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NOISE POLLUTION (PHT ZANNIN, SECTION EDITOR)

How the COVID-19 Pandemic Muted and Remixed the World's Acoustics for a While

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Abstract

Purpose of Review This review aims to analyze the effects of the pandemic on the world's sound environment.

Recent Findings The confinements associated with the pandemic led to a reduction in sound levels worldwide and a change in the perception of soundscapes in the absence of traffic noise and human-generated noise.

Summary In response to the COVID-19 pandemic, many countries and regions around the world adopted a series of interventions in 2020 that have been referred to as "lockdown" or "confinement." These sets of restrictions had a clear and obvious consequence derived from the absence of people in the streets and the reduction of daily activity and commuting, which caused an unprecedented silencing on a large scale. Along with the silence that ensued, the pandemic and the confinements affected acoustics and our relationship with sounds on different scales. In the cities, this phenomenon had a strong reduction in acoustic intensity due to the absence of vehicles on the streets. Perhaps this was more perceptible in our neighborhoods, with notable changes in their soundscapes, first due to the absence of people in the streets and later due to more outdoor activity derived from the fear of the spread of the virus in indoor spaces. The longer periods of time spent in our homes during the lockdowns also highlighted the importance of sound insulation in buildings and the acoustic conditioning of our schools or homes.

Keywords Pandemic · Soundscape · Noise · Lockdown · Sound

Introduction

In response to the COVID-19 pandemic, many countries and regions around the world adopted a series of interventions in 2020 that have been referred to as "lockdown" or "confinement" (including with varying degrees of enforceability, stay-at-home mandates, curfews, quarantines, medical cordons, and similar social restrictions). These restrictions were implemented with the aim of reducing the spread of SARS-CoV-2, the virus that causes COVID-19.

In January 2020, the restrictions began in Wuhan (China). In February, several locations in northern Italy were also confined. Throughout March, lockdowns began in many countries around the world. By April 2020, approximately half of the world's population was under some form of confinement, with more than 3.9 billion people in more than 90 countries or territories having been requested or instructed by their governments to stay home. These are measures that have been used for the control of disease for centuries, but the scale of those implemented in 2020 is believed to be unprecedented [1–6].

These restrictions had a direct effect on (a) ground transportation, with substantial percentages of the population unable to go to work or having to work from home; (b) air transportation, with only those flights dedicated to the provision of medical supplies and other essential products maintaining a regular activity; and (c) water transportation, where there was an enormous reduction in recreational activity, as well as significant effects on maritime trade and port calls [7–10].

The pandemic has certainly had tremendous consequences for the world's population in terms of infections, hospitalizations, and number of deaths and has had major consequences for the world economy. However, on the other hand, the pause in various forms of transportation and the

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confinement of people and their absence from the environment had considerable environmental consequences, with the return of animal species to the urban environment and beaches and the reduction of the levels of atmospheric pollution in populated areas and ecosystems [9, 11–21].

Acoustics, in many different dimensions, has been one of the aspects of our lives that has had severe repercussions, which we aim to address in this paper. This is a global phenomenon, as proven by Lecocq et al., who collected seismic observations from all over the world and were able to prove the effects of anti-pandemic measures on a substantial decrease in seismic noise around the planet [22]. The change in acoustics has affected natural environments, both on land and at sea [23–29], but this article focuses on urban environments in a more specific way. To this end, we have structured this article into 4 sections addressing different scope levels: Our Cities, Our Neighborhoods, Our Buildings and Homes, and Ourselves (individuals).

In each section, we will critically analyze the main scientific publications that have appeared internationally over the last two years. In the first section, we will address cities, and we will analyze the drop in noise levels because of the reduction in traffic flows. We will continue to zoom in to analyze the effects the pandemic had on the soundscape of our neighborhoods. In the third section, we will enter residential buildings and homes to explore whether the changes in living habits introduced by the lockdown have affected neighborhood relationships regarding noise. We will try to describe how the lockdown affected the inner sound quality of our homes, modified by the increased presence of family members performing activities for which the dwellings are not properly adapted. Finally, we will try to analyze, from an acoustics point of view, other effects that the pandemic or the measures adopted to fight it, such as wearing a mask, have had on individuals.

Through this structure, we intend to compile the main documents produced by the scientific community in the field of acoustics during two years of the pandemic, addressing aspects as diverse as the effect of the absence of noise, the change in soundscapes in cities, the relationship between environmental noise and the spread of COVID-19, or the communication problems associated with the use of a face mask.

Cities

As may be obvious, cities are the environment in which the acoustic effects of confinement were most accentuated. As the main centers of attraction and concentration of activity, the restrictions of mobility had a much more noticeable effect than in other areas with less population density and less traffic intensity. Moreover, as these restrictions were enacted at the city level, their effects could be observed in a very remarkable way in widespread regions and in very distant areas within the same city.

In this section, we intend to conduct an objective analysis of the reduction of noise pollution, quantifying the drop that occurred in the cities. To do so, we will take some examples of those cities that are equipped with continuous noise monitoring systems, since these networks have made it possible to follow the evolution of this phenomenon.

One of the cities with the most extensive network of sound level meters is Madrid (Spain), and it is also one of the cities that suffered the most rigid and prolonged confinement during 2020 [30]. The noise monitoring network in Madrid has 31 monitoring terminals placed throughout the city in areas classified as traffic-dominated, active, or quiet. The average reduction in the sound level on working days was close to 4 decibels in the day, evening, and night indicators in every area type. Sound level reduction was higher during the weekend due to the absence of leisure and commercial activity. The mean reduction in the weekend L_n indicator was higher in areas dominated by traffic noise (although the highest reduction, 11 dB, was observed in an active area with quite a number of bars and restaurants) [30]. Even in these circumstances, traffic was still the main source of noise in Madrid. Figure 1 shows two locations that are 12 km apart, one at a main node in the city center and the other located in a residential area on the outskirts, where the Ld indicators follow the same trend over time.

Road traffic was not the only noise source affected by the lockdown. As an example, Fig. 2 shows the decrease in noise levels reported by AENA (airports manager in Spain) in one of the locations closest to Madrid-Barajas Airport. Aircraft noise decreased by 18 dBA, while the reduction in overall values (all sources) only reached 9 dB, since, during the confinement, traffic noise took the lead in this area that is rather distant from any urban center [31].

In the case of Barcelona (Spain), its monitoring network combines type 1 and type 2 noise monitoring units, for a total of 112 distributed throughout the city. The analysis of the data shown by Bonet-Sola et al. [32] shows a significant reduction in noise levels. The reduction reaches, on average, 7 dBA in the most severe phases of confinement in the city when compared to the situation in previous years. Neither in Barcelona was the reduction homogeneous; it reached 9 dB in the nightlife areas in the city, while the reduction was 7 dB in commercial and restaurant areas and 5 dB in areas with dense traffic flows.

Similar to what occurred in the case of Madrid, the progressive release of the restrictions in Barcelona reactivated city activity, and with it came a gradual restoration of noise levels until they reached values comparable to those of previous years once the confinement was over. It can be seen that the recovery of noise activity is not complete, although

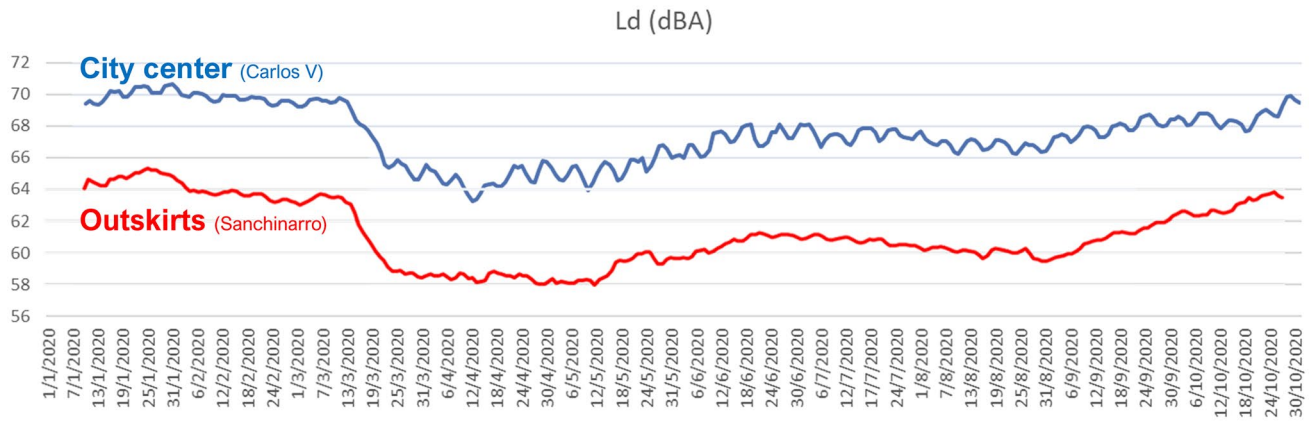

Fig. 1 L_{day} indicator (moving average) in Madrid

it is unclear whether this could be related to the noise abatement strategies that the city has been implementing in recent years, as shown in the trends prior to the lockdown, or that the full normality was not reached after the end of the lockdown.

In the case of Italy, the lockdown began slightly earlier than in Spain on March 10 and lasted until May 4, when the confinement was progressively lifted. In Milan and Rome, there was also an opportunity to monitor the phenomenon in terms of sound intensity thanks to the noise monitoring networks resulting from the LIFE DYNAMAP project [33].

In Milan, the network consists of 24 monitoring units located in a pilot area within the ring road, which is mainly dominated by traffic noise. The evolution of the L_{den} and L_n indicators on a weekly basis, compared to the previous year, clearly shows the effects of confinement. The decrease in sound levels was progressively shown over 2–3 weeks, and a maximum reduction of 7 dB was achieved between the end of March and the beginning of April, at the point of the greatest severity of the confinement. Since then, activity has gradually recovered, with the previous year's numbers having been recovered by the beginning of June.

In the case of Rome, the sensors are located along the ring road, which showed a very important reduction in traffic volume (approximately 60–70% in light vehicles) during the lockdown. The analysis was carried out on three sensors. When comparing the strictest lockdown week with the equivalent week of the previous year, two of the locations reached a reduction greater than 9 dB, while the reduction on the third one was greater than 7 dB. All these reductions occurred despite the fact that, due to the loss of traffic intensity, there was a significant increase in the average speed of the road.

Additionally, in Rome, the team led by Aletta conducted a very interesting study in which they collected traffic data to perform noise simulations [34]. The data they acquired using the floating vehicle technique allowed us to obtain the origin–destination matrices needed to generate the traffic models they used to describe the circulation flows of the city's streets. These data were used to feed an acoustic

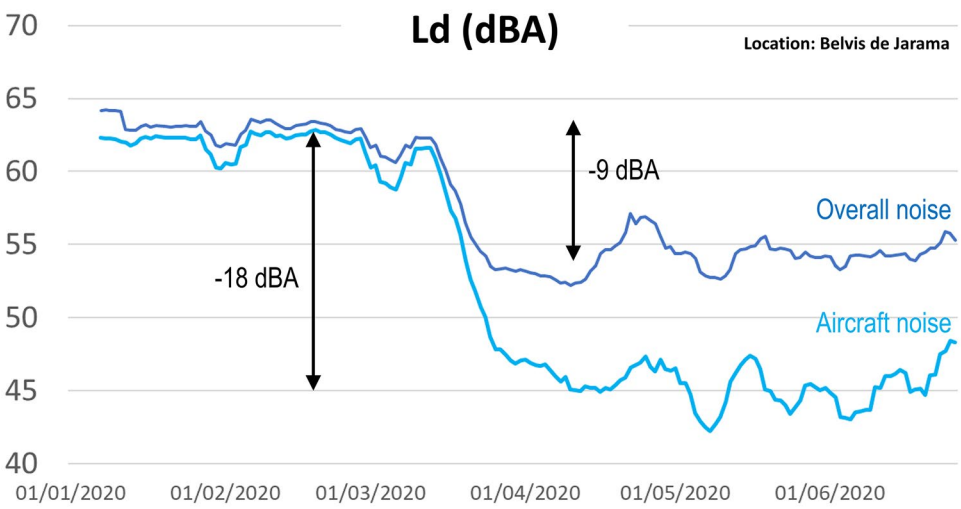

Fig. 2 L_{day} indicator close to Madrid-Barajas airport

model based on the CNOSSOS-EU method that allowed the research team to obtain a noise map for three scenarios that could be assimilated to pre-lockdown, lockdown, and post-lockdown. Although the quantitative results of this simulation study do not converge with the results of the previous measurement-based study, both qualitatively show a reduction in noise levels on the Rome ring road. Moreover, the simulation study shows that the reduction is greater on the inner roads of the ring road, since on those streets, the reduction in traffic intensity does not have such a direct effect on the increase in vehicle speed.

In Germany, there were severe restrictions in mobility as a response to COVID-19. In the city of Bochum, 22 instruments have been carrying out continuous noise measurements in connection with a previous project since 2019, allowing for a pre-post analysis of the effects of the pandemic in the city [35]. The analyses showed an average reduction in noise levels of close to 5 dB, with the strongest decreases observed in the urban forest, green spaces, and residential areas (6-dB drop), while in the main street, the decrease was only 4 dB. Pre-pandemic Sundays used to be the noisiest day of the week in urban forest and urban agricultural land areas, but the levels dropped during the lockdowns and converged with those registered during the rest of the week. However, unlike what has been shown in other cities, the researchers have not discovered significant changes in the daily temporal pattern, with a homogeneous reduction in noise levels throughout the 24 h of the day.

In southern France, Acoucité investigated the effects of noise in 4 conurbations, thanks to the use of 21 permanent noise monitoring stations. The study analyzed the results measured between early January and mid-March (the start date of confinement) and from then until mid-May. The researchers observed a reduction of between 4 and 6 dB in the locations most affected by traffic noise, in line with what has been shown in other studies. They also mention a different impact of the lockdown between weekdays and weekends, but interestingly, there are differences from one city to another. For Grenoble, the reductions are generally more pronounced on working days, while in Lyon, Aix, Saint-Etienne, and Toulouse, the opposite is observed. Unfortunately, the authors do not provide any hypotheses that could justify these differences [36, 37].

Mimani and Singh studied the acoustic impact of the lockdown from 25 March to 31 May 2020 on locations across seven major Indian cities based on the data recorded by the National Ambient Noise Monitoring Network (NANMN). This network consists of 10 monitoring units in each of the cities: New Delhi, Lucknow, Kolkata, Hyderabad, Chennai, Bengaluru, and Mumbai. The results showed that the daytime and night-time reductions ranged from approximately 4 to 14 dB(A) compared to mean pre-lockdown levels. When the lockdown restrictions began to relax, the noise levels started to increase almost linearly, reaching the pre-pandemic levels [38].

In Granada, Spain, Vida and his colleagues carried out a study on four iconic urban spaces with touristic relevance. These are places where citizens and visitors gather to talk, walk, play or simply enjoy the environment. The authors performed measurements in 2020 that they compared with measurements conducted in 2019. In these environments, with little or no traffic noise, the sound of the human voice was already predominant before the confinement but was muted by the restrictions. Although in this case the sampling periods are short, the sound level reductions obtained are the highest reported in this review (20–30 dBA), giving way clearly and noticeably to other natural sounds that in some of the locations were barely present before the confinements [39].

The study by Aletta et al. [40], which was carried out in London using short-term measurements, is worth mentioning. The study shows that in London there was also a significant reduction in noise levels due to traffic noise. However, it points out that the largest drop occurred in the so-called active areas, where in addition to traffic, there were many people active on the streets, while the drop was much smaller in areas that were already quieter before the confinements. These results and conclusions are fully consistent with what has already been described in other cities mentioned above.

Due to the large number of studies and papers that have been presented in journals and conferences, it is impossible for this review to cover all of them. In our opinion, the main methods and conclusions are perfectly reflected in the abundant sample that we collected in this article. Nevertheless, we would like to mention some of them here, as they can provide an idea of the general importance of the phenomenon worldwide [10, 41–56].

To conclude this section, we must mention a small note that highlights the importance of this community noise as an indicator of human activity and reveals how confinements have had a widespread impact in each of the cities, in addition to its incidence on the local soundscape. Therefore, there are several investigations that establish a relationship between noise levels and other markers that permit the assessment of the effectiveness of anti-pandemic actions and recommendations or allow the monitoring and prediction of the evolution of the pandemic on the basis of indicators anticipated by noise. For instance, Diaz et al. [57] discussed the relationship of the virus with the incidence and severity of COVID-19, showing noise level as a proxy related to the transmissibility of the virus. Moreover, Rumpler et al. used the evolution of the measured noise levels in central Stockholm to track both the evolution of adherence to the recommendations made by the Swedish government and the impact of the recurrence of cases combined with reinforced recommendations [58, 59]. A similar approach, considering

low frequency and infrasound, was applied in Las Vegas to determine the associations with anthropogenic activity during the pandemic [60].

Finally, we must take into account that, according to experts, aerosols seem to be one of the main paths of transmission of the virus [61, 62]. Thus, when we speak, the emission of aerosols increases. Furthermore, the higher the intensity of our voice, the higher the concentration of aerosols we emit but also the greater their size [63]. For these reasons, it made sense for a while to establish a link between loud noise and greater transmission of the virus. Thus, there were recommendations in some places to maintain silence in the modes of transportation [22, 64].

Neighborhoods

As Wójciszyn-Wasil relates, there was a change of meaning in the perception of soundscapes. For example, silence went beyond the elimination of noise and became, during the confinements, "a metaphor for danger, fear, loneliness, longing for a return to daily activities" [65]. There were also sounds, previously distant, that acquired a depth and a higher level of awareness in our minds, such as the sound of ambulances, the sound of people coughing, or the sound of applause for professionals in the health care system [66–68]. Now that we have discussed the noise pollution that affects a city as a whole, let us zoom in a little and look at the neighborhoods, closer to the citizens and their perception. In this section, we examine how the soundscape and its perception in our neighborhoods have changed because of the pandemic. Obviously, when analyzing at this level of scale, local factors are of greater importance. The diverse range of measures adopted by each country or local authority and their gradations, coupled with socioeconomic and cultural variables, make it difficult to generalize conclusions. However, we have tried to highlight some of the more distinctive consequences in a residential area, such as the absence of people on the streets.

The data analysis carried out in Madrid by Asensio et al. allowed the research team to use the data from the noise monitoring network as a proxy for human activity in the city. These sound level time history data were analyzed at hourly intervals, separately on weekdays and weekends, to analyze changes in activity patterns throughout the day. During confinement, the reduction in street activity after three o'clock in the afternoon was noticeable. Furthermore, on weekends, the city woke up approximately 2 h earlier than before COVID-19. In contrast, weekdays seemed to have a more moderate morning rush hour during confinement [30].

Legal or other self-imposed restrictions, such as the #stayhome movement, led to fewer people on the streets. Not only did we go out much less, but we also went out in a certain state of fear. Whether we went to work or went shopping, we went out with a purpose, not just to hang out. We kept our social distance. We kept our conversations short and cautious, when meeting friends or neighbors in the street. The silence of the neighborhoods made conversations stand out; they were no longer private. Therefore, not only was there a reduction in sound levels, but the soundscape also changed quite noticeably. Especially noticeable is the lack of children's activity in the streets. The bans on going out, the closing of schools and parks, and the cessation of children's interactions also caused the streets to become more muted. This situation was most profound in the parks. These spaces are usually a meeting point for children and adults, where conversations, games, and shouting used to provide an environment that was vibrant, for some, or noisy for others. With the pandemic, these empty spaces turn the soundscape into something sadder and more muffled, beyond the reduced loudness. With the reduction of technology, natural sounds, including human voices, emerged. All of these are perceptions that we have experienced firsthand, have gathered from our family or friends, or even from our work environment. At the same time, these impressions raise questions that various research studies have tried to address.

In the aforementioned study on Granada, the effect of the absence of people in a neighborhood is clearly shown. Since the study focused on areas with little traffic, the noise reductions make it possible to assess more clearly the effect of the absence of people in the streets, not only by reducing the sound intensity but also by modifying the noise spectral patterns and the perception of the soundscape. The study points out the relevance that the human voice can have as an acoustic pollutant of an environment, this being a source that is very often ignored in the acoustic planning of a municipality [39].

Lenzi and colleagues conducted an investigation into the perception of soundscapes in a neighborhood in Euskadi (Spain) during confinement from March 15th to May 25th, 2020. The researchers collected sound recordings, photographs, and field notes over 50 days in a residential street of the Getxo neighborhood, near one of the main arteries, and in the vicinity of a square, a school, and a playground (capturing different activity layers). The recordings were analyzed by experts using two different methods. On the one hand, an adapted version of the Swedish Soundscape Quality Protocol was used [69], and on the other hand, a method based on free annotations regarding the audio events existing in the recordings and a taxonomy for the classification of the free labels were used. The results of this research seem to confirm that in the first phase of confinement, when people were allowed to go out to work and essential shopping, the soundscape reduced the number of sounds associated with transportation, so sounds more closely related to the human voice began to stand out and were perceived as more

pleasant. Later, with increasing restrictions and a practical disappearance of people from the streets, it was the sounds of birds and dogs, along with other natural sounds, that began to come to the foreground. At the same time, rising temperatures made it possible to do more activity with open windows and balconies, which allowed, to some extent, the return of neighborly conversations to the soundscape. The descaling phase, also subjectively, brought sounds back to the streets, increasing the number of technological sounds, and with them raising the loudness and the eventfulness of the soundscape while lowering the pleasantness.

In France, Acoucité carried out an online survey to determine how citizens perceive the change in soundscapes caused by confinement. Participants were asked to rate their perception of noisiness when inside their home for the two obvious scenarios: pre-lockdown and lockdown. On a scale of 0 to 10, the average noisiness was 6.3 before the lockdown and dropped to 2.4 during the lockdown. Those participants residing in areas affected by airport noise, which was significantly reduced during the confinements, reported higher levels of noisiness in the pre-confinement scenario and therefore a greater reduction with the arrival of the lockdown. For instance, only 4% of the respondents in Lyon lived near an airport, and the reported nuisance drop was 2.7, while the percentage of respondents in Nantes living near an airport was 96%, and the declared nuisance drop was much higher at 6.2. Perhaps these numbers could suggest that the type of predominant noise source in an area also influences the reduction in perceived noisiness, although it would be necessary to quantify the actual reduction in sound intensity in different environments [37].

A rather different approach was presented in Mitchell et al. [70]. This study is based on the modeling of pleasantness and eventfulness metrics defined in the ISO 12913 standard for the evaluation of a soundscape [71, 72]. The authors trained models of each of these metrics from data obtained in 2019, which they applied to the acoustic dataset they were able to obtain from 2020 recordings. Thus, despite the impossibility of obtaining field surveys, they made a prediction of soundscape modifications during confinement, which were completed with data from online listening tests. The results indicate a higher salience of natural sounds and a lower dominance of human sounds. Perceptions shifted toward less eventful soundscapes, which in spaces usually dominated by traffic were perceived as more pleasant. Conversely, in locations dominated by human and natural sounds, the lack of eventfulness caused a shift toward less pleasant perceptions.

Another indicator commonly used to assess noise in an area is the number of complaints. It is quite straightforward that the higher the number of complaints issued, the higher the perception of nuisance in a community [73–79]. However, the perception of noise and the decision to register a complaint are highly subjective, with multiple psychological and socioeconomic factors that can have a strong influence [75, 76, 80].

The increase in noise complaints has made headlines in many newspapers and has prompted warnings from authorities around the world; however, references to technical studies of this phenomenon have, until now, hardly been relevant [81–84]. Therefore, we will focus on two studies conducted in two iconic cities, New York and London.

Ramphal and colleagues analyzed the temporal patterns of the more than 4 million noise complaints recorded in the New York City database from 2010 to February 2021 [85]. Their analysis shows the increase in the number of complaints in recent years and specifically examines the period between March 2020 and February 2021 to compare whether the observed increases in the number of complaints continue the trend of previous years. The results show a sharp increase in the number of complaints in this pandemic year, especially during the warmer months, probably in connection to the time the windows stayed open. The increase observed was inversely proportional to the income of a community, which was surprising, since the lowest income communicates are usually more reluctant to complain [86, 87].

In Greater London, a group of researchers from the University College London undertook a study to examine how noise complaint patterns changed during the first stages of the lockdown implementation during the spring of 2020 and the influence that urban factors (including housing, demographics, transport, and traffic noise level bands) may have had on this change. The researchers focused on a 2-month period, comparing the trends in complaints recorded in 2019 and 2020, and found that the number of complaints had indeed increased from just under 3 to 4.3 complaints per 1000 inhabitants, a growth of more than 40%. The increase in the number of complaints was smaller in the wealthier parts of the city, but population density does not appear to be a statistically significant factor in this relationship. Perhaps the possibility should be explored that in both cities, affordability is a confounding factor that is associated with the quality of housing and its insulation, the number of residents in the homes themselves, or even the number of people who have jobs that allow them to work from home and that distract them from the causes of complaints.

To conclude, with regard to complaints, we will mention a study carried out in Dallas that, contrary to those observed in London and New York, mentions a reduction in the number of complaints during the months of the pandemic, especially in the center of the city, which, apparently, was more relieved of traffic noise [88].

A particularly relevant issue that the pandemic raised in some cities (especially in Spain, but not only there) is that of COVID terraces [89–92]. At first, the restrictions imposed by the competent authorities were very strong, with orders

to stay at home and the closure of bars, restaurants, and other places where it was foreseen that it would be difficult to keep the accumulation of people under control and to maintain social distance. Subsequently, as the mechanisms of virus transmission became better understood, guidelines were given in the direction of avoiding enclosed spaces and of socializing, with precautions, in open spaces. In this sense, and with the aim of giving a respite to restaurants, bars, and cafes, which had faced such a difficult time during the pandemic, the use of public space for the installation of terraces, the COVID terraces, was more flexible. Users could not or did not want to enter indoor spaces, and the COVID terraces allowed for a certain degree of normality to return to our lives.

The COVID terraces, in some cases in an excessive manner, occupied pedestrianized streets, sidewalks, or parking spaces in cities and invaded once silent neighborhoods with their noise. Suddenly, residents of these areas saw their lives turn into an agony because of the COVID terraces, and at least in some of the cities, they are beginning to organize themselves to fight against this phenomenon that, 2 years after the confinements, continues to attack their privacy, their well-being, and their rest, becoming a public health problem in these areas. The phenomenon of leisure noise in residential streets is not new, at least in southern European countries; however, the pandemic caused its instantaneous and uncontrolled growth, and its management and reduction will be a challenge that the residents of these areas will probably have to face through legal actions in court [93–97].

Buildings and Homes

Due to mobility constraints and the prioritization of working from home, the home environment became the place where all daily activities took place for many of us. We spent more time at home, as did our neighbors. Additionally, we were having more spare time, not being able to maintain our busy lives and or even go outside. Those lucky enough not to have experienced this before noticed that our homes are not as quiet and peaceful as we would like them to be. This is in part because of the noises that have always been there and that we did not hear because we were away from home. However as the time we spend in our homes multiplies, so does our noisy activity. Thus, our loud neighbors are being louder than ever because they are spending more time in their homes, and we are there to listen to those sounds. In addition to the noise from televisions, music, voices, or household appliances, we had new sound sources from our neighbors. Since they could not go out, many chose to exercise at home, dance, or pursue other types of physical activity, generating structure-borne noise with the disturbances that this generates. With schools, music academies, and rehearsal rooms closed, homes also became centers of musical practicing, even though they were not properly adapted for this purpose. This is how we realized that the insulation of our homes could be improved. In many cases, the reduced traffic noise became more annoying than ever under these circumstances, just because we were there to hear it, as well as the noise of construction, cleaning, or gardening work in our streets. However, not only did we wish for better insulation of the exterior facades but also of the interior partitions, those that separate us from our neighbors, and sometimes even from the people with whom we cohabit in our homes.

The first study we refer to is an online survey conducted internationally, with over 1000 responses collected in a number of different countries [98]. The questionnaire aimed to collect the subjects' assessment of the changes that the pandemic introduced into the urban soundscape and the effects to which this led inside their homes. The results showed that the reduction in outdoor sound levels was clearly perceived and even appreciated, regardless of the respondent's place of origin, which, given the large international participation in this survey, highlights the global nature of the pandemic measures and their effect on urban noise. However, the generalized reduction in outdoor noise levels did not translate as clearly into the interior of homes, probably due to the relevance of noise produced by neighbors in more crowded houses during the confinements. Additionally, in the online survey carried out in Spain and reported in (53), a reduction in traffic noise annoyance during confinement was observed, while at the same time, there was an increase in self-reported disturbance from neighbor noise.

In Andargie et al. [99], we find a study conducted in Canada using surveys in multiunit residential buildings. The results show that despite the decrease in outdoor noise, it continues to be a reason for annoyance, particularly the noise from traffic and construction work, and furthermore, it is reported to affect the ability to work from home. Neighbors' noise is also reported as a source affecting the ability to work, but noise coming from occupants in the same suite (i.e., roommates and family) presents the biggest issue. This study suggests that noise is the primary cause that may impede the extensive implementation of teleworking in the long term.

In Şentop Dümen and Şaher [100], efforts were focused on analyzing annoyance through population surveys in Turkey, relating environmental noise reduction to annoyance and to stress and anxiety levels. This survey study, with more than a thousand responses, shows how the annoyance produced by traffic noise dropped with the reduction of the sound level, more significantly in places that were noisier before the restrictions. In line with the main conclusions in Canada, in this study, it was also observed that the annoyance produced by the residents of one's own dwelling increased notably, but it did not reveal an effect of the

restrictions in relation to the annoyance caused by the noise of neighbors. The study also found an association between anxiety levels and noise annoyance. However, this association seems to disappear when comparing pre- and during confinement scenarios, which may suggest that such associations may only occur in stable and much less uncertain scenarios than a pandemic.

In London, Lee and Jeong conducted a study on attitudes toward outdoor and neighbor noise during the COVID-19 lockdown [101]. They followed a double track, the first via a social media analysis (Twitter) and the second via an ad hoc online questionnaire. The number of tweets containing noise-related complaints doubled, particularly about airborne noise produced by neighbors' voices, shouting, TV, or music. The same trend was corroborated by the questionnaire, in which participants perceived a reduction in outdoor noise but also reported an increase in annoyance from neighbors' noise.

Additionally, in London, Torresin and colleagues conducted an online survey to characterize the indoor soundscape during confinement [102–105]. The survey targeted London residents who worked from home during confinement, focusing on two activities performed at home during the pandemic: working and relaxing. The study suggests that the sound environment we require during work tasks is more demanding than in our relaxation time. In the latter, we can overcome the lack of comfort or the excess noise by controlling the volume of television or music. However, we require a quieter environment during work, and therefore, even if the space used is the same, it is less comfortable for work time than for our leisure time. The study again highlights the importance of the perception of noise produced by neighbors on reported comfort and well-being, especially during relaxation time. It also establishes the number of cohabitants in the dwelling as a moderating variable, which is in line with the findings in other studies that mention the problems caused by noise from cohabitants when working from home.

Individuals

On a personal level, there is no doubt that the pandemic, the restrictions, and their consequences have also had a notable impact on each of us at the individual level. With regard to the subject of this article, acoustics, the use of the mask in particular is one of the elements that has had the greatest impression on our everyday life. Beyond the discomfort that its use can cause, the facemask has entailed a real communication problem, which we will try to briefly address in this section.

When any kind of facemask is placed in front of our phonatory apparatus, the transmission of sound is affected. This produces a loss of sound intensity, which is transferred to a worsening of the signal-to-noise ratio and is therefore reflected in a loss of speech intelligibility. Several studies have addressed this phenomenon to determine the effect of different types of masking elements. Some evaluate the objective attenuation produced by the element by itself, while others evaluate the insertion loss it introduces, the subjective effect that this device could be causing on the speaker, or address the effects on specific groups of workers [106–117]. This might be a particularly serious problem in the case of people with hearing problems, since not being able to see the mouth of the interlocutors makes communication even more difficult for this segment of the population [118].

The systematic review conducted by Shekaraiah and Suresh suggests that wearing masks results in vocal fatigue, discomfort, and perceived voice problems, which may be due to the attenuation that all types of facemasks introduce in the audible frequency range. In this sense, surgical masks would offer the least attenuation loss and therefore put the least strain on the speaker's voice [119]. We can obtain some details in the study carried out by the University of Illinois, which shows the attenuation the mask produces in the frequency range above 1000 Hz, which coincides with the range of maximum voice emission, being more pronounced at the front [120, 121].

Some studies have attempted to quantify the loss of speech intelligibility using automatic speech recognition tools. Those carried out in the English language show that speech intelligibility is only reduced in noisy environments where the signal-to-noise ratio is excessively reduced [122, 123]. However, the results shown in Luján [124] on the Spanish language suggest a loss of intelligibility of between 5 and 13% depending on the type of mask, even in the case of absent background noise.

Facemask use can be more problematic in some places than others. For example, it becomes a serious problem in schools, both for teachers and students. On the one hand, we have the aforementioned problem of loss of speech intelligibility. However, many schools in different countries had to maintain ventilation by keeping the windows open, often while the teachers were giving their lessons [125–127]. When the windows are opened, the acoustic insulation disappears, and outside noise penetrates the classroom. The teachers have has to raise their voice to improve the signal-to-noise ratio of their speech, which can cause problems for their vocal health. On the other hand, students will also be affected because noise can bring greater distractions, making it more difficult to maintain concentration, which is exacerbated by the problem of speech intelligibility, all of which can have repercussions on academic performance [107, 113, 128].

Conclusions

First, the pandemic was global in nature and triggered a widespread response by governments through the application of containment and mobility restrictions. Therefore, the consequences on the acoustic environment are extensive and consistent with the reduction in mobility. In fact, several studies have shown that there is a strong correlation between human activity and acoustic variables in an environment, and these can even be used as a proxy for measuring the effectiveness of various governmental interventions or even as early predictors of disease incidence.

The average reduction in each city reached between 4 and 8 dB compared to the pre-pandemic situation, with the reduction in road traffic being the main contributor at the macro level. On a smaller scale, the existence of other noise sources and the specific effect of anti-pandemic measures on that specific source can lead to larger locally induced decreases, resulting in a variability of measurements across the locations in each monitoring network. Consistent with this, the drop in active areas is higher than that observed in traffic-dominated areas, with the greatest drops observed in areas where human voices were the only source prior to the lockdown.

Despite, or because of, the reduction in noise levels outdoors, the soundscape inside our homes did not seem to benefit much. Several studies point to the fact that the reduction in outdoor ambient noise was not transferred inside the dwellings, but rather, the residents' perception of the indoor soundscape deteriorated, especially due to an increase in disturbance caused by noise from neighbors. The perception was even less pleasant for those who had to work from home, where activities require a higher level of concentration and greater silence, to which neither the neighbors nor the people living in the dwelling contributed.

Our neighborhoods became quieter, which did not necessarily translate into an improvement in the perception of pleasantness. The suppression of sounds in our environment makes the soundscapes more muffled, but this is only perceived as an improvement in regard to the absence of unwanted noise sources, such as traffic noise. Although some studies show that the absence of human sounds is perceived as negative, it is also clear that this is highly dependent on the type of activity that generates it, as, for example, noise generated by bar terrace users has become a major problem in Spanish cities.

The use of the mask has led to a certain loss of speech intelligibility, which has to be compensated by a greater vocal effort on the part of the speaker. This can have important repercussions in certain jobs, such as teachers who have to work for many hours making this vocal effort in an environment that may not be the quietest.

Compliance with Ethical Standards

Conflict of Interest The authors have no conflicts of interest to declare. All coauthors have seen and agree with the contents of the manuscript, and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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