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THE ACOUSTIC ENVIRONMENT AND PEOPLE WITH HEARING IMPAIRMENTS DURING THE COVID-19 PANDEMIC

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ABSTRACT

Hearing impairment is a global concern that remains understudied and unaddressed. The coronavirus disease (COVID-19) pandemic exacerbated auditory and health-related matters among people with hearing impairments. However, how the pandemic changed their acoustic environments and modified their soundscape experiences has yet to be reviewed. This systematized review aims to summarize unprecedented changes in acoustic environments experienced by people with hearing impairments during the COVID-19 pandemic. Papers related to pandemic soundscape experiences among individuals with hearing impairments, including hearing loss, tinnitus, and auditory-related symptoms, were selected for this review. The literature search was conducted in February 2023. Based on the qualitative summary of the nine included articles, this review shows that the increased quieting of everyday environments was observed among people with hearing impairments during the initial phase of the COVID-19 pandemic (e.g., lockdown periods). However, this pandemic quietness may have induced some adverse consequences: potentially degraded speech abilities for people with hearing loss and exacerbated the perceptions of tinnitus or misophonia due to the enhanced indoor noises. These findings suggest that the inclusion of the diverse auditory perceptions will be a key for the new normal soundscape agenda to proceed toward post-pandemic era.

Keywords: *human hearing characteristics, pandemic soundscapes, aural diversity, systematized review.*

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1. INTRODUCTION

Hearing impairment is a global concern that remains understudied and unaddressed. Currently, more than 1.5 billion people are affected by some degrees of hearing loss worldwide [1]. The severity of hearing loss is often categorized as mild, moderate, (moderately) severe, profound, or complete: the 1.16 billion people with mild hearing loss [1]. While hearing loss is most prevalent for those older than 50 years [2], more than 1 billion young people worldwide could be at risk of hearing loss from exposure to unsafe listening practices [3]. There are more dimensions to hearing impairment than hearing loss alone [4]. People may experience hearing difficulties (HD) while their hearing thresholds are within the range of normal limits. Tinnitus is also a common hearing-related complaint where there exists the sensation of ringing in the ear while there is no corresponding external stimulus [1]. The prevalence of tinnitus occurrence ranges from 5.1% to 42.7% in the general population [5]. Given the prevalence of these distinct hearing characteristics, it would be challenging to find people having completely unimpaired or "normal" hearing and being free from any potential risk of hearing loss. In other words, most people will experience some degrees of hearing impairments and concern about hearing health in their lives.

People with hearing impairments have been those hardest hit by the COVID-19 pandemic. One of their biggest challenges was auditory communication with a person wearing a face mask [6]. While a face mask presents as a protection against the virus, it causes decrease in speech intelligibility and conceals lip-reading cues, resulting significant issues in the verbal communication. Besides, healthcare accessibility, including audiological consultations and hearing aid maintenance, was difficult for them during the pandemic because the pandemic reduced access to healthcare services and professionals [7,8]. Furthermore, people with hearing loss would be more susceptible to the implementation of physical and social

distancing (e.g., no face-to-face interactions) and its adverse consequences for their mental health, including social isolation and loneliness [8]. Therefore, the COVID-19 pandemic exacerbated auditory and health-related matters among people with hearing impairments.

While the unprecedented changes of the COVID-19 pandemic have affected multiple facets of human healthy life, they have also altered acoustic environments as experienced by people (or soundscape experiences [9]) in this peculiar context. When the lockdown was one of the few preventive measures against the pandemic, most social and commercial activities were minimized. As a result, many studies observed the reduction of the physical noise levels from anthropogenic noise sources outside, including roads, aircraft, and outdoor human activities [10]. While the initial pandemic phases (e.g., lockdown periods) showed a glimpse of the potential global quieting, several studies indicate increase in indoor housing noises from family and neighbors, which hindered people's daily activities such as working from home (WFH) [11] and learning from home (LFH) [12].

However, many previous soundscape studies expect ontological normality (i.e., normal hearing) as a gold standard [13] whist leaving out those with atypical hearing profiles such as hearing loss. One of the previous review studies [10] is not an exception. Their study summarized the global trends of the pandemic soundscapes observed while the initial surge of the COVID-19 infection. However, their target population was limited to people without hearing disabilities, namely they dismissed unignorable 20% of the global population (i.e., 1.5 billion people) [1]. Given that most people will experience some degrees of hearing impairments across their life courses, the real diversity of human hearing characteristics should be acknowledged and carefully considered, as referred to the concept of aural diversity [13]. Therefore, there is some room for further exploring how the pandemic soundscapes were experienced by individuals with hearing impairments.

This paper summarizes unprecedented changes in acoustic environments experienced by people with hearing impairments during the COVID-19 pandemic by conducting a systematized review of relevant studies. This review is a complement of the comprehensive summary of the effects of the COVID-19 pandemic on soundscapes that have been reported elsewhere [10], considering unique expectations and attitudes toward the soundscapes as well as various listening profiles and experiences among people with atypical hearing characteristics.

2. METHOD

This follow-up review retrieved those articles that were excluded due to their impaired hearing in the previous study [10] and updated the database search since 2022. Therefore, a basic methodology of this review was adapted from that previous study.

2.1 Search strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used as a basis for reporting reviews in this study [14]. Given that not all elements required for a full systematic review, such as two reviewers and quality assessment of individual studies, were included, this review is referred to as a systematized review [15]. To identify potentially relevant studies, three journal databases (i.e., Scopus, Web of Science, and PubMed) were used. The peer-reviewed scientific papers, including gray literature, published from 2019 to 2023, written in English, were considered. The search keywords comprised two components: (1) relevant terms related to COVID-19 (e.g., "coronavirus", "pandemic" "2019-nCoV", or "SARS-CoV-2") and (2) relevant terms related to acoustic environment or soundscape (e.g., "sound environment", "noise environment", "community noise", or "urban sound"). These two search strings were then combined using the Boolean operator "AND" to seek all possible combinations. Given that hearing impairments are more than hearing loss alone [4], the database search was intended to first cover broader populations, not limiting to specific groups of hearing impairments. The database search was conducted in February 2023.

2.2 Study selection

A total of 2600 results (2584 of records identified through database searching and 16 of additional records identified through other sources) were imported into EndNote for screening. After 1094 duplicates were removed, the remaining 1506 were initially screened through their tiles and abstracts. Abstracts reporting on experiences, perceptions, or descriptions of acoustic environments among people with hearing or auditory impairments during the COVID-19 periods were selected for full-text assessment. Assessments were also undertaken on articles where the abstracts were unclear whether they considered differences in subjects' hearing profiles or not. After this initial screening, 330 unique papers went through full-text assessment. The inclusion criteria for study population (people with hearing or auditory impairments) as well as exposure (audible acoustic stimuli), environment (any

environments where people can experience and/or perceive) and outcome (any changes occurred during the COVID-19 pandemic) were applied for eligibility for this review. Of the 330 papers, 321 full-text articles were excluded with reasons: 165 articles investigating people with normal hearing only or dismissing assessments of subjects' hearing profiles. As a result, nine original research articles [16-24] were included in this systematized review (Fig. 1).

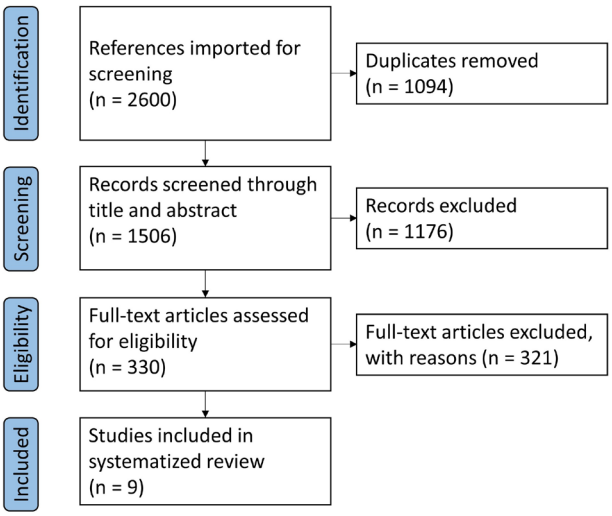

Figure 1. PRISMA flow diagram.

2.3 Data extraction

The nine included articles were reviewed and summarized. Their characteristics, including publications details (author name, publication year), geographical location (country) and date of data collection, pandemic-related situations (lockdown stage), study design, sampling methods, study population (demographics), and hearing profile and assessments were extracted and recorded on Excel spreadsheet. The extracted data were analyzed by descriptive statistics (counts and frequencies). The study's methodological features (evaluation tools and acoustic measures) as well as the findings in the changes in acoustic environments and soundscape experiences were summarized qualitatively.

3. RESULTS

3.1 Study characteristics

Of the nine included papers, two papers [23,24] built upon a single cross-sectional study: both shared the same sample from the same survey questionnaire. Therefore, the present review identified nine papers from eight unique studies.
Four studies were conducted in North America (n = 2 in USA, n = 2 in Canada) [17,21-23], three in Europe (n = 2 in Spain, n = 1 in Italy) [18-20]. One study [16] surveyed 48 countries worldwide; although, the majority respondents were either from North America (USA, Canada) or Europe (EU countries and UK). Most studies have done their data collection during the earlier phases of the pandemic (from April 2020 to July 2020) while two studies [20,23] gathered the data during the later pandemic phases (from April 2021 to September 2021). Pandemic-related situations, such as lockdown restrictions, of the above-mentioned study locations widely differed depending upon the date of data collection as well as the province/state where this data collection was conducted. Of those conducted in the earlier pandemic phases, two studies were conducted during a strict lockdown in Spain [18,19]. One study was done during the initial easing of lockdowns in Canada [21]. Another study in Iowa, USA [17] had no "stay-at-home" order (i.e., statewide lockdown) although non-essential businesses were closed, and large gatherings were restricted. Of those conducted in the later phases, one study conducted a survey one year after the beginning of the lockdown in Italy [20] and the other performed data collection overlapped with a nationwide lockdown during Canada's third wave of the pandemic [23].

3.2 Study design and sampling method

All eight studies were observational studies: five included studies were cohort studies (prospective, experimental, or retrospective cohort studies) [17-19,21,22] and three studies were cross-sectional studies [16,20,23]. Of eight studies, six studies provided sufficient information about their sampling methodologies: one cross-sectional study used probability-based random sampling [23] and the other five studies used non-probabilistic sampling method (e.g., convenience sampling) [16,18-21]. The most cohort studies recruited directly from their clinical patients, as selecting a sample that is most useful to the purposes of the research (purposive sampling).

3.3 Study population

Of the eight studies, six studies investigated adults mostly aged 18 years or older [16-20,23]. The mean age of their participants ranged from 44.7 to 60 (M = 51.9). One study targeted adults aged 65 years and older [22] and their ages ranged from 65 to 93 (M = 76.6). The other for children from infancy (age of 1) to late adolescence (age of 19) (M = 7.7, SD = 5.0) [21]. Males were slightly underrepresented (46.3%) across the eight studies. Sample sizes greatly varied, particularly by the study design. Large groups of participants were found in some cross-sectional studies (N = 3103 [16], N = 6647 [23]) and prospective cohort (N = 342 [18]). Whereas most cohorts were comprised of small groups of participants, ranging from 24 to 50 (M = 41.75).

3.4 Hearing characteristics and assessments

Four studies focused on people with hearing loss, including those with cochlear implants (CI) as well as those suffering from hearing loss without clinical diagnosis [17,21-23]. A cochlear implant is a surgically implanted device that stimulates the auditory nerve directly, and its use is beneficial for people with severe to profound hearing loss [1]. Three studies with CI recipients were cohorts [17,21,22]: some of their participants used both CI and hearing aid (HA). Only one study presented unaided pure-tone-average of 70 dB HL in their recipients' implanted ears [17], indicating their severe hearing loss. The other study assessed participants' hearing loss by their self-reports of hearing conditions [23]. Two studies investigated people with tinnitus: one study assessed their participants' tinnitus by a self-reported survey questionnaire [16] while the other evaluated the tinnitus by specialists at a tinnitus clinic [20]. The latter clinical evaluation also found that more than half of their patients had hearing loss based on the results of the pure tone audiometry testing. Most of the respondents from both studies had chronic tinnitus (more than 6 months). Two studies focused on people diagnosed with misophonia [18,19]. Misophonia is a disorder of decreased tolerance to specific sounds or their associated stimuli [25]: such sounds include eating, chewing, breathing, and typing sounds. Both studies used the Amsterdam Misophonia Scale (A-MISO-S) for diagnosis of misophonia and its severity at a medical psychology center. One study examined people who had been diagnosed with moderate to extreme misophonia specifically [19].

3.5 Pandemic soundscape experiences for people with hearing impairments

3.5.1 People with hearing loss

Three cohort studies investigated the acoustic environments experienced by CI users with hearing loss in the initial phase of the COVID-19 pandemic [17,21,22]. One study used the methodology of Ecological Momentary Assessment (EMA)—repeated questionnaires collecting participants' self-reports in their natural environments [17]. The others used CI datalogging—data acquired through the monitoring of acoustic environments from their CIs [21,22]. Overall, people with hearing loss, who used CIs, spent more time in quieter environment during the initial pandemic periods. From the EMA subjective evaluation [17], adult CI users spent more time at home in a quieter environment. The study indicated that their listening environments had better signal-to-noise ratio, perhaps the acoustic environments were more controllable and predictable, and they felt less socially isolated and with reduced anxiety during-COVID compared to pre-COVID periods. A similar phenomenon was found for people at different stages of life, such as children and older adults, from their objective CI datalogs. Gordon et al. [21] found that children experienced a significant quieting of their daily worlds during the COVID-19 lockdowns: reduced exposure to louder sounds (reduced times at 60 to 69 dBA by 0.49 hour and at 70 to 79 dBA by 1.70 hours) and increased time spent in quiet (sounds < 50 dBA). Likewise, older adults with CI experienced reduced exposure time to speech in the presence of background noise, hence less-complex listening environments [22].

It would have been perfect if this quietness was resulted simply from reduction in unfavorable noise. However, there is a significant decrease in speech-sound exposure, which is particularly concerned language development for school-aged children as well as cognitive/mental health for older adults. That is, this quietness might not have been unconditionally favorable atmosphere for people with hearing loss. Gordon et al. [21] stated that the observed quieting of life due to COVID-19 was not specific to general environmental sounds. Decreased exposure was found for sounds containing speech-in-noise (i.e., voice amid other voices or sounds) but not sound in the noise-only category, suggesting that what the children missed during lockdowns were particular to speech sounds. Give this deficiency, the authors raised concerns for children's language development. The older adults also experienced the similar deficits in time spent in conversation [22], which could also degrade speech performance. Therefore, the

pandemic quietness has both positive and negative facets that have substantially influenced people with hearing impairments: providing less complicated and more controllable sound environments while depriving them of time spent in environments containing human voice, speech, and conversation, and affecting their speech abilities.

One cross-sectional study from two articles [23,24] examined general sound perspectives of residents in Canada through a national social survey between April and May 2021. They included people who self-reported hearing loss as diagnosed and undiagnosed (but suffering from hearing loss), along with people without hearing loss. The study revealed that both diagnosed and undiagnosed (but suffering from) hearing loss increased annoyance to environmental noise due to the pandemic compared to no hearing loss [24]. The survey was administered during the third wave of the pandemic, where its situation was likely to be different from the initial wave of the pandemic in which the above-mentioned three cohort studies were performed.

3.5.2 People with tinnitus

Two cross-sectional studies conducted self-administered questionnaires for adults having tinnitus to explore how COVID-19-related changes, including the changes in sound exposure and noise annoyance, altered their tinnitus experiences [16,20]. One study developed the survey questionnaire comprising of both closed-ended and open-ended questions [16] while the other study employed the standardized questionnaires including Tinnitus Sample Case History (TSCH) [20].

People with tinnitus had heterogeneous perceptual experiences toward their sound environments altered due to the pandemic. Since the COVID-19 pandemic emerged, lifestyles have changed, and working from home (WFH) patterns have become commonplace. Many employees were asked to adjust to their new working environments, which may have lowered tinnitus for some people while increased tinnitus for others [16]. Based on their qualitative data, some participants reported that WFH in quieter environment improved tinnitus experiences (i.e., less tinnitus). In contrast, other respondents stated that the reduction of some background noise (e.g., noise from traffic and a busy office) increased tinnitus perceptions. Moreover, some found that WFH environments exposed them to more noise than usual from neighbors, electrical tools, and children, which aggravated their tinnitus perceptions [16]. Similarly, the other study [20] found the slight increase in the number of tinnitus patients who experienced frequent intolerance to sound (i.e., more frequent noise annoyance) after lockdown compared to before COVID-19. However, the survey of this study was performed one year after the beginning of the lockdown, hence potential recall bias might exist.

While the studies acknowledged the heterogeneous nature of tinnitus experience, being in too quiet as well as being exposed to noisy situation are both reported as detrimental conditions exacerbating tinnitus. Namely, these extreme sound environments may be similarly unfavorable. However, Beukes et al. [16] concluded that the majority participants found their tinnitus was more noticeable and bothersome during the pandemic than before the pandemic as towns and cities were quieter (or too quiet) compared to what they would have been used to. Likewise, Fioretti et al. [20] commented that the absence of environmental sounds from everyday life may have increased the perception of tinnitus.

3.5.3 People with misophonia

Two longitudinal studies by Ferrer-Torres and Giménez-Llort [18,19] explored the complex physical-psychological-social burden of the secondary impact of the COVID-19 pandemic on people diagnosed with misophonia. Their studies used self-report questionnaires for collecting individual's requests, comments, and reasons for clinical consultations [18] and a semi-structured interview for investigating factors related to interpersonal relationships, emotions and other areas connected to misophonia [19].

During the pandemic confinement, people with misophodia were adversely affected by increased auditory stimuli associated with neighborhood and family members, which exacerbated their misophonia symptoms. The long, strict lockdown to hamper the COVID-19 pandemic confined people to their spaces of residence and exposed them to certain unavoidable aversive sounds. Those sounds were relatively adaptable for some people, but they were painfully intolerable for other people, such as those with misophonia. The aversive sounds reported by [18] were related to the intensified and overlapped activities (e.g., walking, homework, playing/singing, television, and keyboard) of their own family members or neighbors as well as new social expressions of support for cheering frontline workers (e.g., songs, handclapping, and music) from neighbors' balconies. The fear of their hypervigilance states (i.e., extreme sensitivity to those aversive sounds in their surroundings) affected other aspects of health and led symptoms of insomnia or amplified sleep disorder [18]. For those with moderate to extreme misophonia [19], more than 80% participants felt increased hypersensitivity and

overstimulation due to sounds produced in the neighborhood, or by family members and pets.
Consequently, it was revealed that the prolonged, strict confinement period due to the COVID-19 pandemic made the soundscape that unavoidably devastated people with misophonia: the increased aversive sounds associated with neighborhood and family members, substantially affecting their daily-life activities and well-being.

4. CONCLUSIONS

Based on the qualitative summary of the included studies, this review shows that people with hearing impairments experienced increased quieting of everyday environments during the early phases of the COVID-19 pandemic. The quiet environments at home were experienced as better signal-to-noise ratio situations, perhaps more controllable acoustic environments. They also improved some tinnitus experiences. However, this pandemic quietness may have induced some unintended consequences: reducing in time spent in environments containing human voice, speech, and conversation, for people with hearing loss, potentially degrading their speech abilities, hence quality of life. These consequences may not be obvious at first glance, but their influences can be substantial even after the pandemic was over. People with chronic tinnitus found that their tinnitus perceptions were more noticeable and bothersome during the pandemic than before the pandemic since their surroundings were quieter than they would have been used to. Despite silence in time of COVID-19 during the confinement period, the increased indoor noises related to neighbors and family members adversely impacted people diagnosed with misophodia.
Although the presented acoustic environments were experienced by people with hearing impairments, these findings would reflect real diversity of human hearing experiences and provide inclusive ideas of designing soundscapes for much broader populations. From the studies [16,20], the heterogeneity of individual perceptions of tinnitus could make the understating of their soundscape experiences difficult and complicated. However, their heterogeneous perceptions must reflect real parts of human hearing diversity so that their hearing-related needs should be proactively supported. Future research should seek potential ideas for designing healthy hearing soundscapes for people with tinnitus. Moreover, being exposed to inescapable aversive sounds inside the home may be believed to be far from rare for broader populations even though they do not develop any misophonia symptoms. However, the lack of understanding due to lack of knowledge of misophonia as well as the lack of empathy for people with misophonia would exacerbate their psychological and psychosomatic problems [18,19]. Therefore, thoughtful approaches to considering their hearing diversity and designing hearing-friendly soundscapes are imperative, which would be inclusive for those with hearing impairments as well as eventually beneficial for all populations.
The original soundscape concept developed by ISO [9] is rather inclusive for diverse auditory characteristics than exclusive. A study of hearing impairments is a central topic of audiology; however, it has merely been gone beyond the surgical or technical (e.g., cochlear implantation, hearing aid technology), linguistic (e.g., speech communication), or architectural (e.g., universal design) implements. Besides, there is little attempt to investigate soundscape experiences for people with hearing impairments. Therefore, the inclusion of the diverse auditory perceptions will be a key for the new normal soundscape agenda.

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