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FIELD AND LABORATORY SOUNDSCAPE ASSESSMENTS OF CONTRASTING URBAN SITES: A CASE STUDY IN TURIN

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Abstract

Soundscape studies allowed a broader understanding of how sound contributes positively to urban quality of life. Investigating soundscape effects in-situ entails logistical challenges that can be simplified by conducting laboratory-based assessments, which emerged as a viable alternative with sufficient ecological validity. This study aims to further investigate said validity by analyzing the soundscape of two distinct urban sites in Turin, both in-situ and in the laboratory, using third-order Ambisonics reproduction paired with a 360° video headset. To represent contrasting acoustic environments, a heavily trafficked intersection and a small public garden were chosen. Participants (N=15) rated each site using the ISO/TS 12913-3 perceptual attributes under both field and laboratory conditions. In accordance with the findings in the literature, the public garden soundscape was perceived as more pleasant in both conditions. Statistical comparison via Wilcoxon signed-rank tests, with Benjamini-Hochberg correction for multiple comparisons, revealed no significant differences between field and laboratory assessments. Results contribute to confirm the ecological validity of laboratory-based soundscape evaluation methods.

Keywords: *soundscape, urban sites, green spaces, Ambisonics, laboratory*

1. Introduction

Soundscape research has progressively shifted the acoustic environment discourse away from a purely noise-centric paradigm, centered on annoyance and health risk, toward a broader understanding of how sound contributes positively to urban quality of life [1], [2], [3]. Within this reorientation, the restorative potential of acoustic environments has gained particular attention: building on Kaplan and Kaplan's Attention Restoration Theory [4], [5], research has consistently shown that soundscapes rich in natural elements (birdsong, water, wind) are perceived as more pleasant and psychologically beneficial than those dominated by road traffic [6], [7], [8]. Complementary evidence from Trudeau et al. [9] and Hong et al. [10], [11] demonstrates that visual context further modulate acoustic appraisal, reinforcing the multisensory basis of restorative experience in urban settings.

However, investigating these effects in-situ entails considerable logistical demands: field experiments are sensitive to weather conditions, constrained by the number of participants that can be simultaneously managed on site, and dependent on the availability of subjects willing to commit time to outdoor sessions. Laboratory reproduction via high-fidelity techniques, particularly third-order Ambisonics combined with immersive visual rendering through head-mounted displays (HMDs), has emerged as a viable alternative to repeated field campaigns, showing sufficient ecological validity [12], [13], [14], [15], [16]. Despite growing evidence in this direction, standardized protocols remain lacking [16].

The present study contributes to this context by comparing subjective perceptual responses and psychoacoustic parameters collected from the same group of participants at two contrasting urban sites in Turin: a heavily trafficked intersection and a small public garden, located 800 meters apart along the same urban axis. Analyzed under both in-field and laboratory conditions, these two sites offer a naturalistic test case for addressing the following research question: can immersive laboratory reproduction faithfully preserve the perceived affective quality of markedly different urban acoustic environments, as it emerges in-situ? Establishing this equivalence is a precondition for using laboratory settings to investigate restorative urban soundscapes without sacrificing ecological validity.

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2. Materials and methods

The study was designed and conducted in two distinct main phases, preceded by pilot sessions aimed at familiarization with the sites and sound sources, and at verifying the instrumentation setup (Fig. 1). The first phase consisted of an in-situ soundwalk; the second phase focused on its laboratory reproduction and subsequent data acquisition at the Audio Space Lab (Department of Energy, Politecnico di Torino).

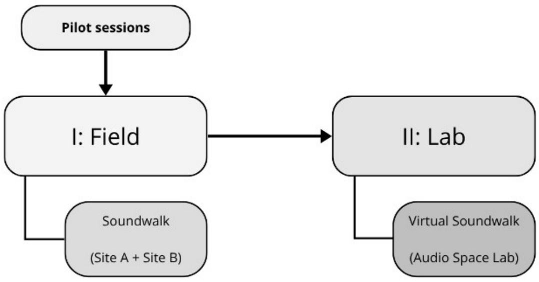

Figure 1. The 2-phases methodological approach.

2.1 In-field soundscape assessment (phase 1)

The in-situ soundwalk was performed in April 2025. Two locations within the city of Turin were selected, as shown on Fig. 2. For each site, the data required for the investigation (audio-visual recordings, subjective assessments) were acquired using acoustic instrumentation, a 360° camera and questionnaires completed by the participants. The two stops were selected during the pilot sessions, evaluating the timing of the experimental procedures. The difference regarding various environmental actors, such as sound and landscape features, played a crucial role in the selection of the stops: while Site A (Fig. 3a) presents a high traffic density, Site B (Fig. 3b) is located in a small public garden enclosed within a city square, which features prominent greenery and a water fountain. The soundwalk lasted 1h 30m in total.

Figure 2. Map of the soundwalk path in Turin (Italy).

a) b)

Figure 3. The two sites examined: a) Site A, b) Site B

2.1.1 Equipment (phase 1)

The instrumentation included a Head Acoustics HSU III.2 analog artificial head, paired with a Head Acoustics SQobold for binaural acquisitions (Head Acoustics, Germany); a 19-channel Zylia ZM-1 microphone (Zylia, Poland) connected to a Windows PC for multichannel recording; a NTi XL2 sound level meter (NTi Audio, Liechtenstein) for monitoring sound levels; and an Insta360 One X2 camera for video footage (Arashi Vision Inc, China). The raw 19-channel recordings were converted in 3rd order Ambisonics format, with a sampling rate of 48 kHz and a bit depth of 24 bits. Conversely, the stereo binaural audio was acquired in .hdf format and subsequently converted to .wav format (48 kHz/24-bit). Prior to each binaural acquisition, the artificial head was calibrated. For recordings involving the Zylia microphone, a dedicated patch was utilized within the Bidule software [17] environment to manage the 18-channel input of the laboratory.

Subjective evaluations were collected using a structured questionnaire derived from the ISO soundscape framework (method A) [18], [19]. The questionnaire was divided into four main sections: sound source identification, perceived affective quality, assessment of the surrounding sound environment, appropriateness of the surrounding sound environment; participants rated each section for both sites, using five-point Likert scales. The questionnaire also included socio-demographic items (age, gender) and self-reported information on familiarity with the site. All responses were collected anonymously and subsequently digitized.

2.1.2 Participants (phase 1)

The research was designed to evaluate the acoustic environment of two locations via a group of 15 self-assessed normal-hearing subjects, who responded to an open call addressed to students and staff of Politecnico di Torino. Participants (12 males and 3 females, with age ranging between 22 and 76 years old) evaluated the environments both in-field and under laboratory conditions.

In field conditions, all recordings for each stop were conducted for a duration of two minutes [20]. During these recordings, participants were instructed to remain silent and to listen actively to the surrounding acoustic environment. Upon completion of the recording and active listening phase, participants were asked to

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complete the questionnaire to acquire subjective evaluations. This procedure was repeated at each stop throughout the soundwalk.

2.2 Laboratory soundscape assessment (phase 2)

The laboratory experiment was held in June 2025 and was designed to reproduce as faithfully as possible the in-field soundwalk, previously conducted in phase 1. All participants who had previously taken part in the in-field soundwalk were invited to attend the laboratory replication. The two-month interval between the two assessments was chosen to mitigate recall biases and mnemonic effects: auditory recognition memory decays substantially faster than its visual counterpart [21], and retrospective soundscape judgments are known to diverge from momentary ones [22].

Each participant experienced, individually, the two selected locations through a combined audio-visual presentation. The Ambisonics recordings acquired during the in-field soundwalk were used as acoustic stimuli. To allow sufficient time for both re-experiencing the scene and completing the questionnaire, each 2-min recording was extended to a total duration of 7 min 30 s, seamlessly looping the original recordings to avoid abrupt interruptions. Playback levels were calibrated to match the in-field sound pressure levels. The visual component was reconstructed from 360° recordings captured in-field and was then delivered through an HMD.

During each session, participants were seated on a swivel chair at the center of the loudspeaker array and head rotation was allowed to fully explore the scene, as seen in Fig. 4. After approximately 2 min of audio-visual exposure, the video faded to black, prompting questionnaire completion (identical to the one administered in-field) while the corresponding audio continued in the background to maintain immersion. The procedure was repeated for both locations; between each assessment, participants had a one-minute break. The total session duration was approximately 10 min per participant.

At the end of the laboratory sessions, binaural recordings were carried out with the same artificial head used in the field, ensuring directly comparable psychoacoustic measurements.

Figure 4. Experimental set-up in the Audio Space Lab.

2.2.1 Equipment (phase 2)

The laboratory is equipped with an 18-loudspeaker array (16 full-range loudspeakers arranged on a spherical layout and 2 subwoofers), enabling third-order Ambisonics reproduction and fully surrounding the listener positioned in the middle of the room.

Video files were edited in DaVinci Resolve [23] to remove artefacts, apply fade-in/fade-out transitions, and rescale the resolution from 5.1K to 4K for compatibility. The two videos were delivered to a Meta Quest 2 (Meta, United States) HMD via a Windows PC running Unreal Engine [24]. Audio-visual synchronization was ensured through a custom MATLAB script coordinating playback between Bidule, Unreal Engine, and the HMD, enabling simultaneous and temporally aligned reproduction.

Final binaural acquisitions were again performed using the HSU III.2 analog artificial head, paired with SQobold (Head Acoustics, Germany).

2.2.2 Participants (phase 2)

Upon arrival, participants provided written informed consent for data collection and processing. Each subject completed the two audio-visual evaluations individually, following the same sequence of locations as in the field experiment. After questionnaire completion, brief verbal feedback was collected to support qualitative interpretation of the results.

2.3 Analyses

2.3.1 Objective parameters

The psychoacoustic parameters were analyzed for each binaural acquisition using the proprietary software ArtemiS (Head Acoustics, Germany). These included the equivalent continuous sound level (L_{Aeq}), Loudness (N), Sharpness (S), and Tonality (T). Additionally, the 50th percentile was calculated for Roughness (R_{50}) and Fluctuation strength (F_{50}).

2.3.2 Subjective data

The projection of responses onto the two-dimensional model of perceived affective quality (Pleasantness–Eventfulness) was performed using the open-source Python library Soundscapy [25]. Statistical differences between field and laboratory conditions were then assessed using the Wilcoxon signed-rank test for paired samples, selected in light of the ordinal nature of the data and the small sample size. To control the false discovery rate across the full set of comparisons, p-values were adjusted using the Benjamini-Hochberg procedure. Effect sizes were calculated as

$$r = Z/\sqrt{N} \quad (1)$$

to support interpretation of results independently of the small sample size.

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3. Results

3.1 Objective parameters

The two sites present markedly different acoustic profiles. In field conditions, Site A recorded a L_{Aeq} of 68.0 dB(A) and a Loudness of 25.0 sone, compared to 60.9 dB(A) and 16.7 sone at Site B; these differences, of approximately 7 dB(A) and 8 sone respectively, exceeded their respective Just-Noticeable Difference (JND) thresholds. Sharpness was considerably higher at Site B (1.60 acum vs. 1.24 acum), likely attributable to the spectral contribution of the fountain present at that location. Tonality showed the most pronounced inter-site contrast, with Site A yielding 0.72 tu_{HMS} against 0.15 tu_{HMS} at Site B, plausibly reflecting the tonal components introduced by continuous traffic flow and vehicle horn signals. Roughness was also higher at Site A (0.14 asper vs. 0.08 asper), consistent with the intermittent and modulated nature of traffic as an acoustic source.

Regarding field-to-laboratory correspondence, L_{Aeq} and Loudness were reproduced within or near their respective JND thresholds at both sites, indicating a generally faithful replication of overall acoustic energy. Fluctuation Strength remained stable across conditions. Sharpness, however, exceeded its JND at both sites (+0.23 acum at Site A, +0.34 acum at Site B), suggesting a systematic spectral imbalance introduced by the reproduction chain. Roughness also showed supra-threshold reductions in the laboratory at both sites, consistent with a partial attenuation of source modulation in the reproduced signal. Tonality variations between conditions remained difficult to assess in the absence of an established JND for this parameter. These results are condensed in Tab. 1.

Table 1. Psychoacoustic parameters variations between field and laboratory conditions; F=Field, L=Lab, Δ=L-F.

Param.	Site A			Site B			JND [26]
	F	L	Δ	F	L	Δ	
L_{Aeq} [dB(A)]	68.0	68.4	+0.4	60.9	62.6	+1.7	~3
N [sone]	25.0	26.0	+1.0	16.7	18.8	+2.1	~1
S [acum]	1.24	1.47	+0.23	1.60	1.94	+0.34	~0.04-0.08
T [tu_{HMS}]	0.72	0.54	-0.18	0.15	0.17	+0.2	n/a
R_{50} [asper]	0.14	0.10	-0.04	0.08	0.02	-0.06	~0.02
F_{50} [$vacil_{HMS}$]	0.2	0.2	0	0.2	0.2	0	n/a

3.2 Subjective parameters

Subjective evaluations revealed markedly different affective profiles between the two sites, consistent with their respective acoustic characteristics. Site A, dominated by heavy traffic noise, was appraised as chaotic, whereas Site B, characterized by natural sounds and urban greenery, yielded a notably less extreme profile, oriented toward pleasantness and calmness. These patterns, which show similar trends both in field and laboratory conditions, are illustrated in Fig. 5.

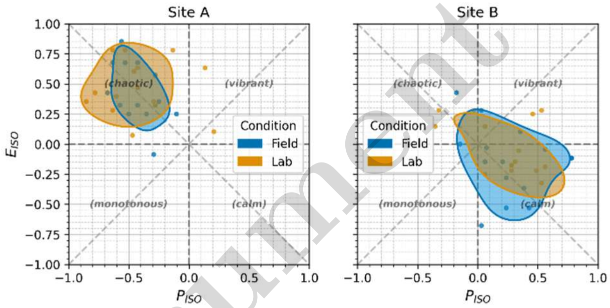

Figure 5. Subjective soundscape assessments for site A and B in field and laboratory conditions.

This picture is further corroborated by participants' responses in the Sound Source Identification section of the questionnaire, which show a predominance of traffic sounds and a complete absence of natural sounds at Site A, contrasting with the broad presence of natural sound sources at Site B. Notably, in the laboratory, participants at Site B reported a greater prominence of natural sounds compared to the field assessment. This finding, considered alongside the supra-threshold increase in Sharpness observed under laboratory conditions, may be attributable to the enhanced perceptual salience of the public garden fountain in the reproduced stimulus. Median values between conditions, as requested by ISO for the analysis of ordinal data, are shown in Fig. 6.

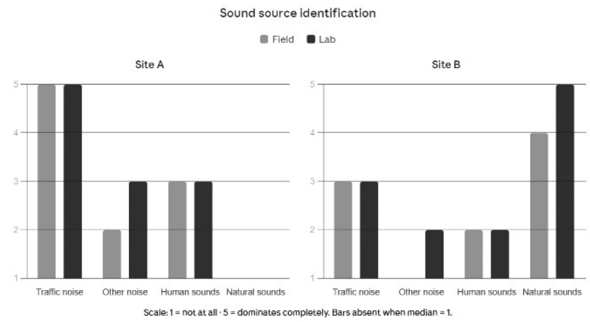

Figure 6. Sound source identification median values between sites and conditions.

From a statistical standpoint, no significant differences ($p < 0.05$) were found between field and laboratory attribute ratings at Site B. At Site A, a nominally

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significant effect was observed for the attribute Uneventful ($p = 0.029$, $r = -0.563$); however, this did not survive correction for multiple comparisons under the Benjamini-Hochberg procedure. This result confirmed the ecological validity of the laboratory reproduction.

4. Conclusions

This study successfully investigated the ecological validity of laboratory-based soundscape reproduction by comparing in-situ assessments with a controlled immersive setup (third-order Ambisonics and 360° video). Although minor technical discrepancies were observed in certain psychoacoustic parameters (notably Sharpness and Roughness), this analysis demonstrated a statistically consistent subjective perceptual experience across both conditions. After applying Benjamini-Hochberg corrections, no significant differences were found between field and laboratory ratings for the ISO/TS 12913-3 attributes, indicating a high degree of perceptual equivalence. While the limited sample size and gender distribution suggest caution in generalizing these results, the findings support the use of high-order Ambisonics and VR as a robust, logistically efficient tool for soundscape research and urban design.

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References

[1] J. Kang *et al.*, «Ten questions on the soundscapes of the built environment», *Building and Environment*, vol. 108, pp. 284–294, nov. 2016, doi: 10.1016/j.buildenv.2016.08.011.

[2] F. Aletta, T. Oberman, e J. Kang, «Associations between Positive Health-Related Effects and Soundscapes Perceptual Constructs: A Systematic Review», *IJERPH*, vol. 15, fasc. 11, p. 2392, ott. 2018, doi: 10.3390/ijerph15112392.

[3] L. Jiang *et al.*, «Ten questions concerning soundscape valuation», *Building and Environment*, vol. 219, p. 109231, lug. 2022, doi: 10.1016/j.buildenv.2022.109231.

[4] R. Kaplan e S. Kaplan, «The experience of nature : a psychological perspective», 1989.

[5] S. Kaplan, «The restorative benefits of nature: Toward an integrative framework», *Journal of Environmental Psychology*, vol. 15, fasc. 3, pp. 169–182, set. 1995, doi: 10.1016/0272-4944(95)90001-2.

[6] S. R. Payne, «The production of a Perceived Restorativeness Soundscape Scale», *Applied Acoustics*, vol. 74, fasc. 2, pp. 255–263, feb. 2013, doi: 10.1016/j.apacoust.2011.11.005.

[7] P. Krzywicka e K. Byrka, «Restorative Qualities of and Preference for Natural and Urban Soundscapes», *Front. Psychol.*, vol. 8, p. 1705, ott. 2017, doi: 10.3389/fpsyg.2017.01705.

[8] K. Uebel, M. Marselle, A. J. Dean, J. R. Rhodes, e A. Bonn, «Urban green space soundscapes and their perceived restorativeness», *People and Nature*, vol. 3, fasc. 3, pp. 756–769, giu. 2021, doi: 10.1002/pan3.10215.

[9] C. Trudeau, D. Steele, e C. Guastavino, «A Tale of Three Misters: The Effect of Water Features on Soundscape Assessments in a Montreal Public Space», *Front. Psychol.*, vol. 11, p. 570797, nov. 2020, doi: 10.3389/fpsyg.2020.570797.

[10] J. Y. Hong e J. Y. Jeon, «Influence of urban contexts on soundscape perceptions: A structural equation modeling approach», *Landscape and Urban Planning*, vol. 141, pp. 78–87, set. 2015, doi: 10.1016/j.landurbplan.2015.05.004.

[11] J. Y. Hong *et al.*, «Effects of contexts in urban residential areas on the pleasantness and appropriateness of natural sounds», *Sustainable Cities and Society*, vol. 63, p. 102475, dic. 2020, doi: 10.1016/j.scs.2020.102475.

[12] L. Maffei, M. Masullo, A. Pascale, G. Ruggiero, e V. P. Romero, «Immersive virtual reality in community planning: Acoustic and visual congruence of simulated vs real world», *Sustainable Cities and Society*, vol. 27, pp. 338–345, nov. 2016, doi: 10.1016/j.scs.2016.06.022.

[13] J. Y. Hong *et al.*, «Quality assessment of acoustic environment reproduction methods for cinematic virtual reality in soundscape applications», *Building and Environment*, vol.

Preliminary document

149, pp. 1–14, feb. 2019, doi: 10.1016/j.buildenv.2018.12.004.
[14] C. Tarlao, D. Steele, e C. Guastavino, «Assessing the ecological validity of soundscape reproduction in different laboratory settings», *PLoS ONE*, vol. 17, fasc. 6, p. e0270401, giu. 2022, doi: 10.1371/journal.pone.0270401.
[15] M. Yang, A. Heimes, M. Vorländer, e B. Schulte-Fortkamp, «Comparison of subjective evaluations in virtual and real environments for soundscape research», *The Journal of the Acoustical Society of America*, vol. 155, fasc. 6, pp. 3715–3729, giu. 2024, doi: 10.1121/10.0026123.
[16] Y. Lu e S.-K. Lau, «The ecological validity of laboratory experiments in soundscape and landscape research: A systematic review and meta-analysis», *Applied Acoustics*, vol. 232, p. 110582, mar. 2025, doi: 10.1016/j.apacoust.2025.110582.
[17] Plogue Art et Technologie, Inc., *Bidule*. (agosto 2025). Plogue Art et Technologie, Inc. Consultato: 14 febbraio 2026. [Online]. Disponibile su: https://www.plogue.com/products/bidule.html
[18] *ISO 12913-2, Acoustics — Soundscape — Part 2: Data collection and reporting requirements*, ISO 12913-2, Geneva., 2018.
[19] *ISO 12913-3, Acoustics — Soundscape — Part 3: Data analysis*, ISO 12913-3, Geneva., 2019.
[20] A. Mitchell *et al.*, «The Soundscape Indices (SSID) Protocol: A Method for Urban Soundscape Surveys—Questionnaires with Acoustical and Contextual Information», *Applied Sciences*, vol. 10, fasc. 7, p. 2397, apr. 2020, doi: 10.3390/app10072397.
[21] M. A. Cohen, T. S. Horowitz, e J. M. Wolfe, «Auditory recognition memory is inferior to visual recognition memory». *Proceedings of the National Academy of Sciences of the United States of America*, *106*(14), 6008–6010. https://doi.org/10.1073/pnas.0811884106
[22] J. Steffens, D. Steele, e C. Guastavino, «Situational and person-related factors influencing momentary and retrospective soundscape evaluations in day-to-day life», *The Journal of the Acoustical Society of America*, vol. 141, fasc. 3, pp. 1414–1425, mar. 2017, doi: 10.1121/1.4976627.
[23] Blackmagic Design, *DaVinci Resolve*. (2024). Blackmagic Design. Consultato: 24 febbraio 2026. [Online]. Disponibile su: https://www.blackmagicdesign.com
[24] Epic Games, *Unreal Engine*. (2023). Epic Games. Consultato: 15 febbraio 2026. [Online]. Disponibile su: https://www.unrealengine.com/
[25] A. Mitchell, F. Aletta, e J. Kang, «How to analyse and represent quantitative soundscape data», *JASA Express Letters*, vol. 2, fasc. 3, p. 037201, mar. 2022, doi: 10.1121/10.0009794.
[26] H. Fastl e E. Zwicker, *Psychoacoustics: Facts and Models*. Berlin, Heidelberg: Springer, 2007. doi: 10.1007/978-3-540-68888-4.

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