Applied Acoustics 183 (2021) 108305

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Indoor soundscapes at home during the COVID-19 lockdown in London – Part I: Associations between the perception of the acoustic environment, occupants activity and well-being

Simone Torresin [a,b,*], Rossano Albatici [a], Francesco Aletta [c], Francesco Babich [b], Tin Oberman [c], Agnieszka Elzbieta Stawinoga [d], Jian Kang [c]

[a] Department of Civil Environmental and Mechanical Engineering, University of Trento, Italy
[b] Institute for Renewable Energy, Eurac Research, Bozen/Bolzano, Italy
[c] UCL Institute for Environmental Design and Engineering, The Bartlett, University College London, London, UK
[d] Management and Committees, Eurac Research, Bozen/Bolzano, Italy

ARTICLE INFO

Article history:
Received 21 April 2021
Received in revised form 8 June 2021
Accepted 11 July 2021

Keywords:
Indoor soundscape
Indoor environmental quality
Acoustic design
Well-being
COVID-19
WFH

ABSTRACT

Since the outbreak of the COVID-19 pandemic, as a result of the adoption of worldwide lockdown measures, the home environment has become the place where all the daily activities are taking place for many people. In these changed social and acoustical contexts, we wanted to evaluate the perception of the indoor acoustic environment in relation to traditional and new activities performed at home, i.e., relaxation, and working from home (WFH). Taking London as a case study, the present paper presents the results of an online survey administered to 464 home workers in January 2021. The survey utilized a previously developed model for the assessment of indoor soundscapes to describe the affective responses to the acoustic environments in a perceptual space defined by *comfort* (i.e. how comfortable or annoying the environment was judged) and *content* (i.e., how saturated the environment is with events and sounds) dimensions. A mixed-method approach was adopted to reinforce result validity by triangulating data from questionnaires and spontaneous descriptions given by participants. In this first part of the study, the main objectives were: (1) evaluating differences in soundscape evaluation, in terms of *comfort* and *content* dimensions, based on the activity performed at home, (2) identifying appropriate conditions for WFH and relaxation, and (3) investigating associations between psychological well-being and indoor soundscapes. The results showed that the environments were perceived as more comfortable and slightly fuller of *content* when rated in relation to relaxation than for WFH, thus suggesting a stricter evaluation of the acoustic environment in the latter case. As regards the second objective, spaces that were more appropriate for relaxation had high *comfort*, whereas spaces appropriate for WFH resulted more private and under control, i.e. with high *comfort* and low *content* scores. Lastly, better psychological well-being was associated with more comfortable soundscapes, both for WFH ($r_s = 0.346$, $p < .0005$), and relaxation ($r_s = 0.353$, $p < .0005$), and with lower *content* while WFH ($r_s = -0.133$, $p = .004$). The discussion points out the need of considering the implications of changed working patterns to rethink the design of soundscapes in residential buildings, also in relation to potential well-being outcomes that will be further investigated in the Part II of the study.

1. Introduction

Since the global outbreak of the SARS-CoV-2 virus (COVID-19 disease), severe lockdown measures have been adopted by governments all around the world to prevent the spread of the virus. Stay-at-home mandates have transformed houses into places where to spend the entire day while working, home-schooling, taking care of families, nourishing, training, socializing, and finally resting.

Several studies have been reporting on the changed outdoor and indoor acoustic contexts during the COVID-19 pandemic and on the impacts of this unprecedented acoustic scenario on people. A general reduction of outdoor noise levels has been observed due to contingency measures in several countries [1–8]. In terms of noise annoyance, studies have showed a persistence [9] or

* Corresponding author at: Department of Civil Environmental and Mechanical Engineering, University of Trento, Italy.
E-mail address: simone.torresin@eurac.edu (S. Torresin).

https://doi.org/10.1016/j.apacoust.2021.108305
0003-682X/

reduction [10–12] in annoyance due to outdoor noise, a reduction [11], persistence [10] or increase [9,12] in annoyance towards neighbourś noise, and an increase in annoyance due to noise from onés own dwelling [9,10] during the lockdown compared to before.

In this sudden acceleration towards remote working and schooling, houses had to host new social functions and to face a new set of challenges, making even more evident now than before the importance of housing to the physical and mental health of building occupants [13]. The indoor soundscape literature has recently stressed the opportunity given by acoustic design to improve health, well-being, and quality of life of building occupants through a perception-based approach, thus making a step forward compared to a mere noise annoyance reduction [14]. Being the perception of the acoustic environment (i.e. the soundscape [15]) highly context dependent, the question is thus how the acoustic conditions at home can support home activities in this changed pandemic context, while ensuring the well-being of the occupants.

With the purpose to address this question, an online survey has been conducted targeting home workers living in UK (London) and Italy. Differently from other studies that have focused on the noise – annoyance binomial during the pandemic (i.e., *how much were you annoyed by these noise sources?*), the present survey has been designed from a soundscape perspective in order to explore both positive and negative effects of sounds and noises, depending on the specific task performed at home during the lockdown. Questions about working typology, housing features, person-related traits, living and urban contexts have been complemented with questions from ISO soundscape standards [16], tailored to address the peculiarities of indoor residential spaces [17]. In particular, the survey evaluated the perceived affective quality of the acoustic environment through an indoor soundscape assessment model developed by the authors [18], building on the existing outdoor soundscape model by Axelsson et al. [19]. The model allows to describe the emotional response to indoor acoustic environments in a two-dimensional perceptual space (cfr. Fig. 1) where the orthogonal axes are *comfort* (an annoying – comfortable continuum) and *content* (an empty - full of content continuum). In the previous laboratory investigation [18] the two dimensions were found to explain together 83% of the total variance in the assessment made by test participants of 20 indoor acoustic environments on 97 attribute rating scales. According to this perceptual space, engaging indoor soundscapes are both comfortable and full of content, detached soundscapes are both annoying and empty, intrusive and uncontrolled soundscapes are annoying and full of content, and finally private and controlled indoor soundscapes are both comfortable and empty.

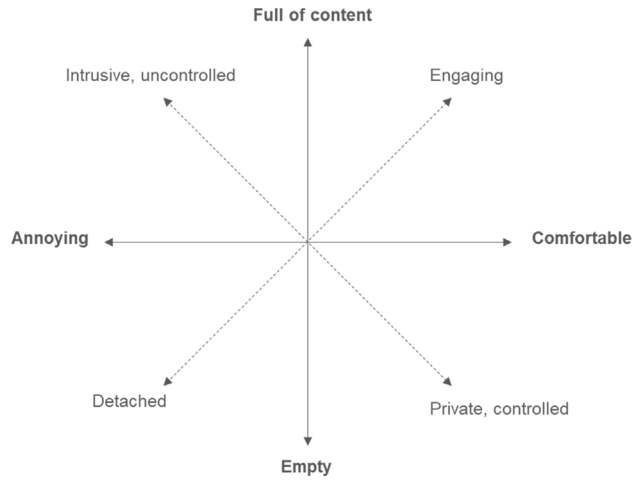


Fig. 1. Model of affective response to indoor residential acoustic environments from [18]

The present survey constitutes the first field application of the model to evaluate the emotional reaction to the residential acoustic environment in relation to two specific activities performed at home during the lockdown, namely working from home (hereinafter WFH) and relaxing. Results are presented in two intertwined papers. In Part I, the main goals are to explore differences in the *comfort*/*content* rating of the built environment based on the performed activity, and to identify *comfort*/*content* combinations characterizing an acoustic environment perceived as appropriate for WFH and relaxing.

Moreover, we wanted to investigate the relationship between the perceived acoustic environment at home, described through the coordinates on the two *comfort* and *content* dimensions, and the psychological well-being of building occupants. Evidence on effects of sound exposure on quality of life, well-being and mental health is far from being conclusive due to a lack of longitudinal and interventional studies [20,21]. Previous research in outdoor soundscape literature suggested a positive association between positively perceived soundscapes and faster stress-recovery processes, better self-reported health conditions and higher self-reported well-being [21–24]. Poor noise conditions at home can result in increased prevalence of mental health symptoms [25] and impede the acquisition of psycho-social benefits from home [26]. For instance, traffic noise was found to cause emotional disorders and hyperactivity in children [20]. Spending the lockdown in houses with poor indoor environmental conditions (including acoustic discomfort) was found to be associated with a higher risk of moderate–severe and severe depressive symptoms [27]. In indoor spaces, natural sounds coming from the outdoor environment and unmasked by the drop in anthropogenic noise in cities during the lockdown [28–30] might provide improved cognitive performance and stress recovery [31], despites findings of restorative effects of natural sounds being still inconclusive [32]. Listening to music can be a coping strategy for dealing with stress, can involve emotion regulation and provide psychotherapeutic effects [33]. Indoor human sounds from family members can also have a restorative potential and activate cerebral functioning [34], but can also result highly disrupting when WFH during a pandemic [9]. In a study with university students during the COVID-19 lockdown, higher exposure to mechanical sounds was found to be associated with a lower restorative quality of home and a worse self-rated health, whereas nature sounds were positively associated with restorative quality, and in turn with better self-rated health [35]. Positive and negative outcomes from the acoustic environment might depend on the type of activity carried out at home [17] and on the degree of interference with the task with which people are engaged [36]. As such, associations between the two soundscape dimensions based on the perceived affective quality responses (*comfort* and *content*) and the subjective psychological well-being are investigated in relation to the two considered home activities, i.e. working and relaxing at home.

In the following, the analysis will focus on data gathered from the London sample. Research questions addressed in this paper include:

1. RQ1. Is there a difference in the evaluation of a space depending on the activity in which the occupant is engaged?
2. RQ2. What are the *comfort-content* combinations, if any, that describe an environment being appropriate for WFH and relaxing at home?
3. RQ3. Are *comfort* and *content* related to occupanťs psychological well-being?

2. Methods

2.1. Participants

An online survey was administered to adult participants via Prolific participant pool [37,38] on 18 and 19 January 2021, while London was in a lockdown condition [39]. Potential participants were filtered through the following prescreening criteria available in the platform: age (18 – 65 years old), no self-reported hearing difficulties, indicating London (UK) as area of residence, and WFH during the COVID-19 lockdown. After excluding 9 participants that failed an attention check included in the survey (cf. Q26 – Appendix A), 464 participants (181 males, 282 females, 1 other; mean age: 32.2 years; SD: 9.1 years) were considered for the data analysis. The survey took on average 29 min to complete and participants were offered a small monetary compensation as a token of appreciation for their time. The study was approved via the UCL IEDE Ethics departmental low-risk procedure on November 26th, 2020.

2.2. Questionnaire design

Study data from the online survey were collected and managed using REDCap electronic data capture tools hosted at University College London (UCL) [40,41]. An excerpt of the questionnaire used for the online survey is provided in Appendix A where only the questions that are relevant to the present study (Part I and Part II) have been reported. The questionnaire included both closed- and open-ended questions. Given the complex and multi-faceted nature of soundscape investigations, a mixed-method approach was adopted [42] by complementing quantitative data from closed-ended questions with data from open-ended questions, according to the principle of triangulation commonly applied in behavioral and social sciences [43]. As depicted in Fig. 2, the questionnaire was made of an introductory section including the information sheet and consent form and five more sections focusing on: (1) the WFH activity; (2) leisure activities performed at home; (3) housing features; (4) the urban context; and (5) person-related characteristics.

In the first section, participants were asked to provide information about the type of work performed at home (Q1), by rating the importance of several activities (e.g., online meetings, reading, thinking/creative thinking). The frequency of headphone use when WFH was assessed in Q2. Participants had then to indicate a room that could be relevant for their WFH activity (Q3), and to describe the dominance of several categories of sounds as perceived in this room (Q4). The question was adapted from the ISO/TS 12913-2 (Method A) [16], by including the following sound sources relevant for indoor soundscapes: traffic noise, other noise from outside (e.g. sirens, construction, industry, loading of goods), natural sounds, human beings outside, other human beings present at home, neighbours, building services at home, building services of neighbours and common areas, and music or TV played by participants themselves. The type of window view from the room where WFH was assessed in Q5, by rating the dominance of vegetation, sky and other buildings when looking outside. A spontaneous description of positive and negative effects of sound exposure while WFH was collected through an open-ended question (Q6). This was done in order not to constraint answers into pre-defined categories and to collect information about aspects that might have not been covered by the researchers in the rest of the questionnaire. The appropriateness of the surrounding sound environment for WFH was evaluated in Q7, by adapting the corresponding question included in the ISO/TS 12913-2 (Method A) [16]. Perceived affective quality responses were collected in Q8. This part was adapted from the ISO/TS 12913–2 (Method A) [16], by using the eight attributes derived in [18] (i.e., Comfortable; Intrusive, uncontrolled; Engaging; Empty; Private, controlled; Annoying; Full of content; Detached).

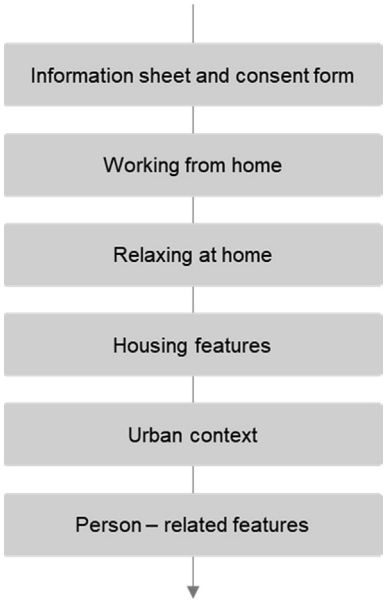


Fig. 2. Schematic representation of the main sections composing the questionnaire. Questions are listed in Appendix A.

Similarly, in the second section, participants were asked to indicate a room relevant for relaxation activities (Q9), which could therefore be different from the one used for WFH, and to answer consequently about sounds heard (Q10), the components of view from window (Q11), the positive and negative effects on relaxation (Q12), the appropriateness of the sound environment (Q13), and the affective response to the acoustic environment while relaxing (Q14). Open-ended questions investigated the impact on several leisure activities. In the present paper, only responses related to watching TV, reading, and listening to music will be considered.

In the third section, information about the housing context were collected and specifically on: the ownership status (Q15), the house size (Q16), the house typology (Q17, i.e. detached single family, semi-detached or terraced house, apartment block), room exposure to quiet or noisy areas (Q18), other people at home (Q19, e.g., roommates, children), the number of people living at home (Q20), and the building service typologies for ventilation (Q21), heating (Q22), and cooling (Q23).

The fourth section was related to the urban context. Participants were asked to provide their postcode (Q24) and to describe the urban area where they live (Q25, i.e. urban, suburban, or rural).

In the last section, person-related information was collected. Noise sensitivity was assessed through a reduced number of items (Q26) extracted from the Weinstein's Noise Sensitivity Scale [44], which is consistent in providing a user profile similar to that of the full scale [45]. Subjective psychological well-being was evaluated through the WHO-5 (Q27) well-being index [46]. The WHO-5 is based on five questions having as time frame the previous two weeks and it has been found to have adequate validity in screening for depression [46]. Lastly, demographic information about age (Q28) and gender (Q29) were collected.

2.3. Data analysis

Statistical analyses were run in IBM SPSS Statistics 26 [47] and in R [48], while qualitative analyses have been conducted in NVivo 12 software.

2.3.1. Projection of the perceptual attribute dimensions onto the circumplex model

The scores derived from the assessment of indoor soundscapes on the eight attributes for the two investigated activities, WFH (Q8) and relaxation (Q14), were processed to be represented as points into circumplex models with coordinates for the two dimensions *comfort* and *content*, following the procedure described in ISO/TS 12913–3 [43]: while no standard or technical specifications currently exist for indoor soundscape [49], we felt it would be sensible to process the data by analogy as per the recommendations of Part 3 of the ISO 12913 series [43]. Every data point represents the assessment by one participant, in relation to the activity being investigated. The coordinates for *comfort* and *content* are calculated as:

$$Comfort = (c - a) + \cos 45^{\circ} \cdot (pc - iu) + \cos 45^{\circ} \cdot (en - d)$$

$$Content = (f - em) + \cos 45^{\circ} \cdot (iu - pc) + \cos 45^{\circ} \cdot (en - d)$$

where *a* is annoying, *c* is comfortable, *d* is detached, *em* is empty, *en* is engaging, *f* is full of content, *iu* is intrusive - uncontrolled, and *pc* is private, controlled. The coordinates are divided by $(4+\sqrt{32})$ to scale the resulting values between −1 and +1.

2.3.2. Assessing associations and differences between groups

As assessed by Shapiro-Wilk's test, *content* scores resulted normally distributed, ($p > .05$), while well-being values from the WHO-5 index and *comfort* scores failed to meet normality assumptions ($p < .05$). As such, non-parametric tests were used to analyze data. Associations were assessed through Spearman's rank-order correlation. Kruskal-Wallis tests were run to evaluate differences between independent groups while the Wilcoxon signed-rank test was used to determine whether there was a median difference between paired observations (i.e., responses given by same participants). Please notice that for a Wilcoxon signed-rank test, the median difference is obtained as the median of the differences between the paired values and not as the difference of the medians of the two groups. The statistical significance threshold was set at 0.05.

2.3.3. Qualitative analysis

The material collected by the open-ended questions was coded in NVivo 12 software, organizing the excerpts according to patterns of semantic content via constant comparisons of data [50]. Only verbal descriptors with more than five occurrences have been retained.

3. Results

Frequency distributions were computed to explore categorical and ordinal variables (cf. Fig. 3). The type of work carried out at home was mainly individual, desk based, focused work, whereas online meetings, telephone conversations, reading, and creative thinking were reported as the most relevant activities. Working from home was to a lesser extent characterized by individual focused work away from the desk, by the use of technical equipment and the reception of visitors, clients, or customers (Fig. 3 a). The majority of respondents (73.9%) reported using headphones at least sometimes while WFH (Fig. 3 b). Bedrooms (41.6%) and living rooms (41.6%, also considering open spaces kitchen-living rooms) were the most used spaces where WFH (Fig. 3 c). As shown in Fig. 3 d, relaxation took place in living rooms (62.5%, if also considering open spaces kitchen-living rooms), followed by bedrooms (33.2%). Having in mind the ambiguity of the term 'studio', there is a possibility that while answering to questions Q3 and Q9 both participants living in a 'studio flat' and having a 'separate study space' in their house have answered in this category (cf. Fig. 3 c and d). However, it should be noticed that those data have only be used to derive information about the exposure to a quiet or noisy side in combination with data from Q18, as reported in the following, and therefore this possible misunderstanding had no impact on the following analyses.

The sound environment while WFH and during relaxation was reported to be dominated by music or TV played by the respondents themselves, by sound generated by other human beings present at home, followed by outdoor sounds and neighbours, as detailed in Fig. 3 e-f. The view from windows in rooms employed for working and relaxing was most often dominated by the view of sky and other buildings, and to a lesser extent by vegetation (Fig. 3 g-h). As regards soundscape appropriateness, the sound environment was evaluated as very and perfectly appropriate for working (56.5%) and relaxing (62.2%) by the majority of respondents.

Most participants do not own the house they live in (55.5%, Fig. 3 k) and almost half of the dwellings (47.4%) have a surface area ranging between 40 and 80 m^2 (Fig. 3 l). Semi-detached or terraced houses (42.5%) and apartment blocks (42.5%) were the most common housing typologies (Fig. 3 m). The spaces where people worked and relaxed at home overlooked urban areas described as quiet (respectively, 52.6 and 51.1%) or as noisy (45.9 and 48.3%, 1.5 and 0.6% missing). The majority of respondents lived with someone else but without children (65.7%), followed by those living also with children (22.0%) and by those living alone (12.3%, cf. Fig. 3 n). In most cases the household consisted of two (37.3%) or three (23.7%) people (cf. Fig. 3 o).

As regards the building services, 13.8%, 5.6%, and 3.2% of respondents dwellings were equipped respectively with air-systems for ventilation, cooling and heating (e.g., HVAC systems, mechanical ventilation, air conditioners).

Houses were mainly located in areas described as urban (68.1%, Fig. 3 p). The map of the city of London depicting the residential areas of respondents is reported in Fig. 4 and it shows a good coverage of the city by the survey.

The WHO-5 well-being index averaged 53.7 ± 19.24 (Mean ± SD), with 100 representing the best quality of life. Noise sensitivity index scored on average 64.19 ± 19.25 (Mean ± SD), with higher scores denoting higher sensitivity to noise.

In the following, results related to the three research questions are presented (sections 3.1 – 3.3), with reference to quantitative and qualitative analyses.

3.1. Difference in soundscape evaluation based on the activity

3.1.1. Quantitative analysis

A Wilcoxon signed-rank test was conducted to determine whether there was a median difference in *comfort*, *content,* and perceived soundscape appropriateness when spaces were considered in relation to the two different activities (i.e., working or relaxing). Data in this section are medians unless otherwise stated. There was a significant increase in *comfort*, (median difference: 0.07), $z = 5.895$, $p < .0005$, and *content*, (median difference: 0.06), $z = 6.259$, $p < .0005$, when evaluated for relaxation compared to WFH, while the evaluation of soundscape appropriateness was not significantly different between the two activities, $z = 1.658$, $p = .097$. However, it must be noted that the respondents rated the soundscapes for the rooms most often employed to perform those activities and that the chosen rooms might have been different. As such, the dissimilar characteristics of the rooms (and related acoustic features) employed for working and relaxing might have confounded the observed differences in *comfort* and *content* evaluations.

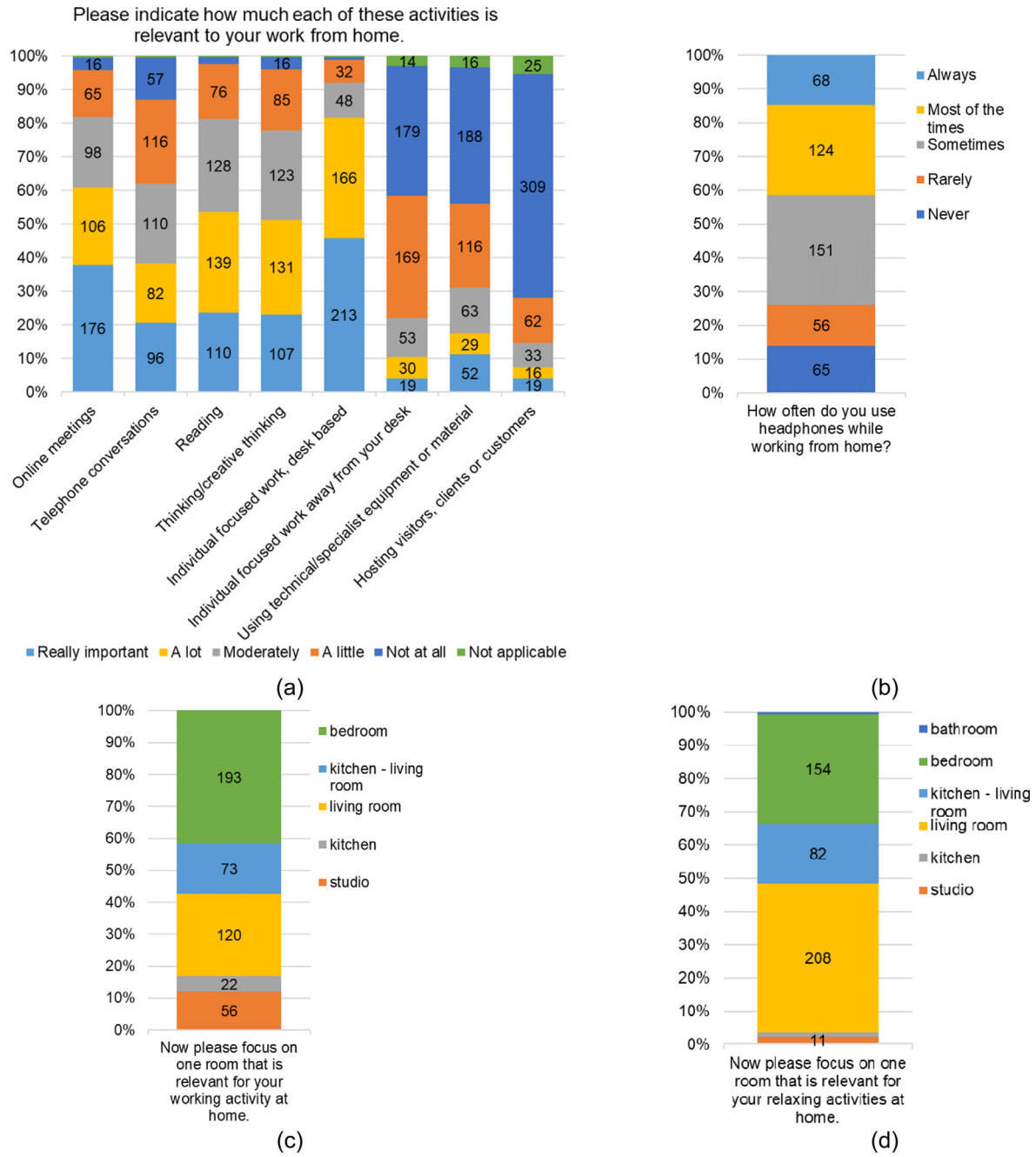
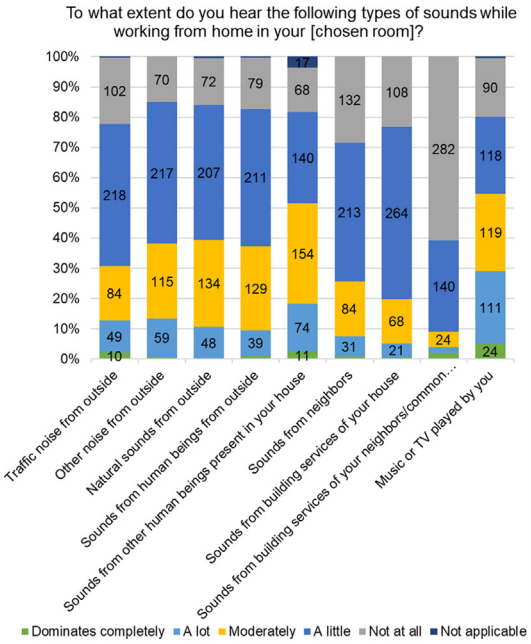


Fig. 3. Absolute and percentage values of responses (N = 464) to: (a) relevance of different activities to WFH (Q1.1 – Q1.8); (b) frequency of headphone use while WFH (Q2); room used for WFH (c - Q3) and for relaxation (d - Q9); perceived dominance of sounds while WFH (e – Q4) and while relaxing (f – Q10); perceived dominance of different components from the window view in the room chosen for WFH (g – Q5) and for relaxation (h – Q11); perceived appropriateness of the sound environment for WFH (i – Q7) and for relaxation (j – Q13); (k) ownership status (Q15); (l) house size (Q16); (m) housing typology (Q17); (n) people living with (recoded from Q19); (o) number of people at home (Q20); (p) type of urban area (Q25). Labels for categories having less than 10 occurrences have been omitted.

Therefore, a further test was run on the subgroup of respondents that chose the same room for both WFH and relaxation (N = 212). Results confirm a significant increase in *comfort* (median difference: 0.07), z = 4.401, p < .0005, and *content* (median difference: 0.03), z = 3.093, p = .002, of the same space when evaluated for relaxation compared to when evaluated for WFH (cf. Fig. 5). Of the 212 participants that selected the same room for both WFH and relaxation, 118 evaluated the environment as more comfortable for relaxing, 67 evaluated the environment as more comfortable for WFH, while 27 expressed no difference in *comfort* evaluation. As regards *content* scores, 110 respondents expressed higher *content* while relaxing, 77 expressed higher *content* while WFH, while 25 respondents expressed no difference. In terms of soundscapes appropriateness, 96 participants expressed no difference, 75 evaluated the sound environment as better for relaxing, whereas 41 respondents evaluated the sound environment as better for working.

3.1.2. Qualitative analysis

Table 1 presents the main themes extracted from the analysis of the questions "*In your view, how is the sound environment currently (positively and negatively) affecting your working activity from*



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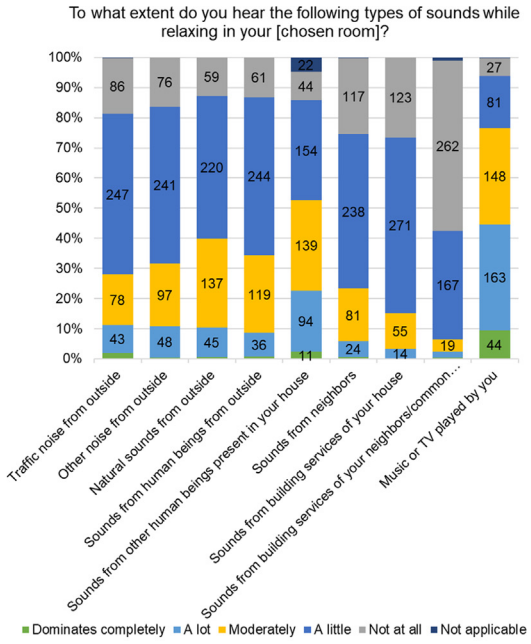

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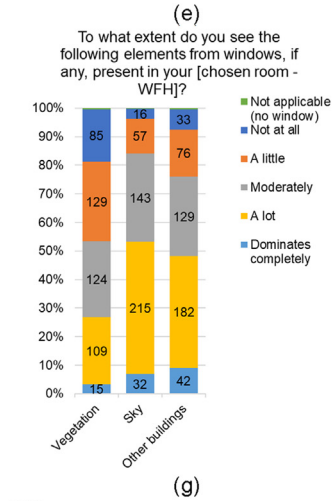

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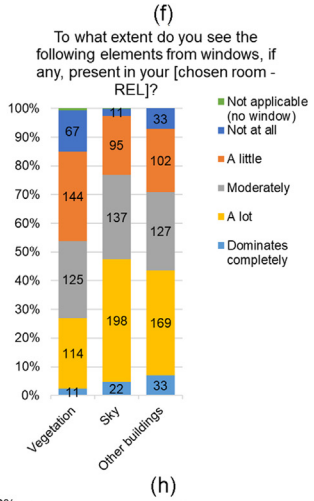

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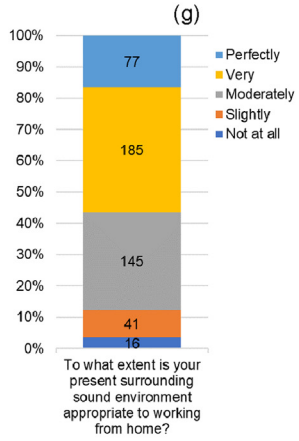

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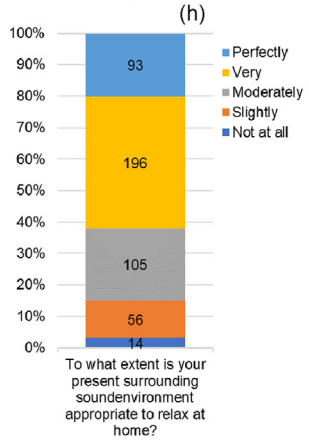

(j)

Fig. 3 (*continued*)

home?" and "*In your view, how is the sound environment currently (positively and negatively) affecting your leisure activities at home? (While watching TV, reading, listening to music)*". While the evaluation of specific sound sources is reported in Part II of the study, here the focus is on general themes that might help confirming and understanding the differences in soundscape evaluation based on the performed activity.

As regards the impact on WFH, participants reported the sound environment often being distracting and disruptive to their work (N = 112). The lack of control over urban noises or the noises from

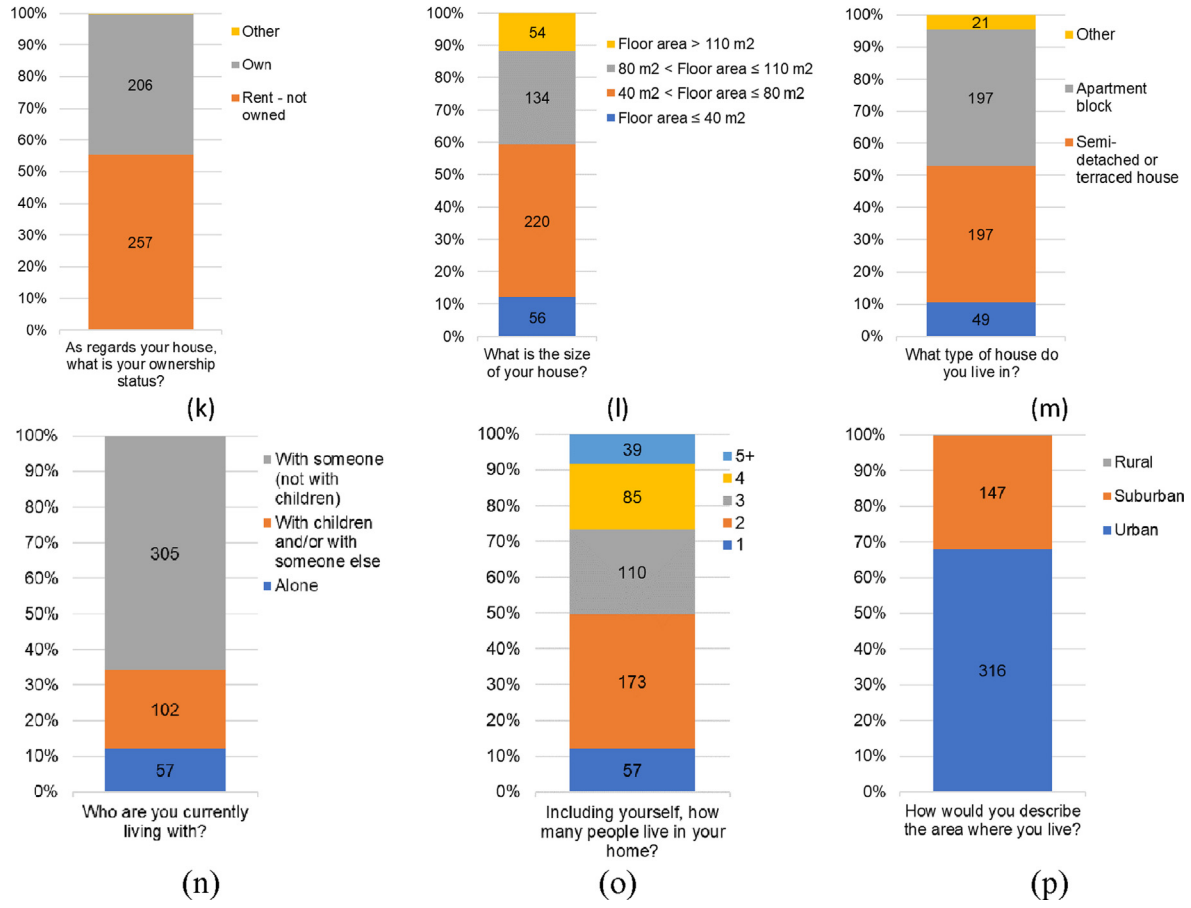

Fig. 3 (*continued*)

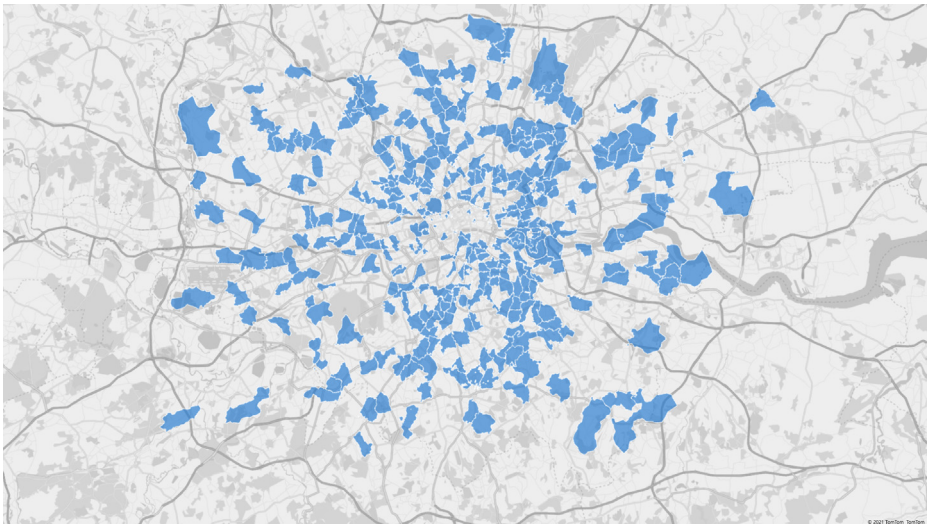

Fig. 4. Area of residence of respondents in London. 3% of postcodes were missing.

neighbours were mentioned as a cause of annoyance and frustration (N = 6). In addition to closing windows (N = 5) and doors (N = 5) because of noise from outside or inside the building, participants resort to listening to music, TV and wearing noise-cancelling headphones (N = 43) to help concentration, provide the wanted background and drown out unwanted sounds. However, podcasts, music and TV played by respondents could also provide further sources of distraction (N = 7). Some of the respondents mentioned they had become accustomed to their surrounding sound environment over time, thus indicating habituation to the acoustic conditions they were exposed to (N = 26). Others could simply "*block out noise*" and isolate themselves while concentrating on the activity

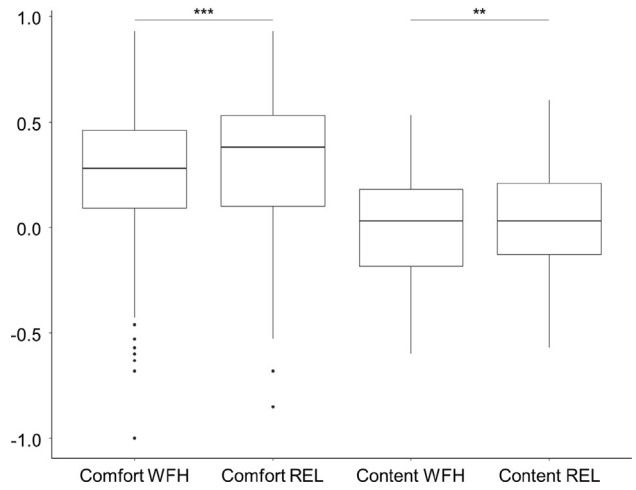

Fig. 5. Boxplots of comfort and content scores by type of the activity performed: working from home (WFH) and relaxation (REL). Data refer to those respondents (N: 212) that chose the same room for both WFH and relaxation. Inside the boxes, the central line is the median value, n.s.: not significant, $^{*}p \leq 0.05$, $^{**}p \leq 0.01$, $^{***}p \leq 0.001$.

Table 1
Main themes extracted from open-ended questions on the impacts of the sound environment on WFH (Q6) and relaxation (Q12).

Working from home (N = 274)	Relaxing at home (N = 282)
Distracting, disrupting (41%)	Music, TV, (noise cancelling) headphones mask other noises (28%)
Hearing sounds is beneficial while working (23%)	Distracting, disrupting (20%)
Music, TV, (noise cancelling) headphones mask other noises (16%)	Noises are present but provide no impact (11%)
Habituation to the sound environment (9%)	Annoying when reading (12%)
Block out noise while concentrating (3%)	Doing it when less noisy (8%)
TV, music played by themselves self-distracting (3%)	Having to increase the volume (7%)
Lack of control (2%)	Hearing sounds is beneficial while relaxing (6%)
Closing windows (2%)	Habituation to the sound environment (6%)
Closing doors (2%)	Closing windows (2%)

they were engaged with (N = 8). Many respondents (N = 62) expressed the beneficial effect of listening to sounds in the background compared to having a completely silent environment, as this could help them feel less lonely, provide some contact with the outside world, relax and feel comforted by the sounds of the family.

Acoustic conditions can be detrimental also for leisure activities performed at home (N = 56). Respondents reported the need to turn up the volume of TV or music because of a noisy environment (N = 20) or to close the windows because of noise from outside (N = 5). Poor acoustic conditions can be problematic when reading, as this activity does not provide any opportunity for masking the background noise (N = 34). However, participants generally reported being less affected while relaxing than during work, because the acoustic environment is usually overpowered by the sound of TV and music (N = 79). Leisure activities are often carried out in the evening when the road traffic is reduced and construction works have stopped, thus resulting in a quieter environment (N = 22). For some of the respondents listening to noise is not an issue while relaxing (N = 32), or they simply got used to it over time (N = 16). The acoustic stimuli can even be beneficial (N = 18), as the sound environment can provide sources of distraction that can be conductive to relaxation, to feeling connected, comforted and less alone, as rendered in the following excerpts:

> *"If I have too much quiet then it gives me too much opportunity to think. So, in order to relax, I need my brain to be occupied with something else."*

> *"The sounds of the street are comforting to me when I relax, I feel at home."*

> *"I like hearing outside noises to keep me feeling connected"*

> *"The noises make you feel like you aren't alone."*

3.2. Comfort-content combinations in relation to soundscape appropriateness

Affective responses to the indoor acoustic environments have been represented in the perceptual space defined by *comfort* and *content* dimensions according to the procedure described in par. 2.3.1. The result is given in Fig. 6, where each data point represents the soundscape assessment by one participant in the room employed for WFH (Fig. 6 a) and for relaxing (Fig. 6 b). In the scatter plot, data points have been grouped by the perceived appropriateness of the acoustic environment to working and relaxing at home (3 categories: not at all & slightly; moderately; very & perfectly). Indoor soundscapes rated as more appropriate for WFH (Kruskal-Wallis, *comfort*: $\chi^2(2) = 195.844$, $p < .0005$; *content*: $\chi^2(2) = 86.827$, $p < .0005$) and for relaxation (Kruskal-Wallis, *comfort*: $\chi^2(2) = 168.699$, $p < .0005$; *content*: $\chi^2(2) = 47.824$, $p < .0005$) were characterized by significantly higher *comfort* and significantly lower *content* scores than those judged as inappropriate for the two activities. Differences in soundscape evaluation across the two activities are investigated in the next section.

3.3. Association between comfort, content and well-being

A Spearman's rank-order correlation was run to assess the relationship between *comfort* scores, *content* scores and psychological well-being. Results showed a statistically significant, moderate positive correlation between *comfort* and well-being for both WFH, $r_s = 0.346$, $p < .0005$, and relaxation, $r_s = 0.353$, $p < .0005$ (cf. Fig. 7 a). Comfortable acoustic environments were associated with higher psychological well-being. As regards content, there was a statistically significant, weak negative correlation between *content* and well-being when soundscape was evaluated for relaxation, $r_s = -0.133$, $p = .004$ (cf. Fig. 7 b). Differently, the relationship between soundscape *content* when WFH and psychological well-being was not statistically significant.

4. Discussion

The study presented the results of an online survey conducted in London with the purpose of exploring the relationships between indoor soundscapes, working and relaxing activities, and psychological well-being. Given the complex and multi-facet problems encountered in soundscape studies, methodological triangulation has been suggested [43] and often applied in previous research to reinforce result validity. In the following, the three main research questions underpinning the study are discussed by triangulating the results from rating scales with those from the qualitative analysis of free format responses.

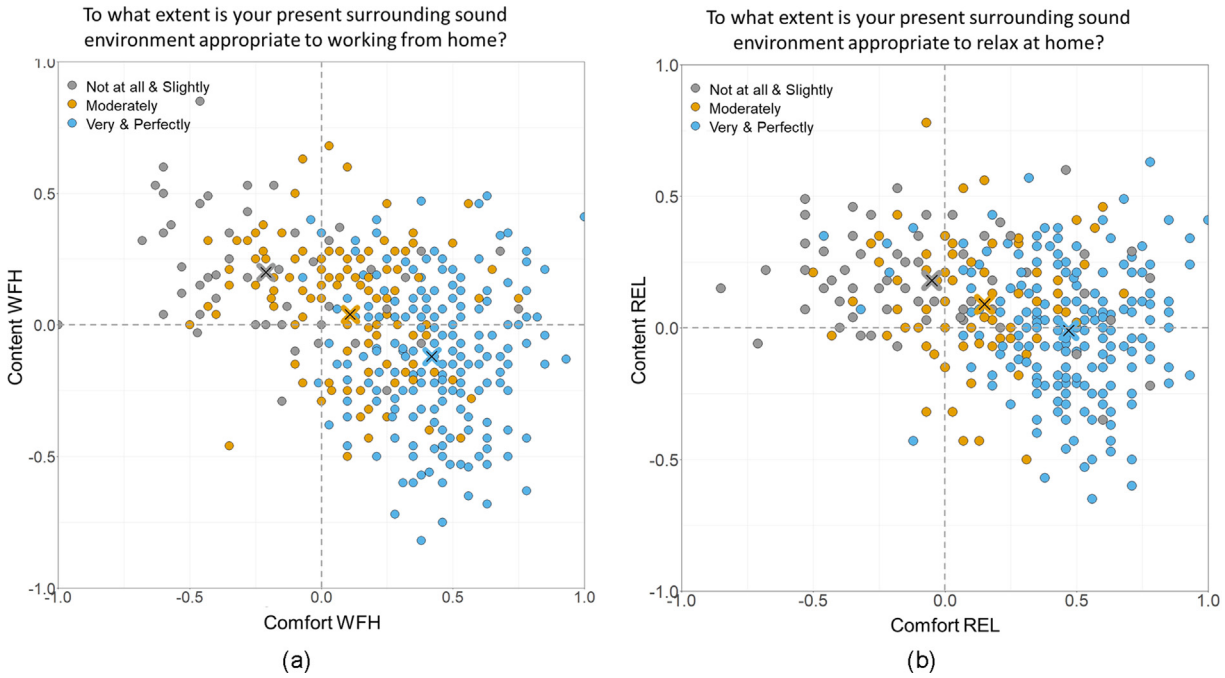

Fig. 6. Projection of the affective responses to the indoor acoustic environment onto the bidimensional circumplex model defined by the *comfort – content* dimensions. Points are grouped by soundscape appropriateness to (a) working and (b) relaxing at home. Crosses depict the centroids of the different groups.

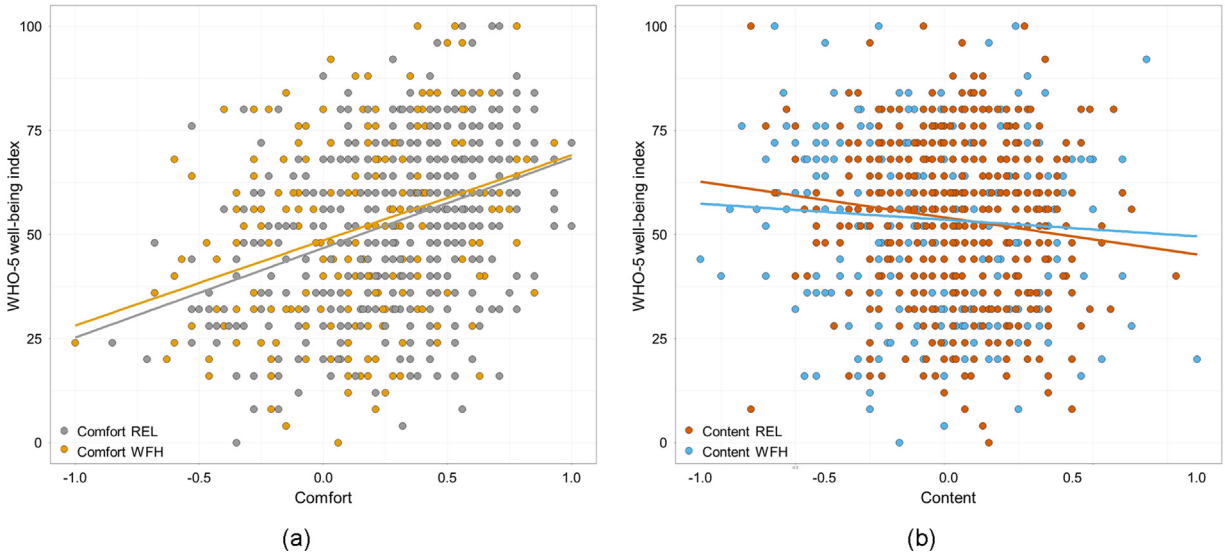

Fig. 7. Scatter plot of *comfort* (a) and *content* (b) scores by psychological well-being. Data are grouped for the two activities in relation to which the soundscape assessment was carried out, i.e. working from home (WFH) and relaxation (REL).

4.1. RQ1. Is there a difference in the evaluation of a space depending on the activity in which the occupant is engaged?

Spaces were rated as more comfortable and more *content*-rich when considered for relaxing than for working from home. The result was confirmed also when selecting the subset of participants that indicated the same room both for relaxation and for WFH. The analysis of open-ended questions can help to shed light on the reasons behind the difference. Despite appropriateness ratings not being significantly different when the environment was evaluated for WFH or relaxation, the analysis of free-format answers showed that the sound environment has been reported to be generally less disruptive during relaxation activities involving listening to music and watching TV compared to WFH and reading. Results revealed that during relaxation, music and TV were reported to overpower the sound environment with sounds over which people had control. Leisure activities were often carried out at quieter times, when the road traffic was reduced, and construction works had ceased. The finding is also consistent with previous studies reporting noise annoyance to be related to the amount of task disruption by noise [17,36,51]. Overall, the analysis suggests that WFH was more heavily affected by the surrounding acoustic environment,

which led to a more stringent assessment of the space in terms of *comfort*. The lack of difference in appropriateness ratings between relaxation and WFH might be due to the fact that the lockdown conditions blurred the distinction between the spaces for relaxation (typically the home environment) and for work (typically the office). During the pandemic, home became both the place where stress and restoration took place, and this might have resulted in participants not being able to distinguish the border between WFH and relaxation and to correctly report on space appropriateness in relation to those two conditions.

While several studies have addressed the impact of noise on valence-related dimensions (mostly annoyance) as a function on the activity at hand [17,36,51–54], this was the first time the impact of acoustic conditions on a *content* dimension has been explored in indoor environments. Higher *content* scores while relaxing are likely due to the saturation of the residential space with music and TV sounds. On the other side, lower *content* scores while WFH might result from being focused on cognitively demanding tasks or from a higher use of headphones during remote working, in both cases leading to a higher isolation to the surrounding sound environment.

4.2. RQ2. What are the comfort-content combinations, if any, that describe an environment being appropriate for WFH and relaxing at home?

Indoor soundscapes perceived as more appropriate for WFH and for relaxation were characterized by higher *comfort* scores and lower *content* scores than those that were rated as inappropriate. By plotting the affective responses to the acoustic environments in the *comfort* – *content* space (cf. Fig. 6), it can be observed that environments perceived as more appropriate for WFH were mainly located in the quadrant of perceived privacy and control over the environment, characterized by high *comfort* and low *content* scores (cf. Fig. 1). This might be partially due to participants reporting lower *content* in relation to WFH than for relaxation, as observed in the previous section. Furthermore, WFH might require soundscapes that are more private and that are perceived as more controlled compared with relaxation. Indeed, indoor soundscapes appropriate to relaxation were more evenly positioned in the half-plane characterized by positive *comfort* scores, thus being either perceived as engaging or as private and under control.

Overall, results suggest that soundscapes characterized by positive valence might be adequate for relaxation, but not necessarily supportive for working if not coupled with low *content*.

4.3. RQ3. Are comfort and content related to occupantś psychological well-being?

The results showed a significant association between soundscapes characterized by positive valence in relation to home working and relaxation (i.e., comfortable, pleasant), and the psychological well-being of respondents (cf. Fig. 7 a), in line with the trends highlighted in the (outdoor) soundscape literature [21–24]. As reported in the literature, access to a high-quality acoustic environment might elicit positive mental states in building occupants, thus fostering psychological resilience and reducing the risks of mental health problems [55]. Moreover, spaces with positive soundscapes can be beneficial for health and well-being by providing psychophysiological recovery from stressors [56]. Conversely, psychological issues might make people more susceptible to acoustic conditions, thus resulting in a more negative perception of the environment and a stronger need for high-quality acoustic conditions [57].

As regards *content*, a weak negative correlation was found between *content* scores and psychological well-being in relation to WFH (cf. Fig. 7 b). The association was not significant when considered for relaxation. Due to the observed need for a private and controlled soundscape for home working, high *content* can result in perceived disturbance and frustration that might induce mental health issues.

4.4. Limitations

Results presented in this study need to be interpreted considering some limitations. Firstly, due to the cross-sectional nature of the study we cannot draw causal claims about the observed associations. The study focused on two out of many activities that are performed at home (i.e., working and relaxing), not addressing scenarios involving people that are external to the house (e.g., temporary visitors), due to the lockdown situation. In a post-pandemic scenario, other factors might affect the perception of the acoustic environment when, for instance, hosting friends at home. While a private and under control soundscape was relevant to WFH, it is likely that a more engaging soundscape would be appropriate for a more convivial situation. Next, the study relied on self-reporting questionnaires, that can result in respondents misunderstanding or not correctly estimating and reporting the objects of investigation. This is particularly true when assessing the emotional response to the acoustic environments by self-reports, as affective qualities might not be accessible by individuals [58]. Furthermore, most of the topics included in the survey have been investigated with structured but not validated questionnaires due to the scant evidence published in the existing literature. Lastly, due to a lack of reference data, it cannot be assumed that the sample is statistically representative of Londoner homeworkers population. However, recruiting participants through an online research platform allowed to avoid some of the limitations of snowball sampling, such as collecting results from participants sharing the same background (e.g., researchers in the acoustic field). Moreover, it can be assumed that people working from home are digitally connected similarly to those engaged with online platforms, in order to being able to perform office work remotely.

5. Conclusions

The paper reported on the results of an online survey conducted on 464 home workers in London in January 2021 during the COVID-19 lockdown. The study constituted a first application of the indoor soundscape model [18] for the assessment of the acoustic environment in relation to two main activities performed at home during the pandemic, i.e. relaxing and home working. Evidence extracted from the analysis of data collected from rating scales and open-ended questions have been combined to increase results validity through methodological triangulation. The main findings are as follows:

(1) Spaces were rated as more comfortable and more *content*-rich when considered for relaxation than for WFH. Despite the non-significant difference in soundscape appropriateness between relaxation and WFH, the more stringent assessment of the same space in terms of *comfort* and the analysis of free format responses suggest that WFH is more affected by the acoustic environment compared to relaxation.
(2) Indoor soundscapes perceived as more appropriate for WFH and for relaxation were characterized by higher *comfort* scores and lower *content* scores than those that were rated as inappropriate. Soundscapes that are appropriate for relax-

ation are characterized by (positive) *comfort* conditions, and can be both full of content (i.e., engaging) or empty (i.e., private and under control). Differently, spaces that are more appropriate to home working are comfortable but also tend to be poor in *content*; i.e., they are perceived as private and under control.

(3) Psychological well-being was positively associated with comfortable soundscapes both in relation to WFH, r_s = 0.346, p < .0005, and relaxation, r_s = 0.353, p < .0005. As regards *content*, a weak negative correlation was found between *content* scores and psychological well-being in relation to WFH, r_s = -0.133, p = .004, but not for relaxation.

Evaluating the affective response to the indoor acoustic environment in the *comfort – content* space helped identifying conditions that were appropriate to home working, compared to leisure activities, reaching a more in-depth knowledge compared to appraisals based on annoyance evaluation. Notably, the new functions dwellings have been called to host since the COVID-19 outbreak, and that will likely last in the post-pandemic era, can make building occupants differently vulnerable to the acoustic conditions at home, and more demanding of high-quality acoustic environments.

In the second part of the study, the influence of acoustical, building, urban, and person-related factors on indoor soundscape perception and well-being will be investigated, thus allowing to explain part of the identified associations between perceived acoustic conditions and occupantś well-being.

Funding

This work was funded by the Chartered Institution of Building Services Engineers (CIBSE) within the project 'Home as a place of rest and work: the ideal indoor soundscape during the Covid-19 pandemic and beyond'. This work was supported by the Programma di cooperazione Interreg V-A Italia-Svizzera 2014–2020, project QAES [ID no. 613474]; and the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme [grant agreement No. 740696].

CRediT authorship contribution statement

Simone Torresin: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Rossano Albatici:** Conceptualization, Writing - review & editing. **Francesco Aletta:** Conceptualization, Methodology, Writing - review & editing. **Francesco Babich:** Conceptualization, Writing - review & editing. **Tin Oberman:** Conceptualization, Writing - review & editing. **Agnieszka Elzbieta Stawinoga:** Formal analysis, Writing - review & editing. **Jian Kang:** Conceptualization, Supervision, Funding acquisition, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank the Department of Innovation, Research and University of the Autonomous Province of Bozen/Bolzano for covering the Open Access publication costs.

Appendix A. – Questionnaire excerpt

ID	Question	Scale	Label
	Working from home		
Q1	"Please indicate how much each of these activities is relevant to your work from home." (Q1.1 Online meetings; Q1.2 Telephone conversations; Q1.3 Reading; Q1.4 Thinking/creative thinking; Q1.5 Individual focused work, desk based; Q1.6 Individual focused work away from your desk; Q1.7 Using technical/ specialist equipment or material; Q1.8 Hosting visitors, clients or customers)	Likert	Not at all (1) – Really important (5); Not applicable (6)
Q2	"How often do you use headphones while working from home?"	Likert	Never (1) – Always (5)
Q3	"Now please focus on one room that is relevant for your working activity at home:"	–	Studio; Kitchen; Living room; Kitchen – living room, Bedroom
Q4	"To what extent do you hear the following types of sounds while working from home in your [*piping: Q3*]?" (Q4.1 Traffic noise from outside - e.g. cars, buses, trains, airplanes; Q4.2 Other noise from outside - e.g. sirens, construction, industry, loading of goods; Q4.3 Natural sounds from outside - e.g., singing birds, flowing water, wind in vegetation; Q4.4 Sounds from human beings from outside - e.g. conversation, laughter, children at play, footsteps; Q4.5 Sounds from other human beings	Likert	Not at all (1) – Dominates completely (5); Not applicable (6)

(*continued on next page*)

Appendix A (*continued*)

ID	Question	Scale	Label
	present in your house - e.g. conversation, music, TV, laughter, children at play, footsteps; Q4.6 Sounds from neighbors - e.g. conversation, music, TV, laughter, children at play, footsteps; Q4.7 Sounds from building services of your house - e.g. heating, cooling, ventilation systems, toilet flushes; Q4.8 Sounds from building services of your neighbours / common areas - e.g. heating, cooling, ventilation systems, let flushes, lift; Q4.9 Music or TV played by you - through headphones or loudspeakers)		
Q5	"To what extent do you see the following elements from windows, if any, present in your [*piping: Q3*]?" (Q5.1 Vegetation; Q5.2 Sky; Q5.3 Other buildings)	Likert	Not at all (1) – Dominates completely (5); Not applicable (no window) (6)
Q6	"In your view, how is the sound environment currently (positively and negatively) affecting your working activity from home? - e.g. heard noises and sounds, building characteristics, urban environment"	–	Text field
Q7	"To what extent is your present surrounding sound environment appropriate to working from home?"	Likert	Not at all (1) – Perfectly (5)
Q8	"For each of the 8 scales below, to what extend do you agree or disagree that the present surrounding sound environment while you are working from home is:" (Q8.1 Comfortable; Q8.2 Intrusive, uncontrolled; Q8.3 Engaging; Q8.4 Empty; Q8.5 Private, controlled; Q8.6 Annoying; Q8.7 Full of content; Q8.8 Detached)	Likert	Strongly agree (5) – Strongly disagree (1)
Q9	"Now please focus on one room that is relevant for your relaxing activities at home:"	–	Studio; Kitchen; Living room; Kitchen – living room; Bedroom; Bathroom
Q10	"To what extent do you hear the following types of sounds while relaxing in your [*piping: Q9*]?" (Q10.1 Traffic noise from outside - e.g. cars, buses, trains, airplanes; Q10.2 Other noise from outside - e.g. sirens, construction, industry, loading of goods; Q10.3 Natural sounds from outside - e.g., singing birds, flowing water, wind in vegetation; Q10.4 Sounds from human beings from outside - e.g. conversation, laughter, children at play, footsteps; Q10.5 Sounds from other human beings present in your house - e.g. conversation, music, TV, laughter, children at play, footsteps; Q10.6 Sounds from neighbors - e.g. conversation, music, TV, laughter, children at play, footsteps; Q10.7 Sounds from building services of your house - e.g.	Likert	Not at all (1) – Dominates completely (5); Not applicable (6)

Appendix A (*continued*)

ID	Question	Scale	Label
	heating, cooling, ventilation systems, toilet flushes; Q10.8 Sounds from building services of your neighbours / common areas - e.g. heating, cooling, ventilation systems, let flushes, lift; Q10.9 Music or TV played by you - through headphones or loudspeakers)		
Q11	"To what extent do you see the following elements from windows, if any, present in your [*piping: Q9*]?" (Q11.1 Vegetation; Q11.2 Sky; Q11.3 Other buildings)	Likert	Not at all (1) – Dominates completely (5); Not applicable (no window) (6)
Q12	"In your view, how is the sound environment currently (positively and negatively) affecting your leisure activities at home? - e.g. heard noises and sounds, building characteristics, urban environment" (While watching TV, reading, listening to music)	–	Text field
Q13	"To what extent is your present surrounding sound environment appropriate to relax at home?"	Likert	Not at all (1) – Perfectly (5)
Q14	"For each of the 8 scales below, to what extend do you agree or disagree that the present surrounding sound environment while you are working from home is:" (Q14.1 Comfortable; Q14.2 Intrusive, uncontrolled; Q14.3 Engaging; Q14.4 Empty; Q14.5 Private, controlled; Q14.6 Annoying; Q14.7 Full of content; Q14.8 Detached)	Likert	Strongly agree (5) – Strongly disagree (1)
Q15	"As regards your house, what is your ownership status?"	–	Rent – not owned, Owned; Other
Q16	"What is the size of your house?"	–	Floor area $\leq$ 40 m^2; 40 m^2 < Floor area $\leq$ 80 m^2; 80 m^2 < Floor area $\leq$ 110 m^2; Floor area > 110 m^2
Q17	"What type of house do you live in?"	–	Detached single family; Semi-detached or terraced house; Apartment block; Other*
Q18	"Please indicate whether the following spaces are present in your house and whether they face a noisy side (e.g. facing a major road, a railway, a busy pedestrian street) or a quiet side (e.g. facing an internal courtyard, a garden, a small street) or whether they are windowless. Please note that it is possible to have multiple noisy or quiet sides" (Studio; Kitchen; Living room; Kitchen - Living room / open plan; Bedroom; Bathroom)	–	It faces a noisy side; It faces a quiet side; It is a windowless room; Room not present
Q19	"Who are you currently living with?"	–	Alone; With roommate(s); With a spouse/partner; With child(ren); With parent(s) or other family members
Q20	"Including yourself, how many people live in your home?"	–	1; 2; 3; 4; 5+
Q21	"How do you ventilate your house? Select all that apply"	Multiple choice	I open the windows; I have mechanical ventilation
Q22	"How do you heat your house? Select all that apply"	Multiple choice	Radiators; Radiant floor; Electric heaters; Fireplace; Stove; Air systems; Other*

(*continued on next page*)

Appendix A (*continued*)

ID	Question	Scale	Label
Q23	"How do you cool your house? [Select all that apply]"	Multiple choice	I have no cooling systems; Radiant systems (e.g. floor, ceiling, etc.); Full air systems (e.g. air conditioners); Air movement devices (e.g. ceiling or desktop fans); By opening windows
	The urban context where you live in		
Q24	Where do you live in London? Please provide your postcode	–	Text field
Q25	How would you describe the area where you live? Finally, something about you	–	Urban; Suburban; Rural
Q26	"Please state to what extent you disagree/ agree with the following sentences:" (Q26.1 I am sensitive to noise; Q26.2 I find it difficult to relax in a place thaťs noisy; Q26.3 I get mad at people who make noise that keeps me from falling asleep or getting work done; Q26.4 I get annoyed when my neighbours are noisy; Q26.5 I get used to most noises without much difficulty)	Likert	Slider: Totally disagree (0) – Totally agree (100)
Q27	"Please indicate for each of the five statements which is closest to how you have been feeling over the last two weeks. Notice that higher numbers mean better well-being." (Q27.1 I have felt cheerful and in good spirits; Q27.2 I have felt calm and relaxed; Q27.3 I have felt active and vigorous; Q27.4 I woke up feeling fresh and rested; Q27.5 My daily life has been filled with things that interest me; Q27.6 It is important that you pay attention to this study. Please select: 'All of the time')	Likert	All of the time (5) – At no time (0)
Q28	"How old are you?"	–	Text field
Q29	"How would you describe your gender?"	–	Male - including transgender men; Female - including transgender women; Other - e.g. non-binary, gender-fluid, agender*; Prefer not to say

* The "Other" option was followed by a text field in which participants were asked to specify their answer.

References

[1] Aletta F, Oberman T, Mitchell A, Tong H, Kang J. Assessing the changing urban sound environment during the COVID-19 lockdown period using short-term acoustic measurements. Noise Mapp 2020;7:1–12. https://doi.org/10.1515/noise-2020-0011.

[2] Basu B, Murphy E, Molter A, Sarkar Basu A, Sannigrahi S, Belmonte M, et al. Investigating changes in noise pollution due to the COVID-19 lockdown: The case of Dublin, Ireland. Sustain Cities Soc 2021;65:102597. https://doi.org/10.1016/j.scs.2020.102597.

[3] Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L. Indirect effects of COVID-19 on the environment. Sci Total Environ 2020;728:138813. https://doi.org/10.1016/j.scitotenv.2020.138813.

[4] Asensio C, Pavón I, de Arcas G. Changes in noise levels in the city of Madrid during COVID-19 lockdown in 2020. J Acoust Soc Am 2020;148(3):1748–55. https://doi.org/10.1121/10.0002008.

[5] Aletta F, Osborn D, Osborn D. The COVID-19 global challenge and its implications for the environment – what we are learning. UCL Open Environ 2020;2:8–10. https://doi.org/10.14324/111.444/ucloe.000008.

[6] Sakagami K. How did the 'state of emergency' declaration in Japan due to the COVID-19 pandemic affect the acoustic environment in a rather quiet residential area? UCL Open Environ 2020;2:1–9. https://doi.org/10.14324/111.444/ucloe.000009.

[7] Manzano JV, Pastor JAA, Quesada RG, Aletta F, Oberman T, Mitchell A, et al. The "sound of silence" in Granada during the COVID-19 lockdown. Noise Mapp 2021;8:16–31. https://doi.org/10.1515/noise-2021-0002.

[8] Redel-Macías MD, Aparicio-Martinez P, Pinzi S, Arezes P, Cubero-Atienza AJ. Monitoring sound and its perception during the lockdown and de-escalation of COVID-19 pandemic: A Spanish study. Int J Environ Res Public Health 2021;18(7):3392. https://doi.org/10.3390/ijerph18073392.

[9] Andargie MS, Touchie M, O'Brien W. Case study: A survey of perceived noise in Canadian multi-unit residential buildings to study long-term implications for widespread teleworking. Build Acoust 2021:1351010X2199374. https://doi.org/10.1177/1351010x21993742.

[10] Şentop Dümen A, Şaher K. Noise annoyance during COVID-19 lockdown: A research of public opinion before and during the pandemic. J Acoust Soc Am 2020;148(6):3489–96. https://doi.org/10.1121/10.0002667.

[11] Bartalucci C, Bellomini R, Luzzi S, Pulella P, Torelli G. A survey on the soundscape perception before and during the COVID-19 pandemic in Italy. Noise Mapp 2021;8:65–88. https://doi.org/10.1515/noise-2021-0005.

[12] Lee PJ, Jeong JH. Attitudes towards outdoor and neighbour noise during the COVID-19 lockdown: A case study in London. Sustain Cities Soc 2021;67:102768. https://doi.org/10.1016/j.scs.2021.102768.

[13] Awada M, Becerik-Gerber B, Hoque S, O'Neill Z, Pedrielli G, Wen J, et al. Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID-19 pandemic. Build Environ 2021;188:107480. https://doi.org/10.1016/j.buildenv.2020.107480.

[14] Torresin S, Aletta F, Babich F, Bourdeau E. Acoustics for Supportive and Healthy Buildings : Emerging Themes on Indoor sustainability. Sustain 2020;6054. https://doi.org/10.3390/su12156054.

[15] ISO 12913-1:2014 - Acoustics - Soundscape Part 1: Definition and conceptual framework 2014.
[16] ISO TS 12913-2:2018 - Acoustics - Soundscape part 2: Data collection and reporting requirements 2018.
[17] Torresin S, Albatici R, Aletta F, Babich F, Kang J. Assessment methods and factors determining positive indoor soundscapes in residential buildings: A systematic review. Sustain 2019;11:5290. https://doi.org/10.3390/su11195290.
[18] Torresin S, Albatici R, Aletta F, Babich F, Oberman T, Siboni S, et al. Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings. Build Environ 2020;182:107152. https://doi.org/10.1016/j.buildenv.2020.107152.
[19] Axelsson Ö, Nilsson ME, Berglund B. A principal components model of soundscape perception. J Acoust Soc Am 2010;128(5):2836–46. https://doi.org/10.1121/1.3493436.
[20] Clark C, Paunovic K. WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Quality of Life, Wellbeing and Mental Health. Int J Environ Res Public Health 2018;15:2400. https://doi.org/10.3390/ijerph15112400.
[21] Erfanian M, Mitchell AJ, Kang J, Aletta F. The psychophysiological implications of soundscape: A systematic review of empirical literature and a research agenda. Int J Environ Res Public Health 2019;16(19):3533. https://doi.org/10.3390/ijerph16193533.
[22] Aletta F, Oberman T, Mitchell A, Erfanian M, Lionello M, Kachlicka M, et al. Associations between soundscape experience and self-reported wellbeing in open public urban spaces: a field study. Lancet 2019;394:S17. https://doi.org/10.1016/S0140-6736(19)32814-4.
[23] Aletta F, Molinero L, Astolfi A, Di Blasio S, Shtrepi L, Oberman T, et al. Exploring associations between soundscape assessment, perceived safety and well-being: A pilot field study in Granary Square, London. Proc Int Congr Acoust 2019;2019-Septe:7946–53. https://doi.org/10.18154/RWTH-CONV-238876.
[24] Aletta F, Oberman T, Kang J. Associations between positive health-related effects and soundscapes perceptual constructs: A systematic review. Int J Environ Res Public Health 2018;15:2392. https://doi.org/10.3390/ijerph15112392.
[25] Ormandy D. Housing and health in Europe: the WHO LARES project. Routledge; 2009.
[26] Kearns A, Hiscock R, Ellaway A, MaCintyre S. "Beyond four walls". The psycho-social benefits of home: Evidence from West Central Scotland. Hous Stud 2000;15(3):387–410. https://doi.org/10.1080/02673030050009249.
[27] Amerio A, Brambilla A, Morganti A, Aguglia A, Bianchi D, Santi F, et al. Covid-19 lockdown: Housing built environment's effects on mental health. Int J Environ Res Public Health 2020;17(16):5973. https://doi.org/10.3390/ijerph17165973.
[28] Derryberry EP, Phillips JN, Derryberry GE, Blum MJ, Luther D. Singing in a silent spring: Birds respond to a half-century soundscape reversion during the COVID-19 shutdown. Science (80-) 2020;370(6516):575–9. https://doi.org/10.1126/science:abd5777.
[29] Lenzi S, Sádaba J, Lindborg P. Soundscape in Times of Change : Case Study of a City Neighbourhood During the COVID-19 Lockdown 2021;12. https://doi.org/10.3389/fpsyg.2021.570741.
[30] Maggi AL, Muratore J, Gaetán S, Zalazar-Jaime MF, Evin D, Pérez Villalobo J, et al. Perception of the acoustic environment during COVID-19 lockdown in Argentina. J Acoust Soc Am 2021;149(6):3902–9. https://doi.org/10.1121/10.0005131.
[31] Ratcliffe E. Sound and soundscape in restorative natural environments: A narrative literature review. Front Psychol 2021. https://doi.org/10.3389/fpsyg.2021.570563.
[32] Hedblom M, Gunnarsson B, Schaefer M, Knez I, Thorsson P, Lundström JN. Sounds of nature in the city: No evidence of bird song improving stress recovery. Int J Environ Res Public Health 2019;16(8):1390. https://doi.org/10.3390/ijerph16081390.
[33] MacDonald RAR. Music, health, and well-being: A review. Int J Qual Stud Health Well-Being 2013;8. https://doi.org/10.3402/qhw.v8i0.20635.
[34] Tanaka YL, Kudo Y. Effects of familiar voices on brain activity. Int J Nurs Pract 2012;18:38–44. https://doi.org/10.1111/j.1440-172X.2012.02027.x.
[35] Dzhambov AM, Lercher P, Stoyanov D, Petrova N, Novakov S, Dimitrova DD. University students' self-rated health in relation to perceived acoustic environment during the covid-19 home quarantine. Int J Environ Res Public Health 2021;18:1–21. https://doi.org/10.3390/ijerph18052538.
[36] Zimmer K, Ghani J, Ellermeier W. The role of task interference and exposure duration in judging noise annoyance. J Sound Vib 2008;311(3-5):1039–51. https://doi.org/10.1016/j.jsv.2007.10.002.
[37] Peer E, Brandimarte L, Samat S, Acquisti A. Beyond the Turk: Alternative platforms for crowdsourcing behavioral research. J Exp Soc Psychol 2017;70:153–63. https://doi.org/10.1016/j.jesp.2017.01.006.
[38] Palan S, Schitter C. Prolific.ac—A subject pool for online experiments. J Behav Exp Financ 2018;17:22–7. https://doi.org/10.1016/j.jbef.2017.12.004.
[39] The Health Protection (Coronavirus, Restrictions) (No. 3) and (All Tiers) (England) (Amendment) Regulations 2021 n.d. https://www.legislation.gov.uk/uksi/2021/8/introduction/made (accessed February 16, 2021).
[40] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap) - a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform 2009;42(2):377–81.
[41] Harris PA, Taylor R, Minor BL, Elliott V, Fernandez M, O'Neal L, et al. The REDCap consortium: Building an international community of software platform partners. J Biomed Inform 2019;95:103208. https://doi.org/10.1016/j.jbi.2019.103208.
[42] Johnson RB, Onwuegbuzie AJ. Mixed methods research: A research paradigm whose time has come. Educ Res 2004;33(7):14–26.
[43] ISO TS 12913-3:2019 - Acoustics - Soundscape part 3: Data analysis 2019.
[44] Weinstein ND. Individual differences in critical tendencies and noise annoyance. J Sound Vib 1980;68(2):241–8.
[45] Benfield JA, Nurse GA, Jakubowski R, Gibson AW, Taff BD, Newman P, et al. Testing Noise in the Field: A Brief Measure of Individual Noise Sensitivity. Environ Behav 2014;46(3):353–72. https://doi.org/10.1177/0013916512454430.
[46] Topp CW, Østergaard SD, Søndergaard S, Bech P. The WHO-5 well-being index: A systematic review of the literature. Psychother Psychosom 2015;84(3):167–76. https://doi.org/10.1159/000376585.
[47] Corp IBM. IBM SPSS Statistics for Windows. Version 2019;26.
[48] Team RC, others. R: A language and environment for statistical computing 2013.
[49] Ercakmak UB, Dokmeci Yorukoglu PN. Comparing Turkish and European Noise Management and Soundscape Policies : A Proposal of Indoor Soundscape Integration to Architectural Design and Application. Acoustics 2019;1:847–65. https://doi.org/10.3390/acoustics1040051.
[50] Hallberg L-M. The "core category" of grounded theory: Making constant comparisons. Int J Qual Stud Health Well-Being 2006;1(3):141–8. https://doi.org/10.1080/17482620600858399.
[51] OUIS D. Annoyance from road traffic noise: A review. J Environ Psychol 2001;21(1):101–20. https://doi.org/10.1006/jevp.2000.0187.
[52] Park SH, Lee PJ, Yang KS, Kim KW. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. J Acoust Soc Am 2016;139(3):1158–67. https://doi.org/10.1121/1.4944034.
[53] Marquis-Favre C, Premat E, Aubrédue D. Noise and its effects - A review on qualitative aspects of sound. Part II: Noise and annoyance. Acta Acust United with Acust 2005;91:626–42.
[54] Guski R. Personal and social variables as co-determinants of noise annoyance. Noise Health 1999;1:45–56.
[55] Rohde L, Larsen TS, Jensen RL, Larsen OK. Framing holistic indoor environment: Definitions of comfort, health and well-being. Indoor Built Environ 2020;29(8):1118–36. https://doi.org/10.1177/1420326X19875795.
[56] Van Kamp I, Klaeboe R, Brown AL, Lercher P. Soundscapes, human restoration and quality of life. In: Kang J, Schulte-Fortkamp B, editors. Soundscape Built Environ., Boca Raton, FL, USA: CRC Press; 2016, p. 43–68. https://doi.org/10.1201/b19145-4.
[57] Lercher P, Van Kamp I, Von Lindern E, Botteldooren D. Perceived soundscapes and health-related quality of life, context, restoration, and personal characteristics. Soundscape. Built Environ 2016;89.
[58] Fiebig A, Jordan P, Moshona CC. Assessments of Acoustic Environments by Emotions – The Application of Emotion Theory in Soundscape. Front Psychol 2020;11. https://doi.org/10.3389/fpsyg.2020.573041.