Psychological Well-being, Age and Gender can Mediate Soundscapes Pleasantness and Eventfulness: A large sample study

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The authors are very grateful to other Soundscape Indices (SSID) project members that helped with data collection. This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. 740696).

Word count (excluding title page and references): 5044

The authors declare that there is no conflict of interest regarding the publication of this article

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Abstract

There is a great deal of literature on contributing environmental factors of soundscape, the perception of the acoustic environment by humans in context. Yet the impact of some contextual and person-related factors is largely unknown. From the questionnaire, adapted from ISO12913-2 and the WHO-5 well-being index, three questions arose: are there differences in Pleasantness and Eventfulness of soundscape among different acoustic environments; are high levels of psychological well-being associated with increased Pleasantness and Eventfulness ratings; and is soundscape Pleasantness and Eventfulness consistent among different age and gender groups? The sample comprised 1180 individual questionnaires, 621 females (52.6%), 532 males (45.1%), mean age 34.95 years ± 15.62, collected from eleven urban locations. Hierarchical clustering analysis was done on the mean of each sound source question for each survey location resulting in three clusters of locations based on sound source composition: Natural-dominant, Traffic-dominant and Mixed-sources. A Kruskal-Wallis was conducted to compare the mean Pleasantness and Eventfulness scores of the three clusters, demonstrating that the soundscape assessment was significantly different depending on sound source composition. Multiple linear regression models were used to analyse the relationship between psychological well-being, age, and gender with soundscape Pleasantness and Eventfulness. Our results indicated first that the positive psychological state was associated with Pleasantness in the all-locations and mixed-sources clusters, and with Eventfulness in the traffic-dominant cluster. Secondly, while age was linked to Pleasantness in all clusters it was merely associated with the Eventfulness in the all-locations cluster. Lastly, gender was associated with Pleasantness only in the all-locations cluster. These findings offer empirical grounds for developing theories of the contextual factors on soundscape.

Keywords: Soundscape, psychological well-being, pleasantness, eventfulness, acoustic environment

Psychological Well-being, Age and Gender can Mediate Soundscape Pleasantness and Eventfulness: A large sample study

Sound is a ubiquitous element in our daily lives. Despite a good deal of literature, it still strongly remains a centre of attention of many scientific communities, from auditory neuroscience to engineering, and physics to environmental psychology. Looking deeper at the evolution of sound-related research in the field of engineering we see a considerable paradigm shift from noise mitigation to pleasant and restorative sound generation to make a comforting acoustic environment. This premise has been proposed with the hope to apply the existing environmental resources in order to provide a healthier environment and better quality of life (Kang, Aletta, Gjestland, Brown, Botteldooren, Schulte-Fortkamp et al., 2016; Kang, Aletta, Oberman, Erfanian, Kachlicka, Lionello et al., 2019). Hence, the soundscape concept, which places the emphasis on *the human perception of acoustic environment in context* has emerged to support this premise. The soundscape entails perceptual attributes (i.e. pleasantness or calmness) that are different from the physical properties of the acoustic environment (International Organization of Standardization Technical Specification, 2019).

While the mechanisms of hearing of environmental sounds are relatively straightforward and well-established, our understanding of the action of the Peripheral and Central Nervous System (PNS and CNS) associated with environmental sound interpretation and the factors influencing the perception of sound is still evolving and a matter of dispute among scientific communities. The soundscape is intimately tied to certain primary factors known as acoustic properties (physical features) of the sound such as frequency/ pitch (Kumar, Forster, Bailey, Griffiths, 2008; Patchett, 1979) and intensity/loudness (Kaya, Huang, Elhilali, 2020) as well as secondary influences like emotions and personality (McDermott, 2012).

Acoustic features variations and soundscape

The acoustic features of the environment are important influential factors of soundscape by definition. Many *in-situ* and laboratory-based studies have pointed to the notion that while noisy areas such as construction sites are perceived as less pleasant and more annoying, locations with natural elements such as forests may elicit more pleasantness and restoration (Li & Kang, 2019; Alvarsson, Wiens, Nilsson, 2010). Pathak and colleagues (2008) evaluated the effect of city noise in a city of India in which the results revealed more than 80% of people were disturbed and annoyed by traffic noise, causing a range of physical issues (Pathak, Tripathi, kumar Mishra, 2008).

Psychological well-being and soundscape

Apart from the acoustic features, there are less studied factors that may be linked to the perception of the acoustic environment such as psychological well-being (Aletta, Oberman, Mitchell, Erfanian, Lionello, Kachlicka et al., 2019). There has been an ongoing attempt to improve the definition of psychological well-being, to move away from the conceptualization of 'psychological health as a state of absence of psychological illness'. The current proposed definition is as follows:

"Psychological health is a dynamic state of internal equilibrium which enables individuals to use their abilities in harmony with universal values of society. Basic cognitive and social skills; ability to recognize, express and modulate one's own emotions, as well as empathize with others; flexibility and ability to cope with adverse life events and function in social roles; and harmonious relationship between body and mind represent important components of psychological health which contribute, to varying degrees, to the state of internal equilibrium" (World Health Organization, 2005).

Individuals with an aberrant psychological state and poor mental health may experience environmental inputs differently to those people who do not experience such issues given that emotions, as one of the core components of psychological well-being, and sensory perceptions are closely intertwined (Kelley & Schmeichel, 2014). As reported in the relevant literature, the impact of psychological well-being and mental state are consistent among all sensory modalities such as vision (Zadra & Clore, 2011), tactile (Kelley & Schmeichel, 2014), olfactory (Krusemark, Novak, Gitelman, 2013), and auditory (Riskind, Kleiman, Seifritz, Neuhoff, 2014). In parallel, studies in the field of psychopathology elucidated that individuals with poor psychological well-being, such as the clinically depressed, maintain bias and anomalous cognition, leading to inaccurate and distorted perception (Beck's cognitive theory) (Clark & Beck, 2010).

Individual differences and soundscape

The perception of the acoustic environment or soundscape involves the sensation, identification, organization, and interpretation of ongoing omnipresent auditory information (Goldstein, Brockmole, 2016). Soundscape does not always maintain consistency and show a huge variation among populations since differences in cultural, socio-economical, ethnic backgrounds and individual differences may moderate the way we perceive sounds (Zhang & Kang, 2007). A longitudinal study by Weinstein (1978) showed that individual differences in college students can lead to different reactions to noise including lower academic ability, less secure social interactions, greater need for privacy. There is evidence to suggest that among all secondary factors, age and gender are considered more important potential confounders (Xiao & Hilton, 2019; Gulian & Thomas 1986).

While previous research has substantially advanced our knowledge of the soundscape determinants, particularly psychological well-being, their results are predominantly limited to controlled laboratory-based experiments, with a focus on individuals with mental disorders. It is also worth noting that our understanding, in particular of the positive effects, has still largely remained unexplored.

To this end, in this large-scale study, we aim to explore the association of psychological well-being, age and gender with soundscape among the members of the public. It is important to highlight that in this study; we introduce two components of soundscape namely 'Pleasantness' (~equivalent of valence/emotional magnitude) and 'Eventfulness' (~equivalent of arousal) by adopting a newly proposed approach to soundscape research from ISO/TS 12913□3:2019 (International Organization of Standardization Technical Specification, 2019), reported in a two-dimensional scatter plot with coordinates for the two dimensions 'Pleasantness' plotted on X-axis and 'Eventfulness' plotted on Y-axis, taking into account the features of the locations. These components are slightly different from the classic pleasantness and eventfulness terms used in the previous literature, and in order to differentiate them they will appear with the first letter capitalized throughout the text.

Therefore, we raise three questions:

i. Are there differences in the Pleasantness and Eventfulness levels among different locations with varying sound source compositions and environmental characteristics?

ii. Are high levels of psychological well-being associated with increased soundscape pleasantness and eventfulness?

iii. Are age and gender as explanatory factors associated with the soundscape Pleasantness and Eventfulness?

Methods

The study was approved by the local ethics committee of University College London (UCL), the Bartlett School, Institute for Environmental Design and Engineering (IEDE) (Dated 11-10-2019).

Locations

The present work is a large-scale study with data collected from the general members of public in several locations in London with varying acoustic features including unnatural, natural, and mixed of the former and later acoustic features (See Appendix B).

Participants

All passers-by of the data collection spots were approached in 11 locations/sites in London by the researchers and were asked if they were willing to participate in our study. Only individuals on the phone, with headphones on due to attention distraction, or individuals that were deemed to be younger than 18 years old (proxy consent required) were excluded in data collection. The total number of surveys that were originally collected from the sites was 1467.

The setup and procedures of this study allowed us to test a large group of participants with high diversity with rather various demographics including gender, age, education level, occupation, and ethnicity (n= 1180) (Table 1).

Demographic characteristics	n (%)
N = 1180	Age mean = 34.95 years ± 15.62
Gender	
Female	621 (52.6)
Male	532 (45.1)
Age	
18-30	614 (52.03)
31-40	199 (16.86)

Demographic characteristics	n (%)
41-50	117 (9.91)
51-60	101 (8.56)
61-70	72 (6.1)
71+	36 (3.05)
Education Level	
Some high school	24 (2)
High school graduate	183 (15.5)
Some college	146 (12.4)
Trade/ technical/ vocational training	56 (4.7)
Graduate from university	421 (35.7)
Some postgraduate work	57 (4.8)
Postgraduate degree	279 (23.6)
Occupation Status	
Employed	675 (57.2)
Unemployed	34 (2.9)
Retired	88 (7.5)
Students	369 (31.3)
Other	46 (3.9)
Rather not say	18 (1.5)
Ethnicity	
White	831 (71.1)
Mixed/Multiple ethnic groups	62 (5.3)
Asian/Asian British	165 (14.1)
Black/African/Caribbean/Black British	33 (2.8)
Middle Eastern	23 (2)
Rather not say	31 (2.7)
Other ethnic group	23 (2)

Table 1

The sample demographic characteristics

Measures

The questionnaire, presented in full in Appendix A, comprising 38 items, is an adapted version of ISO/TS 12913-2:2018 (Axelsson & ISO/TC 43/SC 1/WG 54, 2012; International Organization of Standardization, 2018) and WHO-5 well-being index (World Health Organization, 1998), as well as demographic information. In order to answer the questions raised in this study the authors only report some sections of the questionnaire which then undergo the statistical analyses.

Sound sources.

Sound sources refers to questions, asking to what extent the participants hear different types of sounds, namely traffic noise such as cars or buses, other noise such as sirens or construction, sounds from human beings such as conversation or laughter, and natural sounds such as singing birds or flowing water. The participants then assessed each source on a 5-point scale from ‘not at all’ to ‘dominates completely’. With this method, it is possible for participants to provide their overall impression of a complex and dynamic acoustic environment, in which many different sound sources compete for their auditory attention.

Locations were selected which represented a variety of usage types, visual character, and sonic characteristics. The minimum and maximum value of several acoustic metrics recorded at each location during the survey sessions are presented Table B.1 in Appendix B.

Perceived affective quality/Perceptual attributes.

The perceived affective quality (PAQ) of the sound environment as adopted in the method ‘A’, described in C.3.1 of ISO/TS 12913-2:2018, consists of category scales containing five response categories, based on the Swedish Soundscape Quality Protocol (SSQP; 41) (International Organization of Standardization, 2018). It includes a question ‘to what extent they agree/disagree that the present surrounding sound environment is …’. The participants judged the quality of the acoustic environment by 8 adjectives: pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, or monotonous. The answers were presented in a 5-point Likert scale ranging from ‘strongly agree’ to ‘strongly disagree’. The perceptual attributes measure as a unidimensional measuring tool for the perception of the acoustic environment has not been validated to this date.

In order to maintain data quality and exclude cases where respondents either clearly did not understanding the PAQ adjectives or intentionally misrepresented their answers, surveys for which the same response was given for every PAQ (e.g. ‘Strongly agree’ to all 8 attributes) were excluded. This is justified as no reasonable respondent who understood the questions would answer that they ‘strongly agree’ that a soundscape is pleasant and annoying, calm and chaotic, etc. Cases where respondents answered ‘Neutral’ for all PAQs are not excluded in this way, as a neutral response to all attributes is not necessarily contradictory. In addition, surveys were discarded as incomplete if more than 50% of the PAQ and sound source questions were not completed.

WHO-5 well-being index.

WHO-5 well-being index asks how individuals have been feeling over the last two weeks such as ‘I have felt cheerful and in good spirits’. WHO-5 has been designed for multiple research and clinical purposes, covering a wide range of mental health domains namely perinatal mental health, the geriatrics mental health, endocrinology, clinical psychometrics, neurology, and psychiatric disorders screening.

The WHO-5 well-being index is known to be one of the most valid generic scales for quantification of general well-being. In terms of the construct validity of the scale, WHO-5 showed to have properties that are a coherent measure of well-being (Topp, Østergaard, Søndergaard, Bech, 2015). With regards to relevant literature, WHO-5 confirmed that all items constitute an integrated scale in which items add up related information about the level of general psychological well-being among both youngsters and elderlies (Blom, Bech, Hogberg, Larsson, Serlachius, 2012; Lucas-Carrasco, Allerup, Bech, 2012). For the purpose of analysis, a composite WHO-5 score is calculated by summing the responses to each of the 5 questions (coded from 0 to 5), then multiplying by 5 to get a single score which 0 (the lowest level of well-being) to 100 (the highest level of well-being) (Topp et al., 2015).

Demographic characteristics.

Demographic characteristics were presented such as age, gender, education level, occupational status, and ethnicity. Some blank spaces were provided if they wanted to add further information. At the end of the survey, participants had the opportunity to write down any additional questions or remarks and were thanked for their participation.

Procedure

The participants were approached and asked if they were interested to participate in the study. All participants received information about the aim of the study, its procedures, confidentiality of research data, and how to contact the investigators, the supervisor of the project, or a member of the ethical committee. An informed consent document was given to participants, who declared to have read and understood the general information, take part voluntarily, and have understood the fact that they can stop their participation and withdraw their consent, anytime, and without any consequences. They could start filling in the questionnaire if the participant gave his/her consent. If they had no questions, they received either a paper version or an e-version of a questionnaire. The online questionnaires were collected and managed using REDCap electronic data capture tools hosted at UCL (Harris, Taylor, Minor, Elliott, Fernandez, O'Neal et al., 2019) and typically took between 5 and 10 minutes to complete. The goal of the researchers on site was to collect a minimum of one-hundred questionnaires from each selected site, which was typically achieved over a period of 2-3 days each consisting of approximately a 4-hour session. In some cases, either due to extenuating circumstances, time constraints, or excluded surveys, the full one hundred surveys were not achieved. The data was collected from 28th February 2019 to 18th October 2019 between 11am to 3pm.

During the survey period, acoustic and environmental metrics were simultaneously collected through binaural recordings, a calibrated sound level meter (SLM), and an environmental meter collected temperature, lighting level, and humidity data. The SLM was set up in the space in which the questionnaires were conducted and left running for the full duration of the survey in order to characterize the acoustic environment. The environmental metrics were not reported in this study since they were not in the scope of this paper. The full protocol and data treatment as part of the SSID Database creation is described in detail by Mitchell and colleagues (Mitchell, Oberman, Aletta, Erfanian, Kachlicka, Lionello et al., 2020).

Statistical analysis

If required, the data were checked for normality using analytical Kolmogorov–Smirnov/Shapiro–Wilk's tests. Since majority of our data were not normally distributed to address the objectives of the study, we used non-parametric methods. The soundscape data were analysed according to the ISO 2019 proposed dimensional which collapses the perceived affective quality responses the participants gave to each of the 8 dimensions (Figure 1) down to a 2-dimensional coordinate scatter plot with coordinates for 'Pleasantness' on the x-axis and 'Eventfulness' on the y-axis (Section A.3 ISO/TS 12913-3:2019(E)) (International Organization of Standardization Technical Specification, 2019). These dimensions are calculated as shown in Formulas (1) and (2) and the resulting Pleasantness and Eventfulness coordinates have a range of ±9.66:

$$Pleasantness\ (P) = \sum_{i=1}^{8} PAQ_i \times \cos\theta_i$$

(1)

$$\text{□□□□□□□□□□□□}\ (\text{□}) = \sum_{\text{□}=1}^{8} \text{□□□}_{\text{□}}\ \text{□}\ \sin \text{□}_{\text{□}}$$

(2)

where, PAQ_1 = pleasant, $\theta_1 = 0°$; PAQ_2 = vibrant, $\theta_2 = 45°$; PAQ_3 = eventful, $\theta_3 = 90°$; PAQ_4 = chaotic, $\theta_4 = 135°$; PAQ_5 = annoying, $\theta_5 = 180°$; PAQ_6 = monotonous, $\theta_6 = 225°$; PAQ_7 = uneventful, $\theta_7 = 270°$; PAQ_8 = calm, $\theta_8 = 315°$.

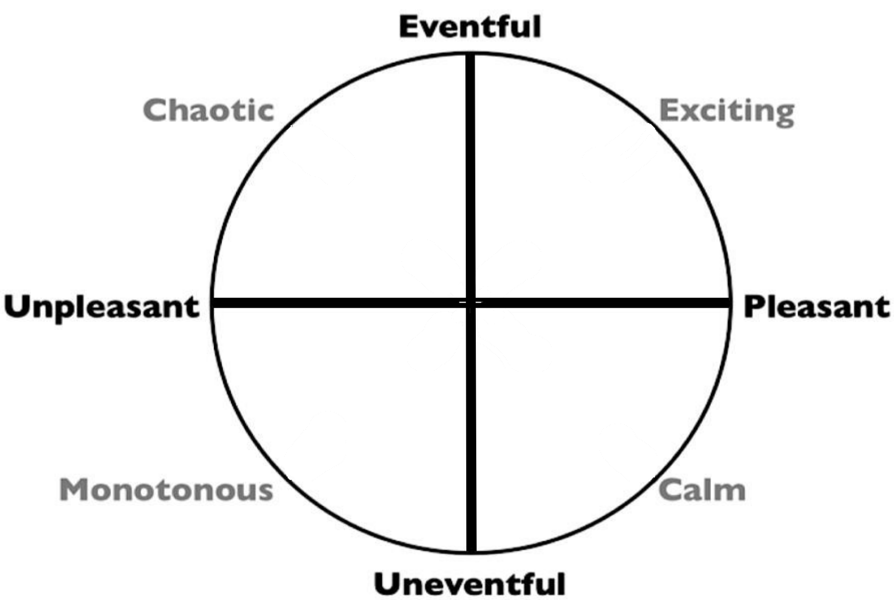


Figure 1 represents the perceptual attributes in relation to each other with the features of the locations (Axelsson, Nilsson, Berglund, 2010).

Clustering analysis was conducted on the sound sources questions (4 scales). The mean response for each of the four scales (presence of: Traffic noise, Natural sounds, Other Noise, and Human sounds) was calculated for each survey location, then clustered using hierarchical agglomerative clustering. The locations were thus separated into 3 groups according to their sound source composition. Our rationale for the clustering analysis was to investigate the psychological aspects of soundscape assessment, controlling for the semantic meaning assigned to certain sound sources and for general psychoacoustic factors. The analysis was conducted using the statistical software R (version 3.5) (R Core Team, 2013).

To investigate the difference in the Pleasantness and Eventfulness scores of three clusters of urban locations, we performed a Kruskal-Wallis analysis followed by post hoc Dunn's (1964) test that was conducted for the pairwise comparisons with a Bonferroni adjustment ($p<0.05$).

Finally, multiple linear regression models were used to analyse the relationship between psychological well-being (measured by WHO-5) (continuous), age (continuous) and gender (dichotomous, 1 assigned for male and 2 assigned for females) as in explanatory variables, and soundscape assessment (Pleasantness and Eventfulness) as an output (continuous). The p value was a priori set to $p<0.05$.

All the analyses excluding clustering were performed by using both statistical software R (version 3.5) (R Core Team, 2013) and IBM SPSS Statistics (version 26.0) (IBM Corp, 2019).

Results

Hierarchical clustering analysis

To cluster the locations, the mean response for each sound source question (range 1-5) within each location was calculated. These values are taken to represent the sound source composition for each location, describing the proportion of each type of sound source within the acoustic environment. The categorization of the locations according to their assessed sound source composition was done by hierarchical agglomerative clustering. Clustering based on perceptual responses as well as based on objective acoustic metrics has previously been successfully employed within the Soundscape literature for separating and identifying soundscape categories (Yong Jeon, Jik Lee, Young Hong, Cabrera, 2011; Aletta et al., 2019).

The hierarchical clustering analysis was performed using Ward's method wherein each location begins as its own cluster, the Euclidean distance between the clusters is calculated, and the clusters with the lowest distance are merged, forming a new cluster. This process is then repeated with the new clusters until the entire group has been grouped into a single cluster (Ward, 1963). The results of this analysis are shown in the dendrogram of figure 2, where the Location IDs are separated into the 3 main clusters.

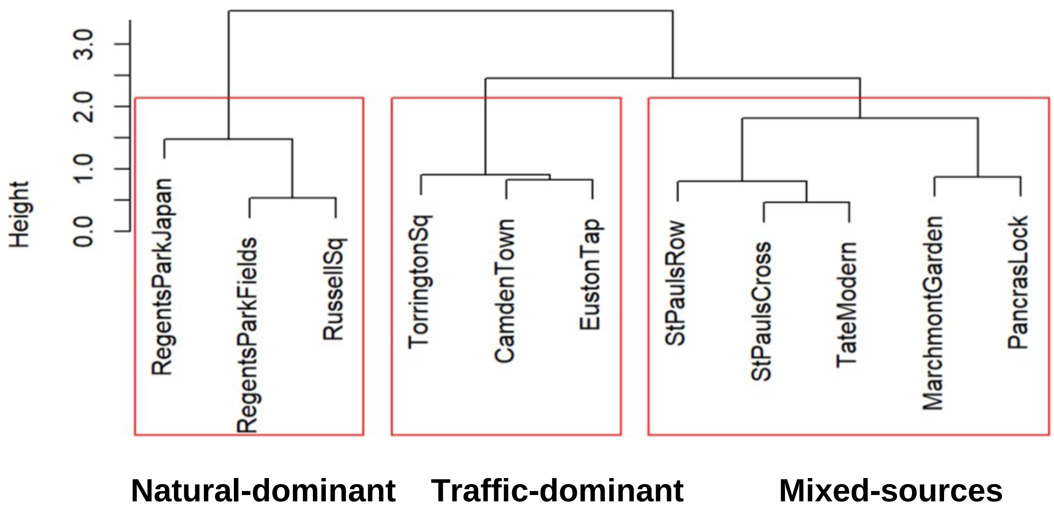


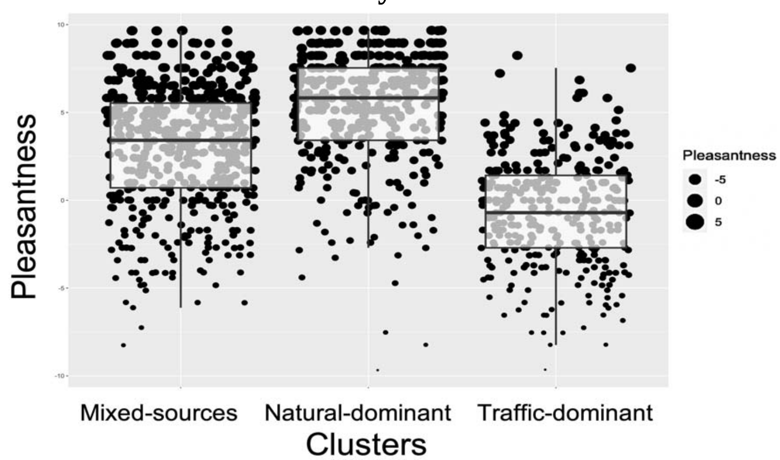
Figure 2. Cluster Dendrogram resulted in three main clusters of natural-dominant, traffic-dominant, and mixed-sources clusters from left to right.

Soundscape Pleasantness and Eventfulness differences among clusters

To determine the differences in the rated Pleasantness and Eventfulness among clusters of natural-dominant, traffic-dominant, and mixed-source, we have further conducted a Kruskal-Wallis test with clusters (mixed-sources, traffic-dominant, and natural-dominant) as factors. Both Pleasantness and Eventfulness scores yielded significant differences among the clusters: for Pleasantness, $\chi^2(2) = 374.95$, p=.001; and for Eventfulness χ^2 (2) = 97.121, p=.001. Post hoc

Dunn's test (1964) demonstrated significant differences between all clusters for Pleasantness (all p= 0.0005), and Eventfulness (all p= 0.0005).

Pleasantness by Clusters



Eventfulness by Clusters

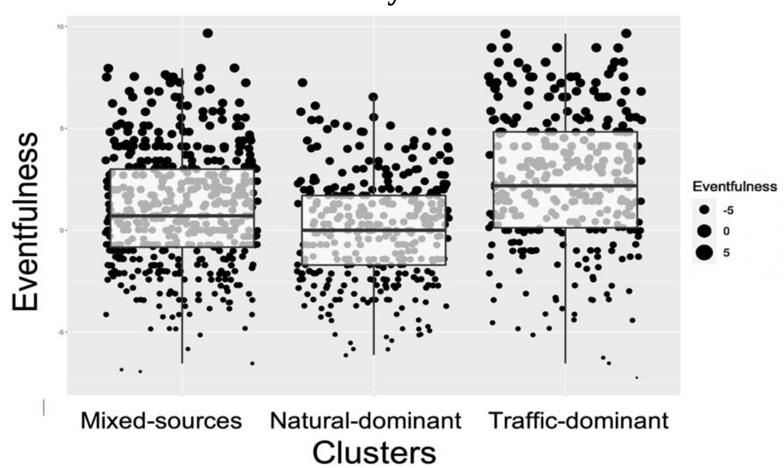


Figure 3. Figure 3. Boxplots of Kruskal-Wallis analyses with error bars for Pleasantness and Eventfulness differences among three clusters. The bold lines represent the mean. The black circles indicate individual data. The size of circles shows the level of pleasantness and eventfulness

Factors associated with Pleasantness and Eventfulness

A series of multiple linear regression analyses was conducted to ascertain the independent effect of psychological status, age, and gender on soundscape Pleasantness and Eventfulness in all-locations (Table 2), mixed-sources (Table 3), traffic-dominant (Table 4), and nature-dominant (Table 5), respectively.

In all-locations, positive psychological state, older age and female gender were independently associated with soundscape Pleasantness, while younger age was only associated with Eventfulness.

Target variables	Factors	*β*	*SE*	*t* value	*p*	CI (95%)
Pleasantness	Psychological status	0.023	0.006	3.91	0.001***	0.011, 0.035
	Age (years)	0.031	0.007	4.008	0.001***	0.02, 0.05
	Gender	0.552	0.24	2.297	0.021*	0.08,1.023
Eventfulness	Psychological status	0.001	0.004	0.36	0.718	-0.007, 0.011
	Age (years)	-0.016	0.006	-2.623	0.008**	-0.028, -0.004
	Gender	0.256	0.185	1.386	0.166	-0.106, 0.62

Table 2. Multiple regression analyses on soundscape Pleasantness and Eventfulness scores in the all-locations.

In the mixed-sources cluster, positive psychological state and older age were independently attributed to soundscape Pleasantness.

Target variables	Factors	*β*	*SE*	*t* value	*p*	CI (95%)
Pleasantness	Psychological Status	0.024	0.008	2.98	0.003*	0.008, 0.04
	Age (years)	0.031	0.01	3.079	0.002**	0.011, 0.051
	Gender	0.498	0.319	1.56	0.119	-0.129, 1.127
Eventfulness	Psychological Status	-0.002	0.006	-0.39	0.694	-0.016, 0.01
	Age (years)	-0.017	0.008	-1.953	0.051	-0.034, 0
	Gender	0.135	0.272	0.496	0.619	-0.4, 0.671

Table 3. Multiple regression analyses on soundscape Pleasantness and Eventfulness scores in the mixed-sources.

In the traffic-dominant cluster, younger age was associated with soundscape Pleasantness, and positive psychological state was associated with soundscape Eventfulness.

Target variables	Factors	*β*	*SE*	*t* value	*p*	CI (95%)
Pleasantness	Psychological Status	0	0.009	0.019	0.984	-0.017, 0.018
	Age (years)	-0.038	0.013	-2.847	0.005**	-0.064, -0.012
	Gender	0.138	0.361	0.382	0.702	-0.573, 0.85
Eventfulness	Psychological Status	0.023	0.009	2.47	0.014*	0.004, 0.042
	Age (years)	-0.006	0.014	-.453	0.651	-0.033, 0.021
	Gender	0.487	0.377	1.29	0.198	-0.256, 1.231

Table 4. Multiple regression analyses on soundscape Pleasantness and Eventfulness scores in the traffic-dominant.

In the nature-dominant cluster, only older age was associated with the soundscape Pleasantness.

Target variables	Factors	*β*	*SE*	*t* value	*p*	CI (95%)
Pleasantness	Psychological Status	0.001	0.009	0.11	0.912	-0.018, 0.02
	Age (years)	0.024	0.012	2.051	0.041*	0.001, 0.048
	Gender	0.305	0.37	0.823	0.411	-0.423, 1.034
Eventfulness	Psychological Status	0.009	0.007	1.3	0.193	-0.004, 0.024
	Age (years)	-0.001	0.009	-0.124	0.901	-0.019, 0.017
	Gender	0.546	0.281	1.945	0.052	-0.006, 1.099

****p<0.001**p<0.01*p<0.05 male =1 female=2*

Table 5. Multiple regression analyses on soundscape Pleasantness and Eventfulness scores in the Nature-dominant.

Discussion

Our initial assumption was that Pleasantness and Eventfulness significantly differ in each of the natural-dominant, traffic-dominant and mixed-sources clusters with varying sound source compositions. We concluded that in terms of the soundscape Pleasantness and Eventfulness, all clusters were significantly different from each other, with the natural-dominant cluster having the highest Pleasantness rating, and the traffic-dominant cluster as the lowest, indicating that a higher presence of natural sounds is considered more pleasant. The opposite pattern was detected in response to Eventfulness with the traffic-dominant cluster having the highest Eventfulness rating and the natural-dominant cluster having the lowest.

We additionally speculated that an increased level of psychological well-being is associated with increased Pleasantness and the Eventfulness assessments of soundscape. The results showed that the psychological well-being was positively associated with Pleasantness in two cases: All-locations and mixed-sources cluster. However, it was associated with Eventfulness exclusively in the traffic-dominant cluster.

Then we hypothesized that differences in soundscape assessments are associated with gender and age. The results of the current study support this hypothesis to a certain degree. In all clusters, age appeared to be a strong factor influencing the Pleasantness assessment while it is shown to influence the Eventfulness assessment only in all-locations. Further investigation revealed that gender was exclusively associated with Pleasantness in all-locations.

Soundscape Pleasantness and Eventfulness differences among clusters

The Pleasantness and Eventfulness were significantly different among all clusters. The Pleasantness appeared to be highest in the natural-dominant cluster, followed by the mixed-sources cluster and then the traffic-dominant cluster. In agreement with our results, Payne and colleagues (Payne, 2013) referred to the pleasantness dimension of soundscape as the positive perception of natural places as well as the restorative capacity of the soundscape. Also, in agreement, Zhang (2014) reported a significant impact of natural soundscape on individuals' restorative experiences and boosting pleasantness. In the study by Axelsson et al. (2010) participants reported that the sound excerpts of natural components are more pleasant than human and technical sounds.

Unlike Pleasantness, the Eventfulness increased the most in the traffic-dominant cluster, less so in the mixed-sources clusters, and lowest in the natural-dominant cluster. These findings are supported by previous research done by Bradley & Lang (2000) and Hume & Ahtamad (2013). In both studies, unnatural and urban sound-clips (i.e. Fire engine siren and traffic noise), inherent in the traffic-dominant cluster in our study, were rated highest in arousal and lowest in the pleasantness dimension. As formerly mentioned by Erfanian and colleagues (2019), throughout the soundscape literature, arousal has been applied as the equivalent of Eventfulness and indicated on the vertical axis of the circumplex models proposed by Axelsson and colleagues (Erfanian, Mitchell, Kang, Aletta, 2019; Axelsson et al., 2010).

These results insinuate the notion that there are multiple primary factors (see McDermott, 2012) that contribute to the perception of the acoustic environment which should be considered important by urban designers and policymakers. It is expected that understanding these factors will provide multidimensional knowledge in guiding the implementation of the technological infrastructure of smart cities.

Psychological well-being and its association with Pleasantness and Eventfulness

Our findings demonstrate a link between the perceived Pleasantness and participants' psychological well-being in all-locations and mixed-sources cluster, whereas the association between psychological well-being and Eventfulness is limited to the traffic-dominant cluster. In a nutshell, positive psychological well-being is attributed to elevated Pleasantness and to lesser degree to increased Eventfulness of the soundscape. Our results can be interpreted in light of previous research and it is consistent with the idea that psychological well-being underlies the perception of the external world (Kelley & Schmeichel, 2014) such as auditory input. While the enhanced global level of psychological state has a positive effect on auditory processing (Kumar, Sangamanatha, Vikas, 2013), there is evidence that suggests an impairment of early auditory processing (analysing, blending, and acoustic input segmentation) in individuals with poor psychological well-being (Kähkönen, Yamashita, Rytsälä, Suominen, Ahveninen, Isometsä, 2007). One of the potential trait biomarkers of poor psychological well-being such as depression (predominantly characterized by low mood and anhedonia (Erfanian, 2018) is the attenuation of neuronal activation in the auditory cortical area leading to alternations in auditory processing (Zwanzger, Zavorotnyy, Diemer, Ruland, Domschke, Christ et al., 2012).

It is noteworthy to highlight that the associations between psychological well-being and the soundscape in our results were confined to the all-locations and mixed-sources cluster for Pleasantness. This may be due to the similarities between these two clusters. All-locations and mixed-sources clusters essentially share resemblance (see figure 1) and as such show less variety in terms of acoustic features with a more consistent noise level, whereas in terms of the acoustic characteristics, the traffic and natural-dominant locations are more varying. The lesser degree of variation in acoustic features of all-locations and the mixed-sources cluster results in little variation in individuals' soundscape assessment which shows that the significant associations are more due to the individuals, not the sound environment itself. Given the high level of the Eventfulness in the traffic-dominant cluster, we speculate that higher levels of psychological well-being results in the amplification of the soundscape Eventfulness which may be due to the ongoing interaction of environmental acoustic elements with the momentary psychological status.

Other studies have investigated the impact of soundscape on psychological well-being and confirmed that pleasant soundscape and in particular natural soundscape contribute to faster stress recovery (Park, Lee, Jung, Swenson, 2020). However, given that all subjects in our study were exposed to the same soundscape prior to completing our survey, this effect should have been applied relatively equally across the sample population. Any positive impact the soundscape has is thus felt by all respondents. Because we are investigating differences across individuals, not across acoustic environments, the impact of the sounds itself on the individual should not have a significant impact. In this way, we argue that the effect demonstrated here is a person's well-being on their soundscape assessment, not the impact of sounds on their well-being.

Age association with soundscape Pleasantness and Eventfulness

According to our findings, age was an important factor in the pattern of soundscape assessments. These findings are in line with previous research, suggesting significant differences among age groups in the soundscape of different acoustic environments (Ren, Kang, Liu, 2016; Yang & Kang 2005). Our findings imply that an increase in age leads to an increase in the positive appraisal of the soundscape Pleasantness and a decrease in the Eventfulness. This is supported by a study by Çakir Aydin & Yilmaz (2016) in which they found that soundscape pleasantness reported by young individuals was significantly lower than the other age groups. In our study, however, Eventfulness appeared to be negatively associated with age which is, again, in agreement with the study from Yang and Kang (2005) as they showed people tend to build a tolerance to natural sound and lose interest in an unnatural sound. The results withstood a control for the effect of age on the soundscape’s pleasantness and eventfulness, suggesting that different neural and behavioural mechanisms are responsible for the differences of soundscape appraisal in age.

First, since the human brain is highly plastic throughout the life span, by aging, the auditory processing changes due to the temporal coding of the auditory cortex (Bones & Plack, 2015; Babkoff & Fostick, 2017). Temporal coding is the ability of the brain to encode sensory information to the action potentials that relies on precise timing. Another possibility is that age is associated with loss of function within the peripheral auditory system (hearing loss due to age or presbycusis) that may lead to the variation of the soundscape (Howarth and Shone, 2006) such that age-related hearing loss is most marked at higher frequencies and higher tone frequencies have shown to be perceived less pleasant and more annoying relative to low tone frequencies (Landström, Kjellberg, SÖDerberg, Nordström, 1994). Last, age could potentially highlight the contextual role of the acoustic environment. Past experiences, memories, and even traumas give a particular context to our perception and shape the soundscape, making individual perception highly diverse, depending on the content of experience/memory. While the increase in age can lead to appreciating different sound elements, lower age seems to be related to more arousing and vibrant sounds (Yang & Kang, 2005).

Gender association with soundscape Pleasantness and Eventfulness

Female participants showed to perceive the sounds more pleasant relative to male participants. Others reported that there are gender-related discrepancies in soundscape, arguing that women are more likely to react strongly to situations with emotional context comparing to men (Yang & Kang, 2005; Mehrabian & Russell, 1974). This could be also due to differences in auditory processing between the two genders which is consistent with existing predictions of female top-down and male bottom-up strategies in spatial processing (ability to find where objects are in space) (Simon-Dack, Friesen, Teder-Sälejärvi, 2009).

Regarding the relationship between psychological well-being, age, and gender with the soundscape, a conclusion can be drawn that the targeted indicators could better explain the variability in the Pleasantness rather than the Eventfulness.

Conclusion

In the current study we clustered the locations in which the data were collected in three different groups, based on the composition of their sound sources. Initially we validated that the soundscape Pleasantness and Eventfulness were significantly different in all clusters, derived from the sound source profile of the locations, with the natural-dominant cluster as the highest-rated in

Pleasantness, and the traffic-dominant cluster the highest-rated in Eventfulness. The multiple linear regression models showed that psychological well-being is significantly associated with Pleasantness of the soundscape in one cluster and total responses with heterogenous sound source compositions including all-locations and mixed-sources cluster. We later demonstrated that in all clusters the Pleasantness was strongly attributed to age, while it is shown to be associated with Eventfulness in only one cluster. Gender was exclusively associated with Pleasantness in one cluster. The findings of this study offer empirical grounds for developing and advancing theories on the influence of psychological well-being on the perception of the acoustic environment namely the soundscape.

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Appendix A

To what extent do you presently hear the following four types of sounds?

	Not at all	A little	Moderately	A lot	Dominates completely
Traffic noise (e.g. cars, buses, trains, airplanes)	○	○	○	○	○
Other noise (e.g. sirens, construction, industry, loading of goods)	○	○	○	○	○
Sounds from human beings (e.g. conversation, laughter, children at play, footsteps)	○	○	○	○	○
Natural sounds (e.g. singing birds, flowing water, wind in vegetation)	○	○	○	○	○

Please identify the single sound source which you perceive as the most prominent in the sound environment (e.g. traffic noise, children at play, water sounds, etc.)

____

To what extent did you hear this sound in the environment?

○ Not at all
○ A little
○ Moderately
○ A lot
○ Dominates completely

From an auditory point of view, how would you rate the water features in this space?

○ Very good
○ Good
○ Neither bad nor good
○ Bad
○ Very bad

From a visual point of view, how would you rate the water features in this space?

○ Very good
○ Good
○ Neither bad nor good
○ Bad
○ Very bad

How much would you say the water features dominate your field of view (visually)?

○ Not at all
○ A little
○ Moderately
○ A lot
○ Dominates completely

For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is...

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
Pleasant	O	O	O	O	O
Chaotic	O	O	O	O	O
Vibrant	O	O	O	O	O
Uneventful	O	O	O	O	O
Calm	O	O	O	O	O
Annoying	O	O	O	O	O
Eventful	O	O	O	O	O
Monotonous	O	O	O	O	O

Overall, how would you describe the present surrounding sound environment?

- ○ Very good
- ○ Good
- ○ Neither bad nor good
- ○ Bad
- ○ Very bad

Overall, to what extent is the present surrounding sound environment appropriate to the present place?

- ○ Not at all
- ○ Slightly
- ○ Moderately
- ○ Very
- ○ Perfectly

How loud would you say the sound environment is?

- ○ Not at all
- ○ Slightly
- ○ Moderately
- ○ Very
- ○ Extremely

How often do you visit this place?

- ○ Never / This is my first time here
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Very often

How often would you like to visit this place again?

- ○ Never
- ○ Rarely
- ○ Sometimes
- ○ Often
- ○ Very often

Please indicate for each of the five statements below which is closest to how you have been feeling over the last two weeks.

	All of the time	Most of the time	More than half of the time	Less than half of the time	Some of the time	At no time
I have felt cheerful and in good spirits	○	○	○	○	○	○
I have felt calm and relaxed	○	○	○	○	○	○
I have felt active and vigorous	○	○	○	○	○	○
I woke up feeling fresh and rested	○	○	○	○	○	○
My daily life has been filled with things that interest me	○	○	○	○	○	○

How old are you?

____

What is your gender? (Optional)

○ Male
○ Female
○ Non-conforming
○ Rather not say

What is your occupational status?

☐ Employed
☐ Unemployed
☐ Retired
☐ Student
☐ Other
☐ Rather not say

Please specify "Other":

____

What is the highest level of education you have completed?

○ Some high school
○ High school graduate
○ Some college
○ Trade/technical/vocational training
○ University graduate
○ Some postgraduate work
○ Postgraduate degree

Please specify your ethnicity.

- ○ White
- ○ Mixed/Multiple ethnic groups
- ○ Asian/Asian British
- ○ Black/African/Caribbean/Black British
- ○ Middle Eastern
- ○ Rather not say
- ○ Other ethnic group

Please specify "Other ethnic group":

____

What is the name of the university you study at, if applicable?

____

Would you consider yourself...

- ○ A local
- ○ A tourist
- ○ Other

Please specify "Other":

____

How long have you stayed in the UK?

- ○ Less than 6 months
- ○ More than 6 months, but less than 6 years
- ○ More than 6 years

Is there anything else you want to let us know about the sound environment? (Optional)

____

____

Thank you for your participation, please hand the tablet back to the researcher.

Filled by the Researcher:

SessionID	______________________
GroupID	______________________
Did this survey have Nicolas's cover sheet?	○ Yes ○ No
Was the participant...	○ Staying ○ Arriving ○ Leaving ○ Passing through
Was the participant...	○ Alone ○ In couple ○ In a group of 3 or more
Recordings taken?	☐ Continuous sound level ☐ Binaural recording ☐ 360 photo ☐ Spatial audio ☐ 360 Video
Any other notes?	___________________________
Was this a test?	○ Yes ○ No
Is this a paper input?	○ Yes ○ No

Appendix B

Location	L_{Aeq}	L_{A90}	L_{A10}	L_{A10}- L_{A90}	L_{AFmax}	L_{AFmin}
Camden Town	69- 84	62-72	70-90	7-25	92-100	55-62
Marchmont Garden	56-58	48-51	57-62	7-12	83-94	45-46
Pancras Lock	59-61	55-56	62-63	7	87-104	49-50
Regents Park Fields	53-64	45-46	55-61	9-16	82-88	42-44
Regents Park Japan	62	60	62	2	83	57
Russell Square	66-73	64-72	69-74	2-5	87-95	59-68
Tate Modern	62-63	55-58	64-65	8-9	85-88	51-53
Torrington Square	64-68	57-58	66-67	9	92-106	51
St. Paul's Cross	61	56	62	6	84	53
St. Paul's Row	62	59	64	6	81	55
Euston Tap	69-73	63-64	70-73	7-10	92-104	58-60

Table B.1 depicts the minimum and maximum value of acoustic metrics of each location during the survey periods.

Locations	N	Natural	Traffic	Human	Other
Camden Town	107	1.33	3.75	3.26	2.66
Euston Tap	102	1.66	3.71	2.56	2.95
Marchmont Garden	106	2.59	2.65	2.66	2.45
Pancras Lock	99	2.38	2.43	2.48	3.28
Regents Park Fields	116	3.09	2.4	2.9	1.87
Regents Park Japan	93	4.02	1.88	2.53	1.52
Russell Square	149	3.27	2.77	3.04	2.16
St. Pauls Cross	66	2.3	2.57	3.31	2.1
St. Pauls Row	69	1.76	2.55	3.45	2.25
Tate Modern	156	2.58	2.5	3.64	2.14
Torrington Square	117	1.93	3.19	3.25	2.81

Table B.2 demonstrates the sound source composition of the selected locations in London.

Figure B1a shows Euston Tap in London represents an acoustic environment dominated by traffic noise.

Figure B1b shows Regents Park Japan in London represents an acoustic environment with natural environmental sound

Figure B1c shows Pancras Lock in London represents an acoustic environment with a mix of natural and unnatural environmental sound

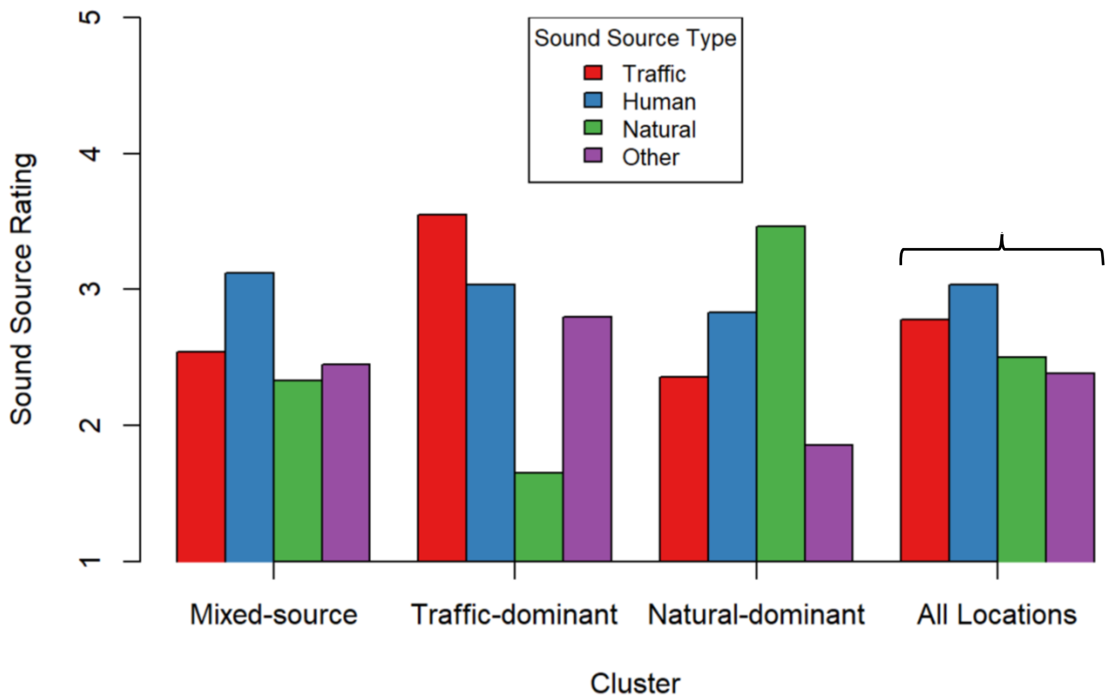

Figure B2. Sound source rating in three main clusters of natural-dominant, traffic-dominant, and mixed-sources and all-locations (total responses).

Figure B2 shows the mean sound source response for each of the 3 clusters and for the full dataset with all locations combined. From this we can see that these clusters have distinct sound source compositions, with varying proportions of each sound source type. It should be noted, however, that all three clusters and the ‘All-Locations’ set have approximately equal ‘Human’ sound source levels and we can say that the character of the acoustic environments of the locations are not distinguished by the presence or lack of ‘Human’ sounds. The first cluster has a slightly higher proportion of ‘Human’ sound sources relative to the other source types, but otherwise contains an equal mix of sound sources. This cluster (containing St. Pauls Row, St. Pauls Cross, Tate Modern, Marchmont Garden, Pancras Lock) is therefore designated as the ‘Mixed-source Cluster’ (n = 496). The second cluster is dominated by ‘Traffic’ sound sources and has a very low ‘Natural’ sound presence. This cluster (containing Euston Tap, Camden

Town, Torrington Sq.) is therefore designated the 'Traffic-dominant' cluster (n = 326). The final cluster is dominated by 'Natural' sound sources with low 'Traffic' and 'Other' sound source levels. This cluster (containing Regents Park Japan, Regents Park Fields, Russell Sq.) is therefore designated the 'Natural-dominant' cluster (n = 358).

It can be readily seen that these clusters generally correspond to the architectural typology and uses of the locations, where the natural-dominant cluster comprises large urban parks with a high proportion of green and natural features which separate the participants from the street. On the other hand, the traffic-dominant cluster is pedestrian areas along particularly high traffic streets in Central London with a mix of people passing through and others congregating. The mixed-source cluster present an intriguing case of locations which are either large pedestrian areas without many natural features, but are physically separated from the road (St. Pauls Row, Pancras Lock, Tate Modern) and small green spaces which, although they may be near the road, are designed to provide a small relaxing area for pedestrians (Marchmont Garden, St. Pauls Cross).