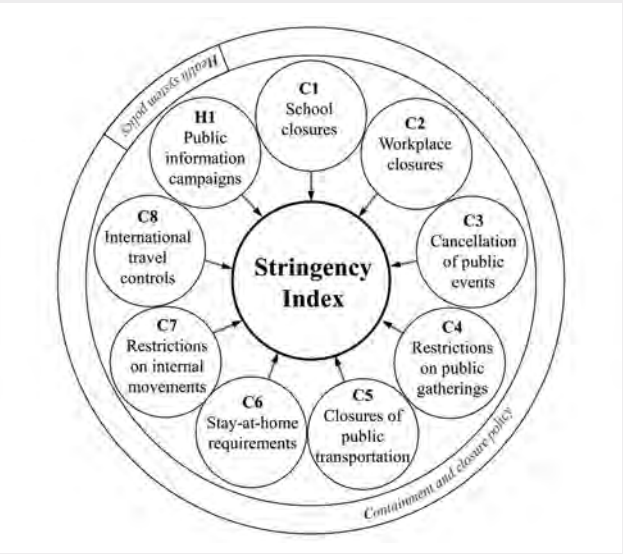


Figure 4. *Each of the nine indicators (C1-C8 and H1;* ***circles with arrows pointing to center****) accounts pandemic-related measures based on two difference policies (containment and closure policy and health system policy;* ***outer ring****), making up a single composite index (Stringency Index;* ***center circle****).*

Enhanced Natural Soundscapes

Soundscapes are created from the integration of various sound sources, including biophonic (animal-produced), geophonic (geophysically created), and anthropogenic sounds, and the number of their interactions (Pijanowski et al., 2011). Given that anthropogenic noises were significantly reduced during the severe lockdown periods, natural sounds (i.e., biophonic and geophonic sounds) were altered as well.

Several studies pointed out that people perceived more natural sounds during the pandemic, frequently referred to as bird chirping, but also the calls of other animals (Di Croce et al., 2022) and the sounds of leaves and the wind (Bild et al., 2022). A French study by Munoz et al. (2020) found that residents clearly perceived a reduction in transport-related noise sources while noting an increase in natural sounds outside their homes. Similar improvements were also observed in urban areas among other European countries (Garrido-Cumbrera et al., 2021). It is possible that a large decrease in anthropogenic noise (or noise pollution) unmasked the existing natural sounds. Moreover, this large reduction potentially alleviated the acoustic pressure on animals that use sound for communication and survival, hence altering their sound-producing behavior. For example, birds increased their singing performance (Derryberry et al., 2020).

The enhanced natural soundscapes resulted in a high restorative quality, potentially reducing pandemic-induced stress and fatigue (Qiu and Zhang, 2021) and, in turn, with better perceived health (Dzhambov et al., 2021) and improved acoustic comfort while working at home (Torresin et al., 2022). Perhaps, the unique array of natural-human soundscape dynamics enabled people to increase their awareness of the sounds from nature.

Cultural and Social Rhythms amid the Crisis

There are other signature sonic signals that emerged during the initial surges of the COVID-19 pandemic. Indeed, people purposely created sounds with particular social, cultural, and ritual emphasis and movements within their contexts. For example, one of the globally expanded movements was the act of *making noise* and *clapping* as expressions of appreciation for the frontline workers fighting against COVID-19. The actions involved people making various kinds of sounds and/or noises from their open windows, balconies, or rooftops. These included clapping hands, clanging utensils (e.g., pots or pans), singing songs, and playing instruments or music. Such practices were known as the 7 p.m. applause in Canada (Catungal, 2021) and were conducted at various other times elsewhere.

Rigal and Joseph-Goteiner (2021) tracked the creation and circulation of these practices that focused attention on the efforts of health care workers. They counted noise-making and clapping practices in 101 countries and 26 global cities spread over the course of several months (e.g., see bbc.in/3PSgt9S for an example in the United Kingdom). The appreciation movements were not limited to health care workers but were also seen for many frontline/essential workers, those who continued working on-site while putting themselves at greater risk of contracting the virus (e.g., food service workers, garbage collector) (Catungal, 2021) (e.g., see bit.ly/46oHkiW for a video of a Broadway star singing for all the essential workers).

Other sound-related movements that emerged during the pandemic were the practice of bell ringing from church towers (see bit.ly/465lAsW) (Parker and Spennemann, 2020) and the public broadcast of the Muslim call to prayer from mosques (see bit.ly/46rgffj) (Riskedahl, 2020),

sounds uniquely delivered from religious communities. Given the pandemic-related noise level reduction, both practices created a strong audible presence in the public community with their sound devices.

Because most of these sound-related practices differed in many ways, including social, cultural, and ritual (religious) contexts, people perceived, experienced, and understood the practices very differently. Although the diversity in listeners' soundscapes should be acknowledged, these momentarily signature soundscapes became a way of sharing people's thoughts and feelings during the pandemic period.

Home Sounded Like Chaos

As people stayed and spent more time at home during the early pandemic period, most of their regular activities were moved from the outdoor to individuals' indoor environments. School and workplace closures resulted in mandatory learning from home (LFH) and working from home (WFH) conditions, respectively. Some on-site social gatherings could be replaced by remote or online venues. In addition to at-home daily activities (e.g., relaxing, sleeping), our living rooms or bedrooms were transformed to temporary office spaces or classrooms, becoming multifaceted spaces where all the activities took place to complement our pandemic-induced limitations.

Increased home activities also resulted in increased exposure to noises from adjacent units or neighborhoods. Being within noisy and crowded environments and having no control over the sounds being transmitted from adjacent areas, people felt that their *homes sounded chaotic*.

Changes in Indoor Soundscapes (Affected Human Responses at Home)

The process of researching indoor acoustic environments and corresponding human perceptions or indoor soundscapes was challenging due to the pandemic situation. Most residents stayed at home during the confinement period and discouraged nonfamily members from visiting. Soundscape researchers had to comply with several preventive measures against the pandemic while seeking alternative approaches to conducting their research activities.

To overcome these limitations, most research activities were moved from in situ to virtual venues and many online surveys were rapidly developed and administered. Online surveys were disseminated via various tools and platforms, including social media platforms (e.g., Facebook, Twitter [rebranded as X]), institutions' websites and mailing lists, and commercial and crowdsourcing entities that recruit research participants. One of the common survey questionnaires for indoor soundscape evaluation asked participants about perceived changes in acoustic environments between the prepandemic and during the pandemic periods. For example, Caniato et al. (2021) conducted an international online survey and asked the participants to rate how their perceptions in their indoor noise level at home had changed during the COVID-19 emergency lockdown in comparison to their prelockdown situation (e.g., "quieter" or "noisier"). Although these methods often suffer from significant sampling and recall biases, there were few available options in the early days of the pandemic declaration for assessing the pandemic impacts on the subjective perceptions of their sound environments and addressing their confinement environments (e.g., home).

Residents' health and well-being were adversely affected by the indoor acoustic environments that were transformed due to the pandemic restrictions. Increased neighborhood and indoor housing noises created poor WFH and LFH conditions, resulting in psychosocial, occupational stress. Andargie et al. (2021) found that airborne noise (e.g., people talking) and impact noise (e.g., footsteps, moving furniture) coming from neighboring suites and shared spaces within suites (e.g., roommates and family members) adversely affected residents' WFH ability. Regarding LFH environments, poorer access to a quiet study space was associated with greater difficulty in academic courses, such as more difficulty keeping up with course readings and completing assignments (Telli et al., 2023). The affected indoor acoustic environments also led to increased adverse psychological responses. For example, Dzhambov et al. (2021) found that greater exposure to mechanical sounds experienced during home confinement was consistently associated with both lower restorative quality of the home environment and worse self-rated health. Those adverse consequences of the pandemic indoor soundscapes on people's health and well-being were substantial.

Unrecognized Vulnerable Populations

The adverse changes were exacerbated among people from distressed or vulnerable communities (Hasegawa, 2023),

with the term vulnerable including a number of potential factors/statutes associated with individuals' vulnerabilities. These include people 65 years and older and children (physiological vulnerability); people with financial difficulties, low educational levels, unemployment status, and/or social classes (socioeconomic vulnerability); and people from racial minorities (social vulnerability).

There were also clear disparities in noise complaints between socioeconomically disadvantaged groups and their counterparts during the COVID-19 pandemic. By analyzing over four million noise complaints from the New York, New York (NYC) 311 calls (a hotline for nonemergency city services and community concerns), Ramphal et al. (2022) found that noise complaints have increased the most in the most economically distressed communities (lowest income quartile) since 2010 and this disparity was further magnified during the COVID-19 pandemic. Similarly, a United Kingdom study analyzed a noise complaint dataset in London and found a significant increase during the lockdown and that this change was even higher in areas with higher unemployment rates, more residents with no educational qualifications, and lower house prices (Tong et al., 2021).

Many socioeconomic circumstances are often interrelated, including higher unemployment rates, lower educational levels, and lower household income. Such interrelationships may further affect housing quality (Sinha et al., 2017), where low qualities of houses would have degraded properties, including poor structural characteristics such as insufficient soundproofing and sound insulation. People living in such vulnerable housing conditions could be prone to unprecedented changes due to the pandemic; hence, the pandemic widened the disparities in residential soundscape experiences.

The impacts of the pandemic were even amplified for children from vulnerable groups who already experienced poorer health and well-being (Jones et al., 2020). During the 2020 lockdown in Spain, for example, children from families with low educational levels and financial difficulties were more likely to suffer from excessive noise at home, which could have further affected the children's physical and mental health (González-Rábago et al., 2021). Moreover, in the United Kingdom, children from financially struggling families found home learning challenging because of noise and a lack of space in their homes, which resulted in decreased engagement with home learning (Easterbrook et al., 2022).

Although the impacts of pandemic soundscapes on those populations were adverse, only a few such studies have been conducted on these topics. Therefore, prospective research efforts are vital to challenge the inequitable environmental issues, identify viable solutions, and make the research outcomes reachable to much broader populations.

Conclusion: Toward Postpandemic Soundscapes

The remarkable changes in the world's acoustical environments and the corresponding auditory perceptual experiences due to the initial pandemic restrictions were mostly ephemeral and are unlikely to be found now that the pandemic is over. Most research studies conducted in the early stage of the pandemic (March-May 2020) saw it as a rare moment that enabled researchers to measure the baseline sound levels in various environments. However, with the gradual ease in the pandemic restrictions, the outdoor noise levels returned to or were even greater than prelockdown levels (Redel-Macías et al., 2021). As we moved away from the first infection wave and experienced subsequent multiple infection surges, the impacts of the pandemic on our soundscapes changed. A study by Michaud et al. (2022), conducted in April-May 2021 during the third wave of the COVID-19 pandemic, showed that most people reported that the pandemic did not affect their annoyance with environmental and indoor noise.

However, some pandemic-induced lifestyles and behavior changes might persist after the pandemic ends, such as reduced air travel for business, more frequent online shopping, and sustained hybrid work styles (both office and remote working) (Salon et al., 2021). The long-term increase in telecommuting is remarkable in that some people decided to continue staying at home and communicate remotely. Indeed, our future soundscape agenda may need to adjust to the needs of remote workers, including improving the indoor acoustic environments for supporting good WFH/LFH performance as well as a range of activities (relaxation or leisure activities) (Torresin et al., 2022). Flexible and multifunctional environments would promote the livability and the quality of life of residents; hence, these themes are crucial for our postpandemic soundscapes (Hasegawa and Lau, 2022;

also see Fiebig and Schulte-Fortkamp, 2024, for a further discussion of postpandemic soundscapes). Besides, restorative soundscapes (e.g., natural soundscapes) should be promoted for alleviating psychological distress within populations.

The world is moving toward endemicity where COVID-19 may exist as a disease that is constantly present but limited to a particular region or population; however, challenges remain unaddressed. Thus, we must be forward thinking, learning from previous experiences and lessons, and keeping ourselves updated to improve soundscapes and enhance people's health and well-being proactively.

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About the Authors

Yoshimi Hasegawa
yoshimi.hasegawa@sydney.edu.au

Sydney School of Architecture, Design and Planning
The University of Sydney
Sydney, New South Wales 2006, Australia

Yoshimi Hasegawa is a postdoctoral research associate in the Sydney School of Architecture, Design and Planning, University of Sydney, Sydney, Australia. She also worked in the Department of Architecture, National University of Singapore, and Kyushu University, Fukuoka, Japan. She received her PhD in architectural engineering from the University of Nebraska-Lincoln. Earlier degrees include a Master of Arts in audio sciences from the Peabody Institute, Johns Hopkins University, Baltimore, Maryland, and a Bachelor of Music in music therapy from the Nagoya College of Music, Nagoya, Japan. Her research has focused on human responses to sounds in built environments for promoting healthy and sustainable cities and human well-being.

Siu-Kit Lau slau@nus.edu.sg

Department of Architecture
National University of Singapore
4 Architecture Drive
Singapore 117566

Siu-Kit Lau received a BEng degree with first-class honors in building services engineering and a PhD degree in acoustics and vibration from The Hong Kong Polytechnic University, Kowloon, Hong Kong, in 1997 and 2003, respectively. He held industry positions with Emerson Climate Technologies from 2002 to 2005, Johnson Electric Industrial Manufacturing Ltd. from 2005 to 2006, and Armstrong World Industries from 2013 to 2015. He was an assistant professor at The Hong Kong Polytechnic University and The University of Nebraska-Lincoln from 2006 to 2009 and 2009 to 2013, respectively. Since 2015, he has been with the National University of Singapore.