

*Highly likely to include sections to go in here -  
Lockdown chapter.*

*Research Article Many selected portions relevant to the chapter Eds → urban context.*

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# Assessing the changing urban sound environment during the COVID-19 lockdown period using short-term acoustic measurements

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**Abstract:** The implementation of lockdown measures due to the COVID-19 outbreak has resulted in wide-ranging social and environmental implications. Among the environmental impacts is a decrease in urban noise levels which has so far been observed at the city scale via noise mapping efforts conducted through the framework of the Environmental Noise Directive. This study aims to understand how lockdown measures have manifested at a local level to better determine how the person-level experience of the urban soundscape has been affected and how these affects differ across urban space typologies. Taking London as a case study, a series of 30-second binaural recordings were taken at 11 locations representing a cross-section of urban public spaces with varying compositions of sound sources during Spring 2019 (pre-lockdown, N = 620) and Spring 2020 (during-lockdown, N = 481). Five acoustic and psychoacoustic metrics ( $L_{Aeq}$ ,  $L_{A10}$ ,  $L_{A90}$ , Loudness, Sharpness) were calculated for each recording and their changes from the pre-lockdown scenario to the lockdown scenario are investigated. Clustering analysis was performed which grouped the locations into 3 types of urban settings based on their acoustic characteristics. An average reduction of 5.4 dB ( $L_{Aeq}$ ) was observed, however significant differences in the degree of reduction were found across the locations, ranging from a 10.7 dB to a 1.2 dB reduction. This study confirms the general reduction in noise levels due to the nationally imposed lockdown measures, identifies trends which vary depending on the urban context and discusses the implications for the limits of urban noise reduction.

**Keywords:** soundscape; quiet areas; psychoacoustics; COVID-19; urban noise levels

## 1 Introduction

The global outbreak of the SARS-CoV-2 virus (COVID-19 disease) during the last months of 2019 and first months of 2020 had a huge public health impact for peoples around the world [1]. The pandemic represents a considerable challenge for both industrialized and industrializing countries and affects all segments of society and community life. Governments around the world reacted with the implementation of unprecedented measures in peacetime in contemporary history, aimed at containing the spread of the virus. These included, among others, social distancing (>2 m distance between people when outdoor and “stay-home” recommendations), stopping non-essential productive and social activities (mostly outdoor) and commuting, as well as limiting air, sea, railway, and road traffic to the bare minimum.

While the above measures are having immense social and financial implications, with adverse effects that will be felt for years, they also had some unintended (and often positive) consequences in terms of environmental pollution [2]. With most productive and industrial activities suddenly on hold and strict limitations on domestic and international travels, significant decreases are being observed for both air and noise pollution. Many research centres and governmental agencies around the world show both pollutants have significantly dropped since lockdown and containment measures were gradually applied in different countries. For instance, regarding air pollution, NO<sub>2</sub> emissions dropped by 30% in Central China alone, CO<sub>2</sub> emissions decreased by 25% in China, and globally by 6% [3].

Likewise, decreasing trends can expect to be observed in terms of noise levels, particularly in urbanized areas. Since the enforcement of the lockdown in France on the 17<sup>th</sup> of March 2020, an average reduction of 7.6 dB(A) ( $L_{den}$ ) was observed on the road network of Paris, with noise

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emission reductions in the 60-90% range [4]. Emissions from air traffic dropped dramatically in the Paris Charles De Gaulle airport area too, with reductions as high as 21.5 dB(A) ( $L_{den}$ ), and a consequent decrease of noise complaints related to aircraft noise. The Department for Ecology, Urbanism and Mobility of Barcelona has been monitoring the reduction of noise levels in the city area on a weekly basis since the implementation of lockdown measures in Spain on the 14<sup>th</sup> of March 2020. The reports show average decreases of 9 dB ( $L_{day}$ ) in noise pollution levels after one week, and an additional 2 dB reduction after two weeks [5].

However, the monitoring initiatives described above as an example (and many others not mentioned here) mostly report information and rely on datasets that are aggregated at city or infrastructure level [6], and based on multi-hour or daily time-averaged indicators (e.g.,  $L_{den}$ ,  $L_{night}$ , etc.), because they take place in the framework of the Environmental Noise Directive [7]. Those indicators are then used in the context of noise mapping to represent spatially what groups of population are likely to be affected by the change. Many local authorities are indeed now producing noise maps to compare the pre-COVID-19 scenarios with the current one. Some local authorities are also combining data from long-term environmental noise monitoring stations with online surveys to gather information on the residents' perception of their sound environment during the lockdown period (e.g., [8]) and some researchers are advocating to harmonize the considerable amount of data that will emerge from this monitoring campaigns around the world [9].

It is important to get such information at city scale because it will reflect trends in reaction to environmental noise from the population, e.g., through noise complaints; indeed, recent research in UK cities has shown that noise complaints patterns will vary depending on urban structure and population factors: noise complaints are likely to be higher in service-oriented cities with high population densities; large and clustered cities also have a higher prevalence of noise complaints compared to others, while fragmented cities are likely to have less noise complaints [10]. Nevertheless, while relevant from a noise exposure and public health perspective, the indicators used for noise maps are not necessarily representative of noticeable changes in the acoustic environment at specific locations. Therefore, the present study aimed at sampling the urban acoustic environment at a much smaller scale and in a more opportunistic way, to investigate whether changes in sound levels observed locally due to the pandemic containment measures would be meaningful in terms of how people perceive environmental sounds [11]. This is in line

with the soundscape approach that deals with acoustic environments as experienced in context, thus typically referring to a smaller timeframe [12] and introducing a qualitative paradigm to "measure" urban acoustic qualities [13, 14]. The measurement technique used in this study is based on binaural recordings [15], so that a better representation of the experience of an acoustic environment can be provided from the perspective of a user, as opposed to long-term noise monitoring techniques that typically do not represent a normal listener's position (e.g., sensors installed on lamp posts or building facades, etc.). The integration of soundscape methodologies and environmental noise methodologies is not new and has proved to add value to the discourse around the characterization, management and design of urban acoustic environments [16–23].

In this study we focus on London, UK. The lockdown measures implemented in the UK to contain the spread of the SARS-CoV-2 virus were not particularly strict if compared with other countries; these came into force on the 26<sup>th</sup> of March 2020 and overall required for people to stay home and only leave their place of residence for limited purposes (e.g., shopping for basic necessities as infrequently as possible; one form of exercise a day, for example a run, walk, or cycle - alone or with members of the same household; going to work if working from home not possible) [24].

Taking advantage of short-term acoustic measurements carried out in 2019, before the implementation of the lockdown measures related to COVID-19, a number of urban locations were selected in London where data were available and measurements were performed again according to the same protocols to assess the extent of sound levels variation achieved at each site. The two scenarios (i.e., pre-lockdown and during-lockdown) are then compared.

The aims of this study are: (1) to investigate the potential of the containment measures to affect the urban acoustic environment at local level, rather than city scale and consider whether the observed changes are likely to be perceptually relevant; (2) to investigate whether the implementation of a nation-wide policy (i.e., location-independent) of lockdown will result in different changes depending on context (i.e., different urban scenarios).

While dramatic for so many aspects, this global public health emergency and the consequent containment measures implemented around the world, offers a unique opportunity to gather information on the actual "background" noise of the city.

## 2 Materials and methods

### 2.1 Site selection

This work relies on a case study in London; the UK capital with approximately 8.9M inhabitants, represents a big-sized city in the European panorama and can possibly be taken as a reference also for other western industrialized countries, where it seems fair to assume significant changes will be experienced (compared to rural settings,

for instance). The reason for studying several locations in London is testing whether a single containment policy (*i.e.*, lockdown implemented universally across the whole UK territory) will eventually result in different outcomes in terms of acoustic environment variation. A brief description of the locations selected is reported in Table 1. The rationale for site selection was covering a relatively broad range of open public spaces where anthropic sources are likely to be relevant (*e.g.*, urban parks, squares, commercial streets, etc.).

**Table 1:** The 11 locations included in the London measurements campaign. Photos are from Google Street View

ID	Location	Description	Dominant sound source(s) in typical condition	Picture
CAM	Camden Town	Exit/entrance to the underground train station	Traffic noise and music	
EUS	Euston Tap	Public transport interchange	Traffic noise	
MAR	Marchmont Community Garden	Pocket park	No dominant sounds	
PAN	St Pancras Lock	Canal walk by a canal lock, mostly green	People talking, children at play and a waterfall	
RPF	Regent's Park Broadwalk	Walk in a large park	Birdsong and people talking	
RPJ	Regent's Park Japanese Garden	A garden within a large park	Waterfall	

ID	Location	Description	Dominant sound source(s) in typical condition	Picture
RUS	Russell Square	Square, mostly green	Fountain, people talking, traffic noise	
SPC	St. Paul's Churchyard	Cathedral's churchyard	Traffic noise and people talking	
SPR	St. Paul's Paternoster Row	Small enclosed square, paved	Traffic noise and people talking	
TAT	Tate Modern	Waterfront, mostly paved	People talking and music	
TOR	Torrington Square	Square, paved	Traffic noise and people talking	

## 2.2 Acoustic measurements

The protocols for data collection for the pre-lockdown situation (Spring 2019) were replicated during the lockdown situation (Spring 2020). The database of short-term acoustic measurements for the pre-lockdown situation in London was provided by the Soundscape Indices (SSID) project [25]. For the cases selected for this study, the database consists of a set of 620 approximately thirty-second binaural recordings (temporal resolution 125 ms) performed at 11 locations; the number of recordings per location varied between 32 and 83. The procedure and equipment for the recordings are described extensively in Ref. [26], as they were part of a larger international soundscape survey campaign. In general, at each location binaural measurements were performed by an operator with a calibrated portable recorder (SQobold, HEAD acoustics GmbH) with head-mounted microphones (BHS II, HEAD

acoustics GmbH) during weekdays' day-time, across 1-4 sessions in different days, each lasting 3-5 hours. The same procedure was repeated by an operator during the lockdown period. In this case the database consists of a set of 481 thirty-second binaural recordings performed at the same 11 locations, with the number of recordings per location ranging between 27 and 80. When repeating during Spring 2020 the binaural recordings that had been performed during Spring 2019, it was ensured that the measurements were restricted to the same times (measurements would not happen outside the slot 10:00am-05:00pm) and to weekdays (avoiding weekends and bank holidays), so that this potential source of uncertainty could be contained. Measurements during the lockdown situation were performed safely by a single researcher on site acting in compliance with the recommendations of the UK Government about social distancing.

## 2.3 Data analysis

From the binaural recordings datasets (both the 2019 and 2020 series), the following acoustic parameters were computed for the left and right channels and the arithmetic average was presented:  $L_{Aeq}$ ,  $L_{A10}$ ,  $L_{A90}$ . There is still no clear consensus on how to merge binaural psychoacoustic readings into single values; in this case an arithmetic average was deemed to be acceptable as the interaural level difference was typically very small (less than 1 dB) [27].

The same procedure was followed for the psychoacoustic metrics of Loudness ( $N_5$ , sone) and Sharpness (S, acum). All parameters were computed using the Artemis Suite software (v. 11.5, HEAD acoustics GmbH). Loudness was calculated according to the ISO 5321 standard for time-varying sounds, in a free-field, with the remaining analysis options left to their default [28]. As recommended by the standard, in order to avoid the under-estimation of evaluated loudness which is seen when using the arithmetic average of the loudness curve, the  $N_5$  value (the 5% percentile value of the time-dependent loudness curve) is used as the single value of loudness. Sharpness was calculated according to DIN 45692, in a free-field, with the remaining analysis options left to their default [29]. It was decided to include psychoacoustic parameters as they can often provide more nuances about the perception of the acoustic environment by people, as well as offer more insights into spectral features that could reflect changes in sound sources [30, 31]. Considering the necessity of keeping the computational time limited, Loudness and Sharpness were selected, because they have been reported to provide a sensible representation of perceptual aspects [32].

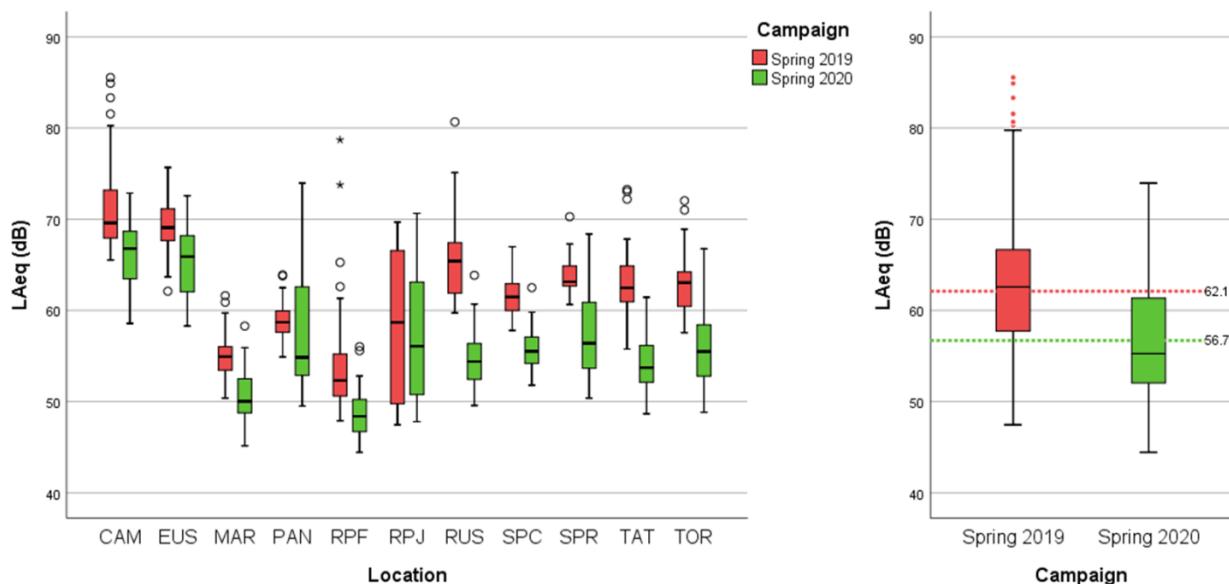
## 3 Results

### 3.1 Effect of lockdown measures on acoustic and psychoacoustic metrics

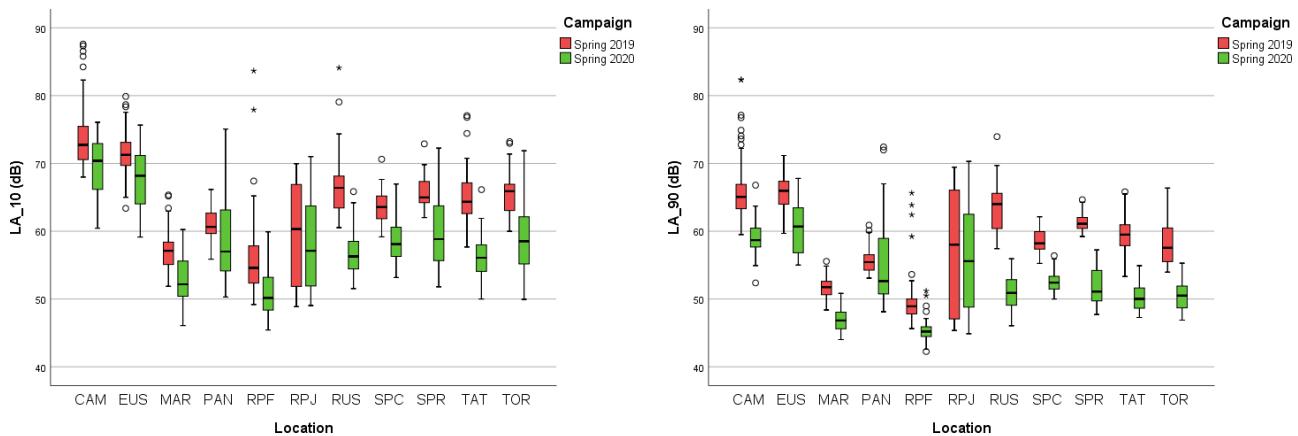
The first aim of this study is investigating what is the effect (mainly in terms of sound levels reduction), at a small scale, of the implementation of lockdown measures in London. Figure 1 shows the distributions of  $L_{Aeq}$  values of 30-second recordings at the eleven locations in London for the Spring 2019 (pre-lockdown) and Spring 2020 (during lockdown) measurements campaigns. The highest mean values for both campaigns are in Camden Town (71.5 dB, 2019; 66.3 dB, 2020) and Euston Tap (69.3 dB, 2019; 65.4 dB, 2020); in the comparison, they show a mean sound

level reduction of 5.1 and 3.9 dB, respectively. These are sites in Central London on arterial roads where the acoustic environment is dominated by road traffic; they are in the immediate proximity of public transport stops, with relatively high number of buses in transit, since bus services timetables underwent little variation during the lockdown (in spite of traveling basically without passengers). So the sound level reduction is mostly due to the lack of private traffic. On the other end of the range, the sites with the lowest mean values for both the pre-lockdown and during-lockdown series were Regent's Park Broadwalk (53.9 dB, 2019; 48.7 dB, 2020) and Marchmont Community Garden (54.9 dB, 2019; 50.7 dB, 2020); these two sites are very different: the former is a large urban park, the latter a small pocket park embedded in the urban fabric of the Bloomsbury area. They are both characterized by an absence of road traffic noise. The sites where the smallest average sound level reductions were observed are Regent's Park Japanese Garden (-1.2 dB between 2019 and 2020) and St Pancras Lock (-1.5 dB between 2019 and 2020): the former is located in the middle of Regent's Park and its acoustic environment is dominated by an artificial waterfall producing a relatively loud sound that masks most other sources, thus the level reduction most likely reflects the absence of visitors; the latter is a canal walk also dominated by the sound of a water feature. The sites with the largest average reductions in sound levels were Russell Square (-10.7 dB between 2019 and 2020) and Tate Modern (-8.8 dB between 2019 and 2020); the acoustic environment in Russell Square is a mix of road traffic noise, a water fountain which features prominently in the centre of the park, and human sounds (e.g., pedestrians in transit, people sitting on benches, etc.), the main uses of the area relate to offices, higher education and universities, and tourism and hospitality; Tate Modern is one of the most iconic art galleries and tourist attractions in London, and its outdoor space is a pedestrians-only area facing the river Thames. The drop in sound level in Russell Square may primarily be a result of the water fountain near the measurement location being turned off during the lockdown, however both locations have seen a dramatic drop in human activities and associated sound sources because of the lockdown policy.

Figures 2 and 3 report the distributions of the  $L_{A10}$  (related to sound events) and  $L_{A90}$  (related to background noise levels) values of the 30-second recordings at the eleven locations in London for the Spring 2019 (pre-lockdown) and Spring 2020 (during lockdown) scenarios. They show identical patterns as per the  $L_{Aeq}$  values for both absolute mean levels and mean sound levels reductions between pre- and during-lockdown. The biggest average  $L_{A10}$  reduction was in Russell Square (-9.9 dB between



**Figure 1:** On the left: Sound levels distributions at the 11 London locations (for Location IDs, see Table 1) before and during the lockdown measures implementation; on the right: Sound levels distributions (aggregated across locations) and corresponding mean values before and during the lockdown measures implementation



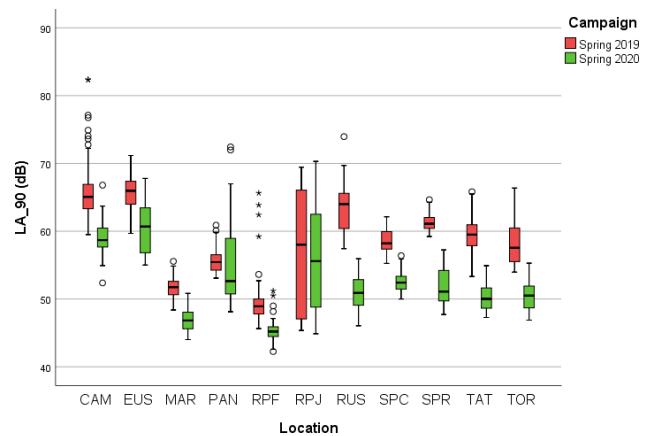
**Figure 2:** Sound levels distributions (10th percentile) at the 11 London locations (for Location IDs, see Table 1) before and during the lockdown measures implementation

2019 and 2020), whilst the smallest variation was in Regent's Park Japanese Garden ( $-1.2$  dB between 2019 and 2020). Similarly, the biggest  $L_{A90}$  reduction was in Russell Square ( $-12.3$  dB between 2019 and 2020), while the smallest variations were in Regent's Park Japanese Garden and St Pancras Lock, with only  $-0.5$  dB of difference from 2019 to 2020 for both, confirming that the background levels are basically unchanged at those locations.

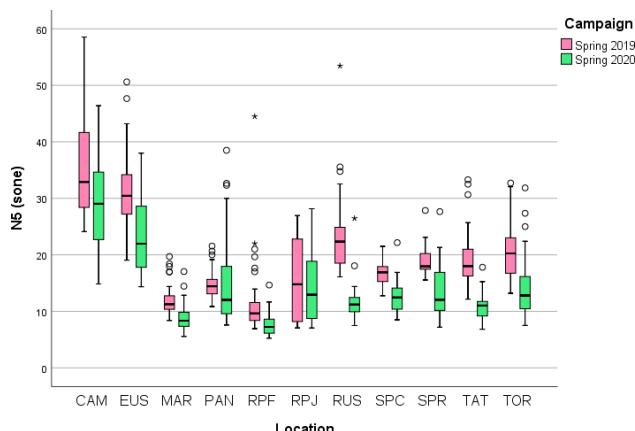
The Loudness ( $N_5$ ) values distributions in Figure 4, aligned with the sound levels representations, show a similar trend: biggest reductions in Camden Town ( $-8.5$  sone between 2019 and 2020) and Russell Square ( $-11.2$  sone be-

tween 2019 and 2020), smallest (almost no) reduction in St Pancras Lock ( $-0.7$  sone between 2019 and 2020).

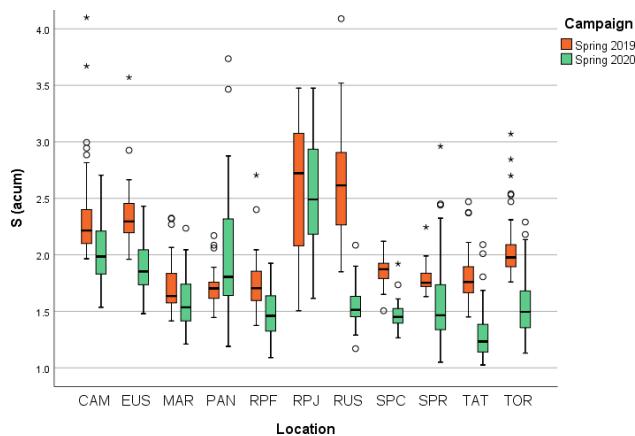
Because Sharpness ( $S$ ) relates to substantially different features of the signal (*i.e.*, spectral structure and amount of energy in the high-frequency range of the spectrum), the values distributions for the 11 locations in the 2019 and 2020 conditions exhibit slightly different behaviours (Figure 5). Sharpness is a measure of the energetic content of a sound in the high frequency range (*i.e.*, the greater the share of high-frequency contribution, the sharper the sound). The locations with the highest sharpness values in the 2019 dataset were Regent's Park



**Figure 3:** Sound levels distributions (90th percentile) at the 11 London locations (for Location IDs, see Table 1) before and during the lockdown measures implementation



**Figure 4:** Loudness distributions at the 11 London locations (for Location IDs, see Table 1) before and during the lockdown measures implementation

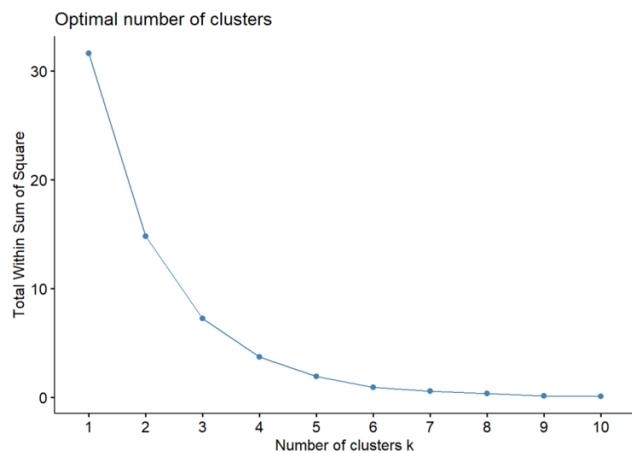


**Figure 5:** Sharpness distributions at the 11 London locations (for Location IDs, see Table 1) before and during the lockdown measures implementation

Japanese Garden (2.60 acum) and Russell Square (2.58 acum), because the acoustic environment of both was affected by a functioning water feature (an artificial waterfall and a fountain, respectively) generating sound in the higher frequency range. Interestingly enough, Russell Square reported the biggest reduction in Sharpness in 2020 (-1.04 acum), because the fountain was not active during the lockdown; while Regent's Park Japanese Garden had almost no variation (only -0.04 acum) as the waterfall kept functioning during the lockdown. An unusual case is represented by St Pancras Lock where the mean Sharpness variation was positive between 2019 and 2020 (+0.26 acum) and had a larger spread of values in 2020; this could be due to the sampling strategy that during lockdown might have given priority to measurement points in the proximity of the water feature.

### 3.2 Effect of the urban setting on sound levels reduction

The second aim of this work was investigating whether the lockdown measures would result in different sound level reductions depending on the urban scenario (and its composition of sound sources). For this purpose, it was decided to define an “Area type” variable that would serve as a proxy for urban (acoustic) context: a  $k$ -means cluster analysis was performed on the mean values of  $L_{Aeq}$ ,  $L_{A10}$ ,  $L_{A90}$ ,  $N_5$  and  $S$  of the 2019 measurements campaign for the 11 locations, after those had been z-score standardized to meet the algorithm criteria. The rationale was clustering urban areas *a priori* based on their “typical” acoustic climate (hence using only data from 2019) and see whether there was an association between area type and noise reduction. The algorithm was set to a three-cluster solution, based on visual inspection of the scree plot as reported in Figure 6 (“elbow method”) [33]. The analysis was conducted in R [34] and figures were produced using the package factoextra [35].

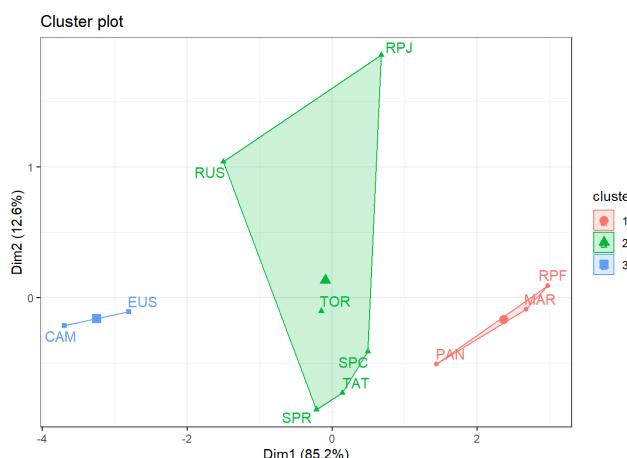


**Figure 6:** Left: “Scree” plot used to identify the optimal number of clusters to use in the  $k$ -means clustering algorithm where an “elbow” can be identified for a three-cluster solution

Figure 7 shows a plot of clustered data based on the two most relevant underlying dimensions for the three-cluster solution. Dimension 1 seems to describe a pattern related to sound level and associated metrics, whilst Dimension 2 is related to Sharpness. This is consistent with previous findings in literature where it was observed that when it comes to categorization and classification of urban acoustic environments based on objective features, most solutions are reduced to intensity- and spectral-related parameters [36, 37].

**Table 2:** Descriptive statistic of the psychoacoustic metrics for the three identified clusters

Cluster	Parameter	Mean values				
		$L_{Aeq}$	$L_{A10}$	$L_{A90}$	$S$	$N_5$
1 – (Quiet areas) [N = 3]	Mean	55.9	58.1	52.4	1.7	12.9
	Std. deviation	2.6	2.5	3.1	0.0	1.8
	Variance	7.0	6.3	9.3	0.0	3.1
2 – (Active areas) [N = 6]	Mean	62.5	64.3	59.6	2.1	18.9
	Std. deviation	2.3	2.5	2.3	0.4	2.5
	Variance	5.3	6.4	5.5	0.1	6.3
3 – (Traffic-dominated areas) [N = 2]	Mean	70.4	72.9	66.1	2.4	34.1
	Std. deviation	1.6	1.9	0.3	0.0	4.4
	Variance	2.4	3.6	0.1	0.0	19.8

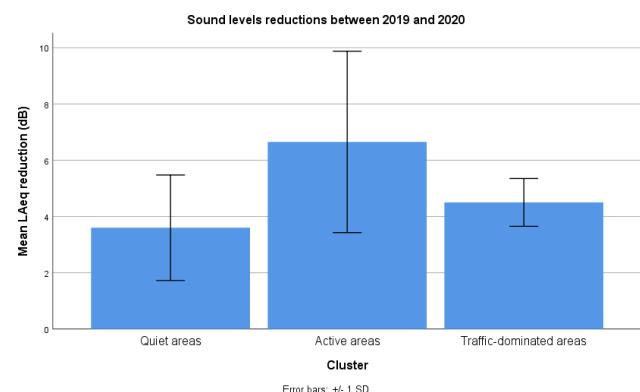


**Figure 7:** Bi-dimensional plot for the three-cluster solution (locations labels as per in Table 1). The clusters have been labelled as: Cluster 1 – Quiet Areas; Cluster 2 – Active areas; Cluster 3 – Traffic-dominated areas

Table 2 shows the basic descriptive statistics of the psychoacoustic features for the 11 locations according to cluster membership; when combining those patterns with information about dominant sound sources as derived from data from Ref. [26], the three clusters could be labelled as: *Traffic-dominated areas* (locations: CAM, EUS), *Active areas* (locations: RPJ, RUS, SPC, SPR, TAT, TOR), and *Quiet areas* (locations: MAR, PAN, RPF). Traffic-dominated areas are on major roads, where road traffic noise is the dominant sound source. Active areas are locations where the human activity (also combined with traffic) is the main contributor to the acoustic environment. Quiet areas are generally parks or areas with greenery that tend to have a relatively low background noise (lack of traffic sources).

When considering the mean  $L_{Aeq}$  reductions between 2019 and 2020 as a function of Area type, it can be observed that they vary across the three clusters, as shown in Fig.

ure 8. The biggest reductions are for Active areas ( $M = 6.6$  dB;  $SD = 3.2$  dB), followed by Traffic-dominated areas ( $M = 4.5$  dB;  $SD = 0.8$  dB), and Quiet areas ( $M = 3.6$  dB;  $SD = 1.9$  dB). A possible explanation for that is that road traffic at the selected locations in London is still sustained to some extent (e.g., circulation of public transport, key workers, etc.), while the most significant variation in Active areas is possibly the very lack of (non-motorized) human activity on site. The locations in the cluster labelled as Quiet areas were already not particularly noisy even before the lockdown, thus the small changes observed are probably once again due to the absence of people.



**Figure 8:** Mean A-weighted equivalent sound level reductions between the pre- and during-lockdown conditions as a function of cluster membership (i.e., Area type)

## 4 Discussion

The soundscape approach, as complementary to noise monitoring techniques, has the potential to reveal de-

tails about the acoustic environments of cities that might otherwise be overlooked with conventional methodologies [38–40]. While no actual perceptual/individual data is discussed here, the protocol for the binaural recordings would be compliant with the Technical Specifications for soundscape data collection ISO/TS 12913-2:2018 [15], thus it can more objectively characterize the acoustic environment as experienced by an average user on site, possibly offering more temporal and spatial accuracy than, for instance, a fixed sensor in a distributed monitoring network. Aggregated data from multiple end-points at city-scale, which many local authorities often rely on, might inform policy from a public health perspective, but it says little about local experience and does not differentiate between contexts, which could instead be relevant for other dimensions of well-being and quality of life [41–43]. The advantage of such approach is that it can also give insights into how the use of open public space has changed during the COVID-19 period [44]. It is worth noting that for this specific study, the set of metrics related to sound levels still plays an important role in characterizing the observed effects of the lockdown measures on the urban acoustic environment, so it is important that such dB-based parameters are taken into account and more efforts are deployed to develop reliable soundscape (*i.e.*, perception-oriented) indices [25, 45].

## 4.1 Sound levels reductions due to the COVID-19 containment measures

The results of this study show that the lockdown and social distancing measures implemented in the whole UK by the national Government produced considerable sound levels reductions on average, but their extent varied depending on urban context (or land use) and pre-existing sound sources which either disappeared or became less prominent in favour of others which were previously more blended into the background noise. The ability to identify and discriminate sound sources in data analysis and track their patterns of variation is a further argument to support the soundscape approach and psychoacoustics more broadly. When looking at the reductions of the level-defining values ( $L_{Aeq}$ ,  $L_{A10}$ ,  $L_{A90}$ ,  $N$ ) and their relationships across the 11 locations, similar patterns emerge. The biggest and smallest variations happen at the same locations for all parameters. This seems to suggest a constant “off-set” in noise, dependent on specific sound sources disappearing; that is, road traffic (even if only partially), water feature, and human sounds. If excluding Regent’s Park Japanese Garden and St Pancras Lock, all other locations

experienced sound levels reductions of more than 3 dB for all parameters, thus making them perceptually noticeable.

On the other hand, when looking at the maximum  $L_{Aeq}$  reduction observed, this was 10.7 dB (Russell Square). It is a dramatic decrease, but when considering that the current lockdown measures are probably one of the most extreme situations London (and other cities around the world) will ever experience, it does raise the question of what is practically achievable in terms of environmental noise reduction in cities. This suggests that infrastructural changes (*e.g.*, change in vehicles fleet, reduction of volumes of car traffic in favour of other types of mobility, etc.) should be implemented to tackle this issue in the future.

## 4.2 Different reductions in different area types

In this paper three “area types” out of the 11 locations sampled in London were identified, corresponding to different patterns of (psycho)acoustic metrics. Separating the land use and urban function from an outline of sound sources is a challenging task as the two are inter-related [46–48]. For this case study, the area types were: traffic-dominated areas, active areas, and quiet areas. Contrary to what one could expect, the biggest effect of sound levels reduction was not observed for traffic-dominated areas, but rather for active areas, where non-motorized human activity was more relevant. Road traffic noise was reduced because of the limitations imposed on the vast majority of drivers, however the traffic volume on the London road network was still far from negligible: ground public transport has been functioning almost regularly during lockdown and the traffic limitations in Central London (*i.e.*, Congestion Charge and Ultra-Low Emission Zone ULEZ) were suspended to ensure critical workers (*e.g.*, medical staff, supply chain and food delivery workers, etc.) would be able to travel round London as easily as possible during the national emergency [49]; therefore, there was also an increase in the number of private vehicle commuting trips that would have been absorbed by public transport under normal circumstances. This was happening also as a consequence of the somewhat conflicting recommendation given by the UK Government to “avoid using public transport where possible” [50]. Eventually the biggest effect in sound levels reduction was observed in active areas because of the lack of people on the street; this was probably also the case for the quiet areas, where natural sounds are still dominant and recreation was encouraged.

## 5 Conclusions

Based on an existing database of calibrated binaural recordings collected during the Spring of 2019 at different locations in London, a comparative study between the acoustic environment recorded then and the acoustic environment at the same locations during the COVID-related containment measures (Spring 2020) was carried out. The two datasets consisted respectively of 620 (Spring 2019) and 481 (Spring 2020) binaural recordings (30 seconds each). More specifically, the main conclusions of this study are:

- Considering the 11 sampled locations in London with 30-second binaural recordings, an average reduction of 5.4 dB ( $L_{Aeq}$ ) was observed on the whole dataset, with a minimum average reduction of 1.2 dB and a maximum average reduction of 10.7 dB. For the other parameters, the average reductions between 2019 and 2020 were:  $L_{A10} = 5.3$  dB;  $L_{A90} = 6.0$  dB;  $N_5 = 5.6$  sone;  $S = 0.34$  acum.
- Sound levels reductions between Spring 2019 and Spring 2020 (lockdown) varied as a function of urban context, with active areas being affected the most (-6.6 dB on average), followed by traffic-dominated areas (-4.5 dB on average) and finally quiet areas (-3.6 dB on average).

As the multi-faceted consequences of the COVID-19 crisis unravel, it is also important to acknowledge that changes are happening at different scales. Because the improvement in terms of environmental noise pollution has been a positive unintended effect of the lockdown measures in many cities, planning for post-COVID scenarios is needed to make sure that sound levels do not go straight back to normal (or even worse) as soon as containments measures are relaxed. A debate in both academia and practice should be encouraged about possible ways to capitalize on this enhanced acoustic quality of urban spaces. The general outcome is that there was a considerable reduction of sound levels at all locations, suggesting that this variation might be common also to other areas of the city (and potentially other urban areas in UK) and the extent of this reduction is such that it would definitely be noticed by a user/listener in context (*i.e.*, perceptually relevant). Future work should indeed take into account perceptual aspects related to urban acoustic environments experienced under social distancing requirements and also looking at cities of different sizes. On the other hand, this study also showed that even with such drastic limitations of human activity, the maximum sound level reduction observed across the

range of sampled sites was still in the region of 10 dB, suggesting that to reduce noise further, different actions (*e.g.*, reduction of volumes of traffic) would need to be implemented to plan healthier and more supportive urban acoustic environments.

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