Comparing soundscape perception in-field and in laboratory: a two-site study in Turin, Italy

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Over the past two decades, laboratory reproduction of soundscapes has been extensively investigated. Technologies such as head-mounted displays (HMDs) and Ambisonics audio have enabled virtual soundwalks to achieve acceptable levels of ecological validity. However, the perceptual impact of higher-fidelity immersive audio-visual reproduction systems has yet to be systematically assessed. Using third-order Ambisonics playback and 360° video delivered through an HMD, this study compared soundscape perception in-field and under laboratory conditions at two urban sites in Turin, Italy, within an Italian-speaking participant cohort. Subjective ratings were evaluated via Wilcoxon signed-rank tests with Benjamini-Hochberg correction. Psychoacoustic parameters were largely stable across experimental phases, with only minor variations observed in sharpness and roughness, suggesting overall accurate acoustic reproduction. No statistically significant differences were identified between conditions following correction for multiple comparisons, pointing to a substantial degree of perceptual equivalence. Nevertheless, directional shifts in perceptual responses were observed for one site prior to correction, highlighting the influence of contextual and psychological factors on subjective soundscape evaluation.
Keywords: soundscape, soundwalk, laboratory, ecological validity

Confronto della percezione del soundscape in campo e in laboratorio: uno studio su due siti a Torino
Nel corso degli ultimi vent'anni, le riproduzioni in laboratorio del soundscape sono state studiate estensivamente. Tecnologie come visori per realtà virtuale (RV) e audio Ambisonics hanno permesso alle passeggiate sonore virtuali il raggiungimento di livelli accettabili di validità ecologica. Tuttavia, l'impatto percettivo di sistemi di riproduzione audio-visiva immersivi ad alta fedeltà non è ancora stato valutato sistematicamente. Usando una riproduzione audio in Ambisonics del terzo ordine e video a 360° riprodotti su visore per RV, questo studio ha comparato la percezione del soundscape in campo e in condizioni di laboratorio in due siti urbani della città di Torino. I parametri psicoacustici sono risultati in larga misura stabili nel corso delle fasi sperimentalii, con sole variazioni minori osservate per sharpness e roughness, suggerendo una complessiva accuratezza della riproduzione acustica. A livello soggettivo, a seguito di analisi tramite test dei segni per ranghi di Wilcoxon e correzione di Benjamini-Hochberg per confronti multipli, non sono state identificate differenze statisticamente significative tra le due condizioni, indicando un sostanziale grado di equivalenza percettiva. Cionondimeno, spostamenti direzionali nelle risposte percettive sono stati osservati per uno dei due siti prima della correzione, evidenziando l'influenza di fattori contestuali e psicologici nella valutazione soggettiva del soundscape.
Parole chiave: soundscape, soundwalk, laboratorio, validità ecologica

1 | Introduction

Since its introduction by Southworth [1] and subsequent theoretical consolidation by Schafer [2], the concept of soundscape has evolved into a multidisciplinary framework emphasizing the perceptual and contextual dimensions of the acoustic environment [3–6]. ISO 12913-1 defines soundscape as "acoustic environment as perceived or experienced and/or understood by a person or people, in context" [7]. Various quantitative frameworks have been proposed to characterize the soundscape, and existing methodologies have extensively explored the ecological validity of its reproduction in the laboratory [8–12]. Laboratory experiments ensure strict control of confounding variables but often face challenges reproducing the multisensory context underpinning holistic soundscape experience, whereas in-situ surveys preserve ecological authenticity at the expense of reproducibility and statistical scalability. Because soundscape perception emerges from multiple interacting factors, large and diverse datasets are typically required, limiting the generalizability of site-specific case studies [13,14]. Over the past two decades, however, research has shown that ecological validity can be substantially preserved through high-fidelity reproduction techniques. Studies based on Ambisonics audio playback demonstrated the comparability of laboratory and in-situ perceptual outcomes [8,15]. Subsequent virtual reality (VR) investigations further indicated that this spatial reproduction approach, when combined with immersive visualization through head-mounted displays (HMDs), can reliably replicate core soundscape dimensions [10,16]. Recent frameworks distinguishing verisimilitude from veridicality further identify Ambisonics and immersive VR as the most consistent configuration for enhancing laboratory ecological validity [11,12,17].

Within this context, the present study evaluates two urban sites in Turin through a controlled comparison between an in-field soundwalk and its laboratory reconstruction at the Politecnico di Torino. By jointly analyzing objective psychoacoustic parameters and subjective assessments, the study also seeks to examine laboratory–field correspondence within the Italian cultural context, where previous cross-cultural evidence suggests specific affective appraisal patterns relative to Anglo-Saxon cohorts [18].

2 | Materials and methods

The research was structured and carried out in two separate main phases preceded by preliminary pilot sessions, as seen in Fig. 1; these sessions, conducted without any participant, were aimed at familiarizing the study coordinators with the selected sites and at validating the instrumentation configuration on site. The first phase consisted of an in-situ soundwalk; the second phase focused on its reproduction and subsequent data acquisition at the Audio Space Lab (Department of Energy, Politecnico di Torino).

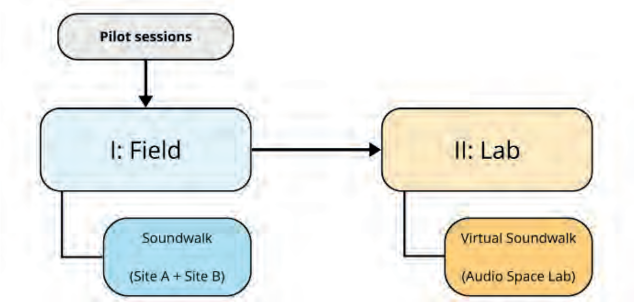

Fig. 1 – The two-phase methodological approach
L'approccio metodologico in due fasi

2.1 | In-field soundscape assessment (phase 1)

Four locations within the city of Turin were initially considered for the in-situ soundwalk. Subsequently, two stops (Site A and Site B, as can be seen in Fig. 2) were selected because of their difference regarding various environmental actors, such as sound and landscape features. Notably, Site B is characterized by notably higher traffic density compared to Site A, which is located in a pedestrian area. The pilot sessions conducted during March 2025 allowed the organizers to evaluate the timing of the experimental procedures.

The in-situ soundwalk was conducted on 15/04/2025, which presented fair weather conditions with mean temperature of 14 °C and mean relative humidity 86%. For each site, the data required for the investigation (binaural and Ambisonics audio recordings, sound pressure level acquisitions, 360° video recordings, subjective assessments) were acquired via acoustic instrumentation, a camera and questionnaires completed by the participants.

Fig. 2 – Map of the soundwalk path in Turin
Mappa della passeggiata sonora a Torino

Binaural acquisitions allowed the collection of the psychoacoustic parameters needed to characterize the environmental acoustic profile; these included the equivalent continuous sound level (L_{Aeq}), Loudness (N), Sharpness (S) and the 50th percentiles for Roughness (R_{50}) and Fluctuation strength (F_{50}). Subjective assessments were collected using a structured questionnaire derived from the ISO soundscape framework (method A) [19,20].

Perceptual aspects regarding the soundscape of both sites were assessed by participants using five-point Likert scales. The questionnaire included core perceptual attributes (e.g., pleasant, calm, vibrant, chaotic, monotonous, annoying, eventful), enabling projection of responses onto the Pleasantness–Eventfulness dimensions. Socio-demographic items (age, gender) and self-reported information on familiarity with the site were also included. All responses were collected anonymously and subsequently digitized.

2.1.1 | Equipment

Various devices were employed for the acquisition of audiovisual data, as shown in Fig. 3. Specifically, 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 array (Zylia, Poland) connected to a Windows PC for Ambisonics recording; a sound level meter for monitoring sound levels; and an Insta360 One X2 camera for video footage (Arashi Vision Inc, China).

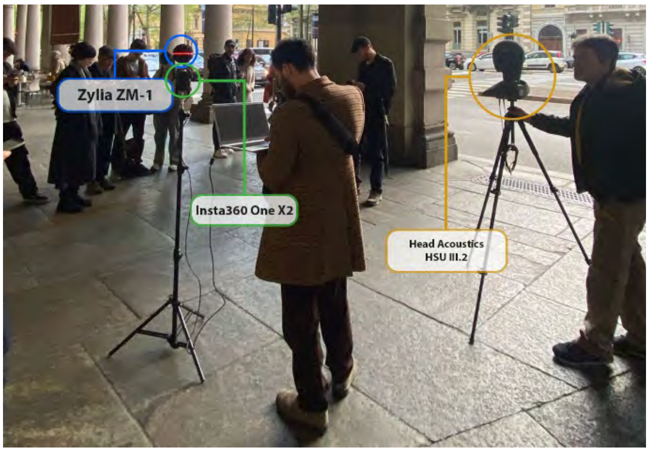

Fig. 3 – Devices employed for the acquisition of acoustic data
Strumentazione impiegata per l'acquisizione dei dati acustici

Immersive audio was recorded 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 [21] environment to manage the 19-channel input.

2.1.2 | Participants

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. Gender imbalance in the participant sample reflected the demographics of the academic environment and availability of the subjects. In field conditions, all recordings were conducted for a duration of two minutes [22]. 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 complete a questionnaire for soundscape assessment. This procedure was repeated at each stop throughout the soundwalk.

2.2 | Laboratory soundscape assessment (phase 2)

The laboratory experiment 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-situ soundwalk were invited to attend the laboratory replication, implemented during the first week of June 2025 in the Audio Space Lab at Politecnico di Torino.

The two sessions were separated by an interval of approximately seven weeks. This interval was primarily determined by logistical constraints related to laboratory scheduling and participant availability; however, it does not rule out carry-over effects related to memory of the field experience, possible re-exposure to the sites between sessions, or contextual differences. These limitations are inherent to within-subjects field-to-laboratory designs in soundscape research and are consistent with the broader challenges of ecological validity discussed in the literature [23].

2.2.1 | Laboratory setup

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. Each participant experienced, individually, the two selected locations through a combined audio-visual presentation, as seen in Fig. 4. 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 prevent any sudden interruptions. Playback levels were calibrated to match the in-field sound pressure levels (63.7 dB for Site A and 75 dB for Site B).

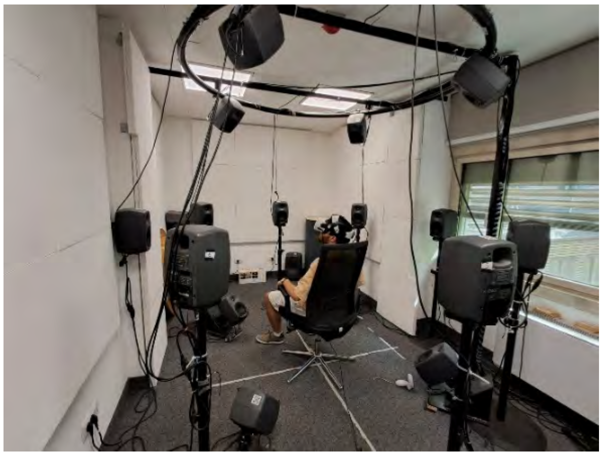

Fig. 4 – Experimental set-up in the Audio Space Lab
Setup sperimentale in Audio Space Lab

Subsequently, each Ambisonics track was reproduced and re-recorded at the listening position. The gain required to reach the target level, defined as the Z-weighted equivalent level (L_Z) measured at each stop, was computed via a dedicated script in MATLAB and manually applied before playback of each scenario. The visual component was reconstructed from 360° recordings captured in situ. Video files were edited in DaVinci Resolve [24] 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 [25]. 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.

2.2.2 | Participants

Upon arrival, participants provided written informed consent for data collection and processing. Each subject completed the four 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

Psychoacoustic parameters were analyzed for each binaural acquisition using the proprietary software ArtemiS (Head Acoustics, Germany). Regarding subjective data, the projection of questionnaire responses onto the two-dimensional model of perceived affective quality was performed using the open-source Python library Soundscapy [26]. Statistical differences between in-field and laboratory conditions were subsequently evaluated by means of the Wilcoxon signed-rank test for paired samples, chosen given the ordinal nature of the variables and the limited sample size. A significance threshold of $\alpha = 0.05$ was adopted for all tests. In order to control the false discovery rate across the entire set of pairwise comparisons, p-values were corrected applying the Benjamini-Hochberg procedure [27]. Effect sizes were calculated as in Equation (1) to support interpretation of results independently of the small sample size.

$$r = Z/\sqrt{N} \tag{1}$$

3 | Results

3.1 | Objective parameters

Laboratory values for L_{Aeq} and Loudness were comparable to those measured in-field, indicating a generally faithful reproduction of the acoustic energy content. Sharpness values were slightly elevated compared to field measurements, reflecting possible differences in spectral balance introduced by the reproduction system. Fluctuation Strength values remained equal across conditions, while small variations were observed for Roughness. These descriptors were particularly sensitive to the presence of intermittent or modulated sound sources, such as traffic flows. The values obtained for each site in-field and in the laboratory are presented in Tab. 1 and Tab. 2, for Site A and Site B respectively. Significant figures were defined according to the just noticeable difference (JND) of each parameter [28,29].

Tab. 1 – Psychoacoustic parameters for in-field and in-lab conditions (Site A)

Parametri psicoacustici in campo e in laboratorio (Sito A)

Parameter	*Field*	*Lab*	*Difference*	*JND [28,29]*
L_{Aeq} [dB(A)]	58.2	56.4	–1.8	~1
N [sone]	12.6	11.8	–0.8	~0.5
S [acum]	1.16	1.42	+0.27	~0.04-0.08
R_{50} [asper]	0.14	0.09	–0.05	~0.04
F_{50} [vacil$_{HMS}$]	0.2	0.2	0	~0.012

Tab. 2 – Psychoacoustic parameters for in-field and in-lab conditions (Site B)

Parametri psicoacustici in campo e in laboratorio (Sito B)

Parameter	**Field**	**Lab**	**Difference**	**JND** [28,29]
L_{Aeq} [dB(A)]	68.0	68.4	+0.4	~1
N [sone]	25.0	26.0	+1.0	~0.5
S [acum]	1.24	1.47	+0.23	~0.04-0.08
R_{50} [asper]	0.14	0.10	-0.04	~0.04
F_{50} [vacil$_{HMS}$]	0.2	0.2	0	~0.012

In summary, the psychoacoustic analysis confirmed that the laboratory reproduction maintained the principal energetic and perceptual characteristics of the original soundscapes of both sites. Deviations were primarily associated with spectral and temporal attributes rather than overall level, providing a quantitative basis for interpreting subsequent subjective comparisons.

3.2 | Subjective parameters

The comparison between in-field and laboratory subjective evaluations revealed some differences emerging only for selected attributes in Site A. For Site B, the overall configuration within the Pleasantness-Eventfulness circumplex space remained stable between conditions. Subjective assessments for both sites are reported on Fig. 5.

From a statistical standpoint, results showed a different pattern across the two sites. For Site B, Wilcoxon signed-rank tests yielded $p > 0.05$ for all eight ISO 12913-1 perceptual attributes, with p-values ranging from 0.317 (*calm*) to 1.000 (*annoying*) and effect sizes ranging from $|r| = 0.07$ (*monotonous*) to $|r| = 0.26$ (*calm*, *annoying*). This indicates a high degree of perceptual consistency between the field and laboratory conditions and suggests that the laboratory reproduction was able to faithfully convey the auditory character of the in-situ environment as perceived by participants.

For Site A, a different pattern emerged. Prior to correction, three attributes exhibited p-values below the conventional $\alpha = 0.05$ threshold: *pleasant* ($Z = -2.26$, $p = 0.024$, $|r| = 0.58$) and *annoying* ($Z = -2.07$, p = 0.039, $|r| = 0.53$), both with large effect sizes, and *calm* ($Z = -1.81$, $p = 0.071$, $|r| = 0.47$), which approached but did not reach the threshold. In the laboratory

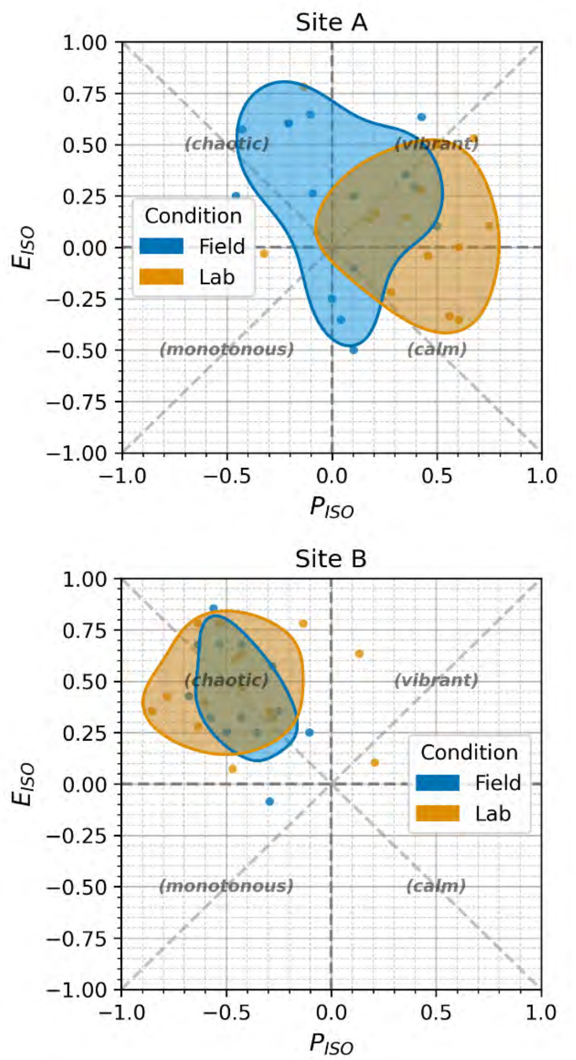

Fig. 5 – Subjective soundscape assessments for site A and B in field and laboratory conditions

Valutazioni soggettive del soundscape per i siti A e B in campo e in laboratorio

condition, participants rated the acoustic environment as more pleasant and less annoying than in the field, with a tendency toward calmer perception. Following application of the Benjamini–Hochberg correction for multiple comparisons, however, none of these differences survived the adjusted significance thresholds, and the remaining five attributes showed no noteworthy differences (p = 0.102–0.608, $|r|$ = 0.13–0.42). These results should accordingly be interpreted as exploratory, suggesting directional trends rather than confirmed effects.

4 | Discussion

A plausible explanation for the markedly altered perception of Site A can be attributed to the presence of music within the soundscape. Music is known to exert both positive and negative influences on perceived soundscape quality, depending on contextual and cognitive factors [30–32]. In Site A case, music constituted the dominant acoustic component, and subjective appraisal appears to have been strongly shaped by the circumstances in which it was encountered. During the in-field soundwalk, participants were explicitly engaged in evaluative listening; under such task-oriented conditions, music may have been perceived as intrusive, functioning as a contextually incongruent sound source [33] – i.e., one that does not conform to prior expectations of the acoustic environment or that is present to an unusual extent. Conversely, in the laboratory reproduction, the reduced realism of the context and the mediated nature of recall may have attenuated this disturbance effect, allowing the musical component to be perceived as comparatively pleasant. Psychoacoustic analysis further suggests that alterations in spatial rendering, particularly the partial loss of source directivity in laboratory playback, may have contributed to this perceptual shift; similar cases are also discussed in the literature [34,35]. Regarding familiarity with VR reproduction, no significant age effect was observed.

Overall, the findings indicate that contextual expectation, task framing, and spatial fidelity interact significantly in shaping the affective evaluation of urban soundscapes. Nevertheless, subjective ratings were broadly consistent with established European patterns, including the association of lower pleasantness with traffic noise and higher vibrancy with human sounds [36], and do not suggest pronounced culturally specific deviations in affective appraisal. This result aligns with prior evidence from the Italian validation of the ISO 12913-2 perceptual attributes [37], which identified only slight cultural differences relative to the English version, insufficient to disrupt the circumplex structure.

5 | Conclusions

This study compared the soundscape of two urban sites in Turin under two conditions: in-field listening and laboratory reproduction of their audio-visual characteristics. Objective (psychoacoustic parameters) and subjective (questionnaire-based perceptual ratings from 15 participants) data were collected during a soundwalk conducted in April 2025 and subsequently replicated under controlled conditions at the Politecnico di Torino.

This analysis demonstrated a statistically consistent subjective perceptual experience across both conditions. Differences observed in the laboratory were attributable partly to acoustic rendering constraints and partly to contextual–psychological factors, as exemplified by the altered appraisal of a musical component in Site A. Following the application of the Benjamini-Hochberg correction, no statistically significant differences were identified between in-field and laboratory ratings across the ISO 12913 perceptual attributes, pointing to a substantial degree of perceptual equivalence between the two conditions. The findings are also largely consistent with established European soundscape appraisal patterns, suggesting that the Italian cultural context does not introduce strong systematic deviations within the ISO 12913-1 circumplex framework. Overall, though the small sample size, unbalanced gender distribution and the approximately seven-week interval between sessions call for prudence in extending these findings to broader populations, they corroborate previous evidence on the ecological validity of laboratory-based soundscape reproduction. Further improvements in veridicality may be achieved through enhanced visual realism, integration of physiological monitoring, and expanded use of VR/AR technologies. In this perspective, the Audio Space Lab represents a viable infrastructure for immersive and methodologically robust laboratory soundscape assessment, potentially reducing reliance on repeated field-based soundwalks.

Conclusioni

Questo studio ha comparato il soundscape di due siti urbani a Torino in due condizioni: ascolto in campo e riproduzione in laboratorio delle loro caratteristiche audio-visive. I dati oggettivi (parametri psicoacustici) e soggettivi (valutazioni percettive tramite questionario, compilato da 15 partecipanti) sono stati raccolti durante una passeggiata sonora condotta nell'aprile 2025 e successivamente replicata in condizioni controllate presso il Politecnico di Torino.

L'analisi ha dimostrato una esperienza percettiva statisticamente consistente in entrambe le condizioni. Le differenze osservate in laboratorio sono risultate attribuibili in parte a vincoli di rendering acustico e in parte a fattori contestuali e psicologici, come esemplificato dalla diversa valutazione della componente musicale nel Sito A. A seguito dell'applicazione della correzione di Benjamini-Hochberg, non sono state identificate differenze statisticamente significative tra le valutazioni in campo e in laboratorio per gli attributi percettivi ISO 12913-1, indicando un sostanziale grado di equivalenza percettiva tra le due condizioni. I risultati sono inoltre in larga misura coerenti con i pattern di valutazione del soundscape da parte di soggetti europei consolidati in letteratura, suggerendo che il contesto culturale italiano non introduce deviazioni sistematiche rilevanti all'interno del framework delineato dalla norma ISO 12913-1. Nel complesso, sebbene la ridotta dimensione del campione, la distribuzione di genere sbilanciata e l'intervallo di circa sette settimane tra le sessioni richiedano prudenza nell'estendere questi risultati a popolazioni più ampie, essi corroborano le evidenze esistenti sulla validità ecologica della riproduzione del soundscape in laboratorio. Ulteriori miglioramenti in termini di veridicità potranno essere raggiunti attraverso un maggiore realismo visivo, l'integrazione del monitoraggio fisiologico e un più esteso utilizzo di tecnologie VR/AR. In questa prospettiva, l'Audio Space Lab del Politecnico di Torino si presenta come un'adeguata infrastruttura per una valutazione del soundscape in laboratorio immersiva e metodologicamente robusta, con il potenziale di ridurre la dipendenza da passeggiate sonore ripetute sul campo.

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