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Tropical Environmental Stimuli Database (TESD): A Validated Database of Tropical Environmental Stimuli

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Article

Keywords: environmental stimuli database, perceived restorativeness, restorative environments, tropical environments, urban green space

Posted Date: November 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11534093/v1

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Additional Declarations: No competing interests reported.

Abstract

The restorative potential of natural environments has been widely documented for its positive effects on cognitive functioning, mood, and overall well-being. However, research in this area remains limited by the lack of standardised and geographically diverse environmental stimuli. Existing databases are predominantly based on temperate or Western settings, which limits their ecological validity for studies conducted in tropical regions. To address this gap, we introduce the Tropical Environmental Stimuli Database (TESD), a validated and continuously expanding repository of stimuli representing natural, mixed urban-nature, and urban settings within tropical contexts. The TESD comprises 360 high-quality, standardised stimuli across visual-only, audio-only, and audio-visual (bimodal) formats, depicting environments that range from natural landscapes to densely built urban areas in Malaysia. Each stimulus is accompanied by normative ratings for perceived naturalness and four restorative qualities derived from Attention Restoration Theory: fascination, being away, scope, and compatibility. The paper details the procedures used to collect, standardize, and validate the TESD. By capturing the distinctive features of tropical environments, the TESD offers a robust and ecologically relevant resource for advancing research on restorative environments, urban green space design, nature-based interventions, and experimental studies that investigate the underlying mechanisms through which natural environments promote health and well-being.

1.0 Introduction

A growing body of research demonstrates that engagement with natural environments supports multiple dimensions of health and well-being, including reductions in psychological distress, improvements in cognitive, affective, and physical functioning (e.g. [1–4]). The restorative effects of nature are explained by several dominant theories, including the attention restoration theory (ART [5]), stress reduction theory (SRT [6, 7]), prospect-refuge theory [8], and the conditioned restoration theory [9]. The attention restoration theory suggests that natural environments promote bottom-up processing, thus facilitate the recovery from depleted attentional resources [5]. This theory serves as the foundation for the concept of perceived restorativeness [10], which measures the extent to which an individual perceives an environment as restorative. The stress reduction theory, on the other hand, posits that exposure to natural environments elicit positive emotional responses, which then alleviate psychological stress. Ulrich et al. [7] argues that this voluntary response reflects an innate human affinity for natural environments. The prospect-refuge theory [8] is closely related to this notion, whereby human favours environments that offer both opportunities to observe (prospect) and to hide and conceal from danger (refuge).

However, opportunities for direct exposure to natural environments are often limited. Urbanisation and dense built environments can restrict access to green spaces [11], while individual factors such as mobility limitations [12], safety concerns [13], and time constraints [14] further reduce the feasibility of spending time outdoors. In such situations, experiencing nature through images, videos or natural soundscapes provide a viable alternative. Brief video exposure to natural settings have been shown to

increase attentional capacity and positive emotions [15]. Interestingly, even static images, when paired with natural soundscapes, have been found to decrease heart rate and improve subjective restorativeness [16].

While virtual exposure has been shown to be a valuable alternative for studying restorative effects of nature, the lack of consistency in the stimuli used across studies poses challenges for comparison, reproducibility and generalizability. First, studies vary widely in how they present natural environments, from static images (e.g. [17, 18]) and videos (e.g. [19, 20]), to immersive virtual environments (e.g. [21]), and even real-world settings (e.g. [22]). These differences result in varying levels of sensory richness and immersion, which can meaningfully influence restorative outcomes. Second, there is substantial variability in the environmental types represented in past research. For instance, Benz et al. [23] used videos based on four relaxation themes including river stream with bird sounds, rain falling in the thicket, sunny tropical beach, and fireplace; whereas Jiang et al. [24] used videos of neighbourhood street covered with tree canopy. Third, many studies also differ in the source and quality of their stimuli, drawing from crowdsourced images (e.g. [25]) or researcher-captured stimuli (e.g.[24]) that lacks standardisation in composition or environmental context. Last, many stimuli used in past research were unvalidated, lacking normative ratings on dimensions such as perceived naturalness or restorativeness. This absence of standardised ratings may partly account for inconsistent findings across studies, whereby some report significant restorative benefits (e.g. [26]) while others fail to replicate such effects (e.g. [27]). The variability in the literature therefore highlights the need for standardised, validated databases of environmental stimuli.

1.1 Existing Databases

To support experimental investigations into the restorative and affective effects of nature exposure, a number of environmental image databases have been developed. Some databases primarily capture affective responses to nature images. For instance, the e-Nature Positive Emotions Photography Database (e-NatPOEM [28]) includes 431 photographs (403 nature images and 28 control images) normatively rated for valence and arousal, offering valuable insights into the emotional qualities of natural scenes. Similarly, the Nencki Affective Picture System (NAPS [29]) provides standardised ratings for valence, arousal, and approach-avoidance across 1,356 images, which includes a subset of natural landscapes. While valuable for studying affective reactions to natural imagery, these databases do not incorporate dimensions central to restoration theories, such as perceived naturalness and restorativeness.

Some other databases focus on semantic and perceptual categorisation. For instance, the Southampton-York Natural Scenes (SYNS [30]) provides 88 scenes (78 outdoor, 12 indoor) sampled across 25 categories including woodlands, coastal, and rural landscapes in Hampshire, United Kingdom. Originally designed for visual perception research, its inclusion of natural scene categories has enabled its use in studies examining responses to environmental stimuli. However, the database is limited to visual stimuli and was not developed to support nature-urban comparisons in environmental psychology

research, as urban and natural categories are treated as separate scene types without a structured nature-urban contrast or normative ratings on environmental psychology constructs.

More recently, the Salford Nature Environments Database (SNED [31]) was developed to support research on restorative environments. SNED includes 500 images (435 natural scenes and 65 urban scenes), each rated on constructs such as familiarity, mystery, interest, pleasantness, valence, arousal, and approach-avoidance, as well as physical properties of the images. Bendall et al. [31] mapped these ratings onto ART-related concepts, interpreting mystery and interest as proxies for fascination, and familiarity as a proxy for compatibility. These ratings are valuable in examining the perceptual features that may contribute to restorative outcomes. However, SNED does not include direct measures derived from the Perceived Restorativeness Scale (e.g., fascination, being away, compatibility, and scope [10]), which remain the primary instrument for operationalising ART [5]. The use of proxy measures rather than PRS items limits the direct comparability of SNED ratings to studies grounded in the PRS framework.

Taken together, existing databases have made important contributions to research on affective responses and restorative environments, yet several gaps remain. Most databases rely on a single sensory modality, typically static visual images, which limits their ability to capture the multisensory nature of real-world environmental experiences. Second, the databases are geographically constrained, with stimuli drawn primarily from temperate or Western regions, offering limited representation of tropical or Southeast Asian environments. Existing collections of stimuli also tend to emphasize a simple nature-urban dichotomy, with relatively little attention given to environments that lie along an urban-nature continuum. Furthermore, none of the reviewed databases provides direct normative ratings derived from the Perceived Restorativeness Scale, despite the central role of perceived restorativeness in restoration theories such as ART. As a result, there remains a need for standardised and validated environmental stimulus databases that integrate multisensory stimuli, broader geographical representation, environments spanning the urban-nature continuum, and normative ratings for measures of perceived restorativeness.

1.2 The Tropical Environmental Stimuli Database (TESD)

A distinctive feature of the TESD is the inclusion of restorative indices derived from participants' ratings using validated versions of the Perceived Restorativeness Scale. By providing standardised measures of perceived naturalness and the key restorative dimensions (i.e., fascination, being away, compatibility, and scope) proposed in Attention Restoration Theory, the database does not only offer a collection of environmental stimuli, but also provides normative data of restorative potential. Fascination refers to the extent to which an environment captures attention effortlessly, without requiring directed cognitive effort. Being away refers to the psychological distance from everyday routines and demands, allowing a temporary shift in mental framework. Compatibility refers to the fit between environment and individual's goals, expectations and interests. On the other hand, scope refers to the environment's ability to provide opportunities that allow for sustained exploration and engagement. This normative data thus allows researchers to select stimuli not only based on environmental characteristics (e.g., natural, urban, or

mixed settings) but also on quantified psychological outcomes, thereby facilitating more targeted experimental designs and enhancing comparability across studies.

While criticism exists regarding the use of images in restoration research, the TESD fills the gap by incorporating auditory stimuli as well as bimodal stimuli (video with corresponding sounds). A qualitative study by Kjellgren and Buhrkall [32] found that viewing pictures of natural environments without auditory input induced negative affective states in some participants, including stress, boredom, and reduced concentration. More importantly, the restorative experiences of visually impaired individuals have been largely overlooked in the environmental restoration literature [33]. Incorporating auditory stimuli is therefore essential, as people with visual impairments often rely on sound as a primary means of experiencing and connecting with nature [34]. Moreover, the inclusion of bimodal stimuli is supported by literature suggesting that audio-visual exposure to nature enhances immersion and strengthens restorative outcomes compared to visual input alone (e.g. [35, 36]). The bimodal stimuli thus provide a more immersive experience, which more closely replicates the real-world environmental encounters.

Unlike databases compiled from various online sources, the TESD was systematically developed through a planned and standardised collection process. Many existing databases, particularly those sourced from photo-sharing platforms such as Flickr, rely on readily accessible images. While convenient, this approach produces stimuli from varied locations and conditions, making them inconsistent and less representative of real-world environments. The TESD, in contrast, was purposefully designed from the ground up with all stimuli collected locally through a standardised method. This approach captures scenes that are more familiar and relatable to participants, offering a more authentic representation of tropical urban green space (UGS).

In addition to focusing solely on natural environments, TESD incorporates mixed urban-nature scenes to better reflect the reality that UGSs often contain a blend of built and natural elements. This aligns with the perspective proposed by Joye and Van den Berg [37], who advocate moving beyond the traditional nature-urban dichotomy. By including these mixed environments, the database allows for exploration of whether such environments can also facilitate psychological restoration.

The TESD was therefore developed as a validated set of environmental stimuli to help enhance consistency for experimental designs, as well as for clinical interventions. By offering a culturally relevant set of stimuli, TESD aims to support future work in identifying how individuals respond to natural and mixed urban-nature environments, and how such responses might inform urban design, therapeutic practices, and public health strategies.

In the current work, TESD comprises 360 high-quality, standardised audio-visual, visual-only, and audio-only stimuli depicting a continuum from lush UGSs to built urban environments in Malaysia. While captured in Malaysia, TESD provides ecological validity not only within the local context but also for broader applications across tropical and equatorial countries. These regions share comparable climatic conditions and vegetation types, which influence both the sensory qualities of environments and the way people interact with them. Grounded in theoretical restorative research, each stimulus is accompanied

by normative ratings for perceived naturalness, fascination, being away, compatibility, and scope. These ratings allow researchers to explore how different sensory modalities and environmental features contribute to psychological restoration in tropical regions. The aim of this paper is to detail the procedures used to collect, standardize, and compile the TESD. The present work introduces the TESD, an evolving database developed to provide a validated foundation for research on tropical environmental stimuli. While this paper documents the initial phase of development, the TESD is designed as a dynamic and continuously expanding resource to support future research and applications.

2.0 Methods

The TESD was initially developed to capture a diverse range of environmental scenes in Malaysia. The aim of this work was to establish a foundation for a living database that could be continuously refined and expanded to support future research on restorative environments, particularly within the tropical regions. The complete set of stimuli, normative ratings, and analysis scripts is openly available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/UWVGE).

2.1 Stimuli Collection

In developing a comprehensive database of tropical environmental stimuli, we focused on UGSs. This focus reflects the lived environment of most Malaysians and, more broadly, of urban populations across tropical Southeast Asia. According to the Department of Statistics Malaysia [38], more than 75% of the Malaysian population resides in urban settings. This pattern mirrors a wider regional trend, with approximately 50% of the population in the Association of Southeast Asian Nations (ASEAN) region now living in urban areas and projections indicating that the region will reach 60% urbanisation by 2050 [39]. Urban populations across Southeast Asia and other equatorial regions face similar ecological conditions, including dense evergreen vegetation and year-round warmth and humidity [40], as well as distinct tropical soundscapes dominated by insect vocalisations and rich bird choruses [41], all of which differ markedly from the temperate settings that dominate the existing restorative environments literature. For city dwellers in these regions, UGSs represent the most accessible and frequently encountered form of nature, particularly given the substantial reductions in green space documented across rapidly urbanising tropical cities such as Kuala Lumpur, Jakarta, and Metro Manila [42]. The TESD therefore offers ecological validity not only for Malaysians samples but also for research conducted across Southeast Asian and equatorial urban populations. As an initial version of this ongoing project, environmental stimuli were collected from UGSs in Johor, Malaysia.

Sites were selected across Iskandar Puteri and Johor Bahru in Johor State, including Sireh Park, Hutan Bandar Mutiara Rini, Hutan Bandar Johor Bahru, Tanjung Piai, Puteri Harbour, Bukit Indah, and Eco Botanic. These locations were chosen to ensure a comprehensive range of environmental variations. The environmental stimuli were captured to represent a continuum of naturalness – from predominantly natural settings to heavily urbanised environments. The aim was to sample a diverse range of environments, including natural, built, and mixed settings.

Video stimuli were recorded using a Canon EOS 1500D DSLR camera equipped with a macro lens, featuring a minimum focusing distance of 0.25 metres. The camera was set with a fixed configuration to maintain consistency across all recordings (shutter speed = 1/50, aperture = F16, ISO = 100). All recordings were captured in full colour and horizontal orientation, lasted approximately 20 seconds to allow for optimal post-editing and trimming.

2.2 Stimuli Standardisation

A total of 120 video clips were collected and processed using CapCut (Version 4.5.0; ByteDance, 2024), a video editing application that supports trimming, audio extraction, and resolution adjustment within a single workflow. Each 20-second source recording was reviewed by the researcher and trimmed to a single five-second segment. Segments were selected to maximise visual stability and minimise incidental camera movement, focal shifts, and extraneous auditory disturbances such as human speech. Where multiple stable five-second windows are available within a recording, the segment with the clearest representation of the dominant scene features were retained. Recordings that did not contain at least one usable five-second segment meeting these criteria were excluded prior to standardisation.

The researcher then used an a priori categorization approach to classify the 120 environmental scenes into three categories based on their dominant visual features. Scenes that predominantly featured vegetation and other natural elements (e.g., sky or water), with minimal or no visible human-made structures, were classified as nature scenes. Those scenes that were composed of mainly built elements were classified as urban scenes. A third category, the mixed urban-nature scenes was introduced to represent environments where natural and built elements coexist. After classifying the 120 stimuli, there were a total of 56 nature, 36 urban, and 28 mixed urban-nature scenes (see Fig. 1 for examples of stimuli).

From each of the 120 trimmed source clips, three distinct stimulus versions were produced, yielding a total of 360 stimuli: (1) a bimodal version comprising the original audio-visual clip; (2) a visual-only version produced by muting the audio track; and (3) an audio-only version comprising the extracted ambient soundscape. Each source clip therefore contributed one bimodal, one visual-only, and one audio-only stimulus to the final database. All stimuli underwent a quality review, including checks for clarity, stable framing, appropriate lighting, and the absence of unintended motion or noise. Only stimuli that met these technical criteria were included in the final database.

All 360 stimuli were uploaded to Qualtrics XM (https://www.qualtrics.com) to be prepared for the rating task. For the bimodal and visual-only presentation of stimuli, videos were resized to a resolution of 1920 × 1080, while preserving the standard 16:9 ratio. No additional transformation was done toward the audio-only stimuli.

2.3 Rating Measures

Participants rated the stimuli based on the four components of restoration: fascination, being-away, scope, and compatibility. The Perceived Restorativeness Scale—Short Form (PR-SF) by Berto [44] was used where the four items were rated on a 11-point Likert scale from 0 *(not at all*) to 10 (*completely*). Given that the PR-SF was primarily used to rate visual stimuli, we adapted a 4-item Perceived Restorative Soundscape Scale—Short Form (PRS-SF) for the audio stimuli. This version was created by using the four items from Berto's [44] PR-SF with language adapted from the Perceived Restorativeness Soundscape Scale (PRSS [45]) (see [46] for a similar approach). Table 1 shows the four items used in both scales. Although the PR-SF and PRS-SF differ in wording to reflect their respective modalities, item content was conceptually equivalent across both scales. Both scales operationalise the same four restorative components derived from ART [5], and cross-modality comparisons should therefore be interpreted as reflecting the same underlying construct.

Table 1
The Four Items Used in PR-SF and PRS-SF

Perceived Restorativeness Scale—Short Form (PR-SF; Berto, 2005)	**Perceived Restorative Soundscape Scale—Short Form (PRS-SF)**
Fascination: The place is fascinating.	**Fascination**: The sounds in the recording have fascinating qualities.
Being-away: This is a place which is away from everyday demands	**Being-away**: The sounds in the recording give me a good break from my day-to-day routine
Scope: This is a place which is very large, with no restrictions to movements.	**Scope**: The sounds in the recording suggest there is much to explore and discover.
Compatibility: In this place, it is easy to orient and move around so that I could do what I like.	**Compatibility**: The sounds in the recording seem to fit together quite well, and it relates to activities I like to do.

2.4 Procedure

The study was approved by the Ethical Committee of the University of Reading Malaysia, with ethical code UoRM REC 2024/02. Informed consent was collected from all participants via online consent form. Participants were then randomly allocated to evaluate 45 stimuli presented in one of the three formats: bimodal, visual-only, or audio-only. Each stimulus was played for five seconds. Participants were asked to attentively view or listen to each clip and imagine themselves in the depicted setting. They first rated the naturalness of each stimulus on a 0 (*not natural at all*) to 10 (*cannot be more natural*) scale. Following this, they rated the restorative value of each clip using four items from the PR-SF (for those assigned to the bimodal and visual format) or the PRS-SF (for those assigned to the audio format). All experimental protocols were conducted in accordance with UoRM REC guidelines and regulations.

2.5 Participants

A total of 37 participants initially took part in the online study. However, eight data points were excluded due to missing data, resulting in a final sample of 29 valid datasets (11 rated the video stimuli, 8 the visual stimuli, and 10 the audio stimuli). The intended purpose of this study was to provide a preliminary validation of the TESD stimuli, focusing on whether participants' perceived naturalness ratings reflected the a priori scene categorisations and whether the stimuli could yield internally consistent restorativeness ratings. The sample size was therefore informed by guidance specific to pilot validation work rather than by power calculations for hypothesis testing. Bujang et al. [47] recommend a minimum of 30 respondents for assessing the reliability of a questionnaire, while Hertzog [48] suggests that 30 participants provides a reasonable basis for preliminary estimation in feasibility studies. Comparable sample sizes have also been reported in recent video stimulus database validations, such as the Affective Video Database Online Study in Virtual Reality (AVDOS-VR; N = 37 [49]).

3.0 Results

The validation process aimed to evaluate (a) the interrater reliability of perceived naturalness and restorative quality ratings, and (b) the expected pattern of differences across environmental categories (nature, mixed urban-nature, urban) and presentation modalities (visual, audio, bimodal). Analyses for this study were strictly descriptive. Interrater reliability across participants was assessed using the intraclass correlation coefficient (ICC) for perceived naturalness and each of the four restorative qualities. A two-way random effect model with absolute agreement was employed, with the average of ratings as the measurement unit. In accordance with Koo and Li [50], ICC values below 0.50 were interpreted as indicating poor reliability, values between 0.50 and 0.75 as moderate reliability, values between 0.75 and 0.90 as good reliability, and values above 0.90 as excellent reliability. ICCs were computed for each construct separately across the three presentation modalities (see Table 2).

Table 2
Intraclass Correlation Coefficient for the Measures of Naturalness, Fascination, Being away, Scope, and Compatibility in each Modality

Construct	**Intraclass correlation coefficient (ICC)**		
	Bimodal	**Visual**	**Audio**
Naturalness	0.88	0.96	0.70
Fascination	0.57	0.54	0.66
Being away	0.74	0.92	0.24
Scope	0.52	0.48	0.33
Compatibility	0.51	0.49	0.21

As shown in Table 2, naturalness ratings demonstrated good to excellent reliability across modalities (ICC = 0.70–0.96). Ratings for the four restorative qualities showed moderate reliability overall, except for being away, scope, and compatibility in the audio-only condition, which showed relatively low agreement (ICC < 0.40). These results suggest that visual and bimodal cues provided more consistent information for evaluating restorative qualities than audio-only cues.

The ratings were averaged across participants and used as the score for each setting. Descriptive statistics for perceived naturalness and restorative quality ratings across scene categories and modalities are presented in Table 3 and Fig. 2. As expected, nature scenes were generally rated higher in both naturalness and restorative qualities compared to urban scenes, consistent with ART. However, mixed urban-nature scenes did not consistently differ from nature scenes across all indices. In some cases (e.g., compatibility and scope in bimodal and visual formats), mixed urban-nature scenes were rated comparable or even higher than natural scenes, suggesting that moderate integration of built and natural elements can also elicit restorative potential. Urban scenes consistently received the lowest ratings across all measures.

Table 3

Means and standard deviations of rated properties

	Nature		Mixed urban-nature		Urban	
	M	*SD*	*M*	*SD*	*M*	*SD*
Perceived Naturalness						
Bimodal	8.17	0.84	6.46	1.63	2.40	1.11
Visual	8.23	1.00	6.24	2.41	2.55	1.70
Audio	7.07	1.39	6.58	1.36	3.44	1.51
Fascination						
Bimodal	5.27	1.76	6.32	1.61	3.07	1.48
Visual	6.26	1.66	6.13	2.11	3.34	1.02
Audio	6.48	1.57	6.23	1.45	3.61	1.54
Being-away						
Bimodal	6.68	1.28	5.18	1.96	2.13	1.01
Visual	7.26	1.39	5.72	2.24	2.54	1.54
Audio	5.68	1.57	5.18	1.64	2.90	1.49
Compatibility						
Bimodal	6.06	1.59	6.15	1.40	3.84	1.85
Visual	5.91	1.73	6.60	1.92	4.16	1.36
Audio	5.60	1.60	5.52	1.28	3.42	1.59
Scope						
Bimodal	6.14	1.69	6.55	1.33	3.85	1.84
Visual	6.29	1.64	6.53	2.00	3.82	1.30
Audio	6.00	1.40	5.96	1.30	3.78	1.78
Perceived Restorativeness						
Bimodal	6.04	1.10	6.06	1.24	3.22	1.25
Visual	6.57	1.34	6.25	1.86	3.47	1.07

Audio	5.96	1.40	5.80	1.30	3.48	1.59

4.0 Discussion

The present study set out to describe the development of TESD, a novel set of standardised audio-visual (bimodal), visual-only, and audio-only representations of nature, mixed urban-nature, and urban environments in Malaysia. The aim was to detail the process of collection, standardization, and compilation of stimuli, as well as to provide an initial validation using perceived restorativeness ratings. This work represents the first systematic effort to establish an ecologically valid stimulus database for restorative environments research in a tropical context, addressing the current overreliance on stimuli from Western, temperate regions [51]. The descriptive findings from the validation provide preliminary support for the ecological and psychological relevance of the TESD stimuli. Descriptive comparisons indicated that nature scenes were generally rated as more restorative and natural than urban scenes, in line with earlier work (e.g. [52]). However, the descriptive ratings also indicated that mixed urban-nature scenes did not always differ from purely natural scenes, and in some cases were rated comparably or even on certain indices. This is consistent with Wilkie and Clouston [53] which suggested that exposure to UGSs can yield restorative outcomes comparable to those of natural environments. Moreover, this finding also highlights the importance of biophilic urbanism [54] to enhance urban liveability by weaving natural elements into built environments, thereby balancing functionality with restorative qualities. Nevertheless, the comparatively low ICCs observed for the audio-only condition suggest that auditory environments may be perceived more heterogeneously across participants, indicating that findings involving audio stimuli should be interpreted with greater caution.

The current version of the database represents the initial stages of a continuing effort to build a comprehensive repository of tropical environmental stimuli. While the stimuli were carefully collected and standardised, the database presently covers a limited range of sites and environmental features. Similarly, the validation sample size was modest, providing a useful first indication of feasibility but not yet allowing for generalisable conclusions. Moreover, while participants were asked to imagine themselves being in the depicted scene, virtual exposure cannot fully replicate multisensory richness of actual environments. Field-based validation is therefore an important next step.

Despite these limitations, the TESD represents a promising resource for advancing both theoretical and applied research. The availability of standardised tropical stimuli provides opportunities for researchers to test restorative theories in new contexts, thereby broadening the generalisability of existing frameworks. In addition, cross-cultural comparisons can now incorporate tropical contexts, addressing calls for greater geographical diversity in environmental psychology. Looking forward, TESD will continue to develop as a living repository. Expansion of database and further validation work by incorporating larger and more diverse samples, will be key to establishing TESD as a robust tool for applied research.

5.0 Usage Notes

The TESD provides audio, visual, bimodal stimuli of nature, urban, and mixed urban-nature scenes from tropical regions. These stimuli enable research on modality-specific effects of environmental exposure, addressing the limited ecological validity and geographical representation of restorative environment research, which was largely relied on Western samples. Another important contribution of this study is the inclusion of auditory and audio-visual formats, extending beyond the traditional reliance on still images (e.g. [30, 31]). While research showed that soundscapes play an important role in shaping environmental experiences and restorative outcomes [45, 55], our findings support this notion where natural soundscapes were rated as more restorative than urban soundscapes. Moreover, the bimodal stimuli may better approximate the real-world experience of the environments, where sight and sound interact and co-occur [56].

Researchers may select stimuli according to study aims, modality, or validated psychological attributes. For instance, unimodal (visual or auditory) stimuli allow investigation of individual sensory contributions to perceived restorativeness, while bimodal stimuli provide more ecologically valid experiences of the environments. Mixed urban-nature stimuli may be particularly relevant for studies on biophilic urbanism, where natural elements are integrated into built environments to enhance well-being while retaining urban functionality.

TESD is applicable to experimental, survey-based, and neurocognitive research, as well as applied domains such as urban design, architecture, and public health. However, users should consider the cultural and geographical specificity of the database. While the stimuli represent typical features of tropical contexts, generalization to non-tropical environments should be made cautiously.

The complete TESD, comprising the full set of 360 stimuli, accompanying normative ratings, and analysis scripts used in the validation study, is openly available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/UWVGE). A complementary website (https://sites.google.com/view/tesd-msia/home) provides a representative selection of stimuli for preview and an overview of the database for non-specialist audiences. All materials were released under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

Declarations

Author Contributions Statement

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Ethical Declarations Statement

Competing interests

The authors declare no competing interests.

Consent to publish

Consent to publish was obtained from all participants.

Funding Statement

This work was supported by the Ministry of Higher Education Malaysia through the Fundamental Research Grant Scheme (Grant number: FRGS/1/2023/SS09/READING/03/1).

Author Contribution

JJYH: Methodology, Data curation, Formal analysis, Project administration, Writing – original draft, Writing – review & editingSS: Supervision, Conceptualisation, Writing – review & editingKWT: Supervision, Conceptualisation, Funding acquisition, Project administration, Writing – review & editing

Acknowledgement

The authors thanked Kong Jia Yee and Natasha Sia Ke Ying for assistance with stimuli collection.

Data Availability

The complete set of stimuli, normative ratings, and analysis scripts are publicly available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/UWVGE).

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Figures

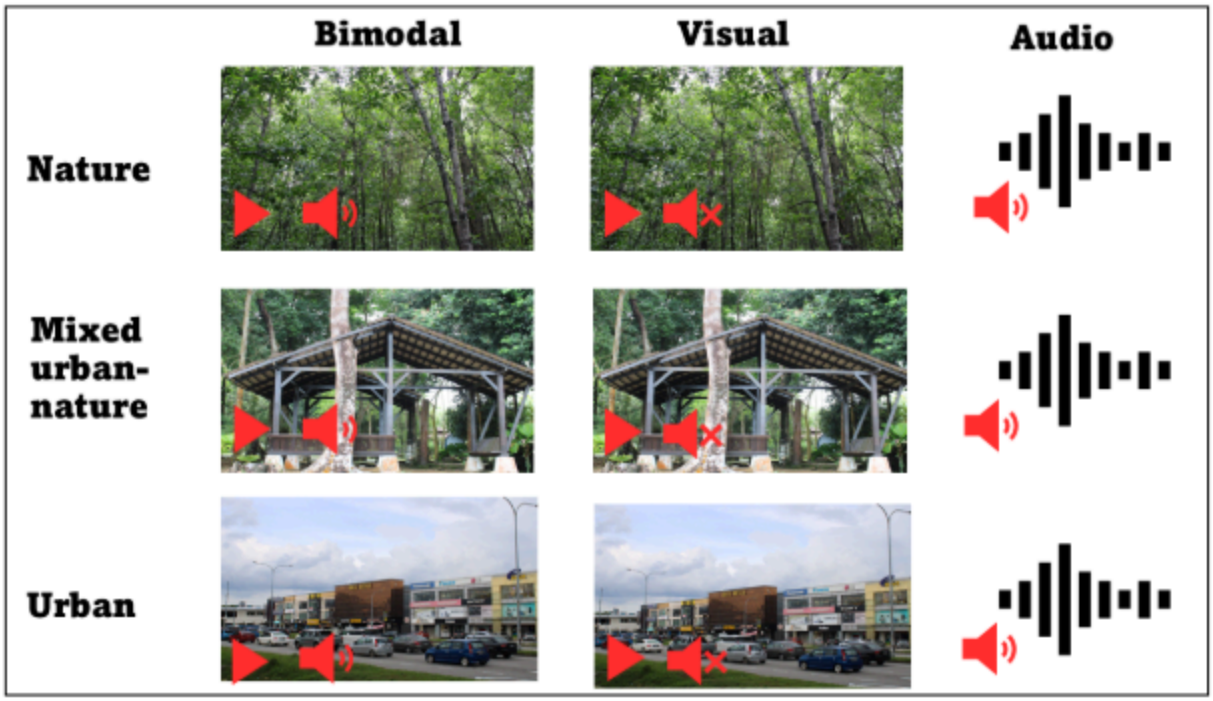


Figure 1

Example scenes from the TESD, representing a continuum from natural to urban environments across bimodal, visual, and auditory modalities.

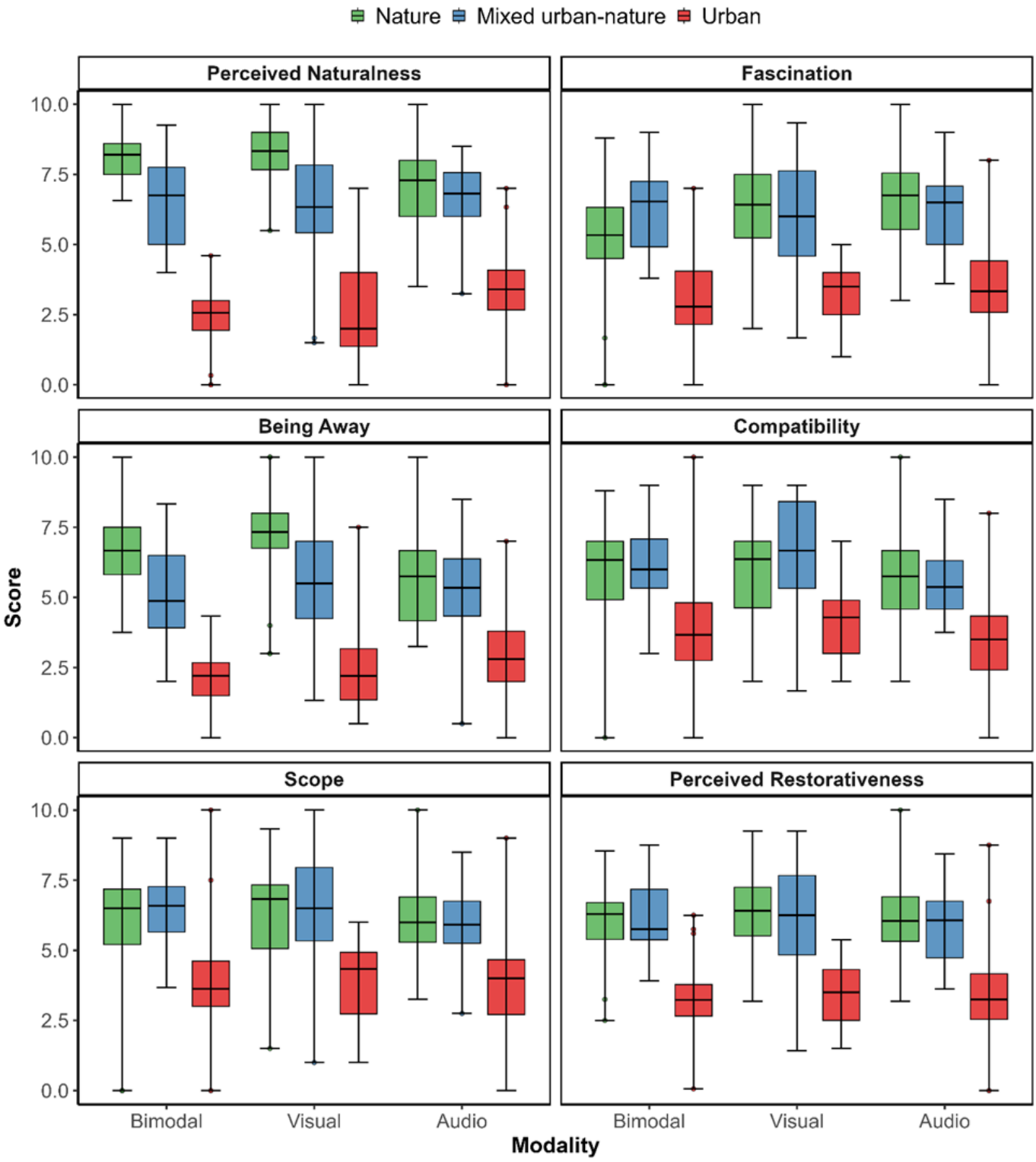


Figure 2

Boxplots of perceived naturalness, fascination, being-away, compatibility, scope, and perceived restorativeness by scene types and modalities.