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Potential restorative effects of urban soundscapes: Personality traits, temperament, and perceptions of VR urban environments

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HIGHLIGHTS

- Urban environments with preferred soundscapes have restorative potential effects.
- New criteria were introduced based on restoration-related semantic terms.
- Physically low-frequency content in a sound environment may affect restoration.
- Participants' overall space preference is key to determine restoration effects.
- Individual traits are examined in depth as they affect perception of soundscapes.

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ABSTRACT

This study investigated the potential restorative (PR) effects of urban soundscapes. To establish a new set of PR criteria for urban environments, this study recreated 10 urban sites in virtual reality, instead of using the typical method of questionnaires. A list of restoration-related semantic terms was derived from narrative interviews of 50 subjects who freely expressed their perceptions of the space. PR criteria were determined based on the derived list and two groups were found: the PR group and potential non-restorative group. The objective characteristics of urban soundscapes—acoustic and visual characteristics and characteristics of moving objects—were analyzed. Participants provided their subjective responses regarding sound source identification, perceived affective quality, and overall quality. The Temperament and Character Inventory-Revised-Short Version and Satisfaction with Life Scale were utilized to analyze participants' individual characteristics. Based on it, a model was developed to predict whether PR criteria could be satisfied, which was 82.6% accurate (85.9% specificity, 71.8% sensitivity). It was determined that the overall level of preference regarding an urban soundscape is a significant factor in satisfying PR criteria. In particular, the design and planning of urban spaces should aim to reduce a space's loudness and increase the revisitation rate to promote the restoration of the urban residents' mental health. Furthermore, for individuals, a trait based on acquired experience has a greater impact on the PR effects of urban soundscapes than innate temperament. This study's findings can serve as supporting data to design sustainable and health-promoting urban soundscapes.

1. Introduction

1.1. Restorative environment

Environmental noise caused by the rapid urbanization of modern society negatively impacts the health and well-being of urban dwellers, causing stress as well as mental and physiological problems; hence, there is an amplified desire for restoration amid stressful urban life (Basner et al., 2014; Stansfeld, Haines, & Brown, 2000). Active use of green infrastructure during urban planning processes promotes stress reduction in city residents (Navarrete-Hernandez & Laffan, 2019). Additionally, the following measures have been proposed to reduce environmental noise: controlling physical noises, redesigning spaces using building materials or noise barriers to control noise transmission,

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and remodeling urban spaces based on the perspectives of residents affected by noise (European Union, 2002; World Health Organization (WHO), 2018).

However, approaching the issue of urban sound environment solely from the perspective of noise and reducing the noise level does not necessarily lead to improved satisfaction (Kang & Schulte-Fortkamp, 2016). Therefore, instead of using the existing noise management approach that considers noise as waste, a new soundscape concept has emerged that defines wanted sound as a resource and attempts to resolve problems in the sound environment from the perspective of preferred sounds (Brown, 2010; Raimbault, & Dubois, 2005; Schafer, 1993; Southworth, 1969). Through cooperation among various interested parties, such as architects, acousticians, and researchers, strategies can be designed to amplify wanted sounds (water or nature sounds) while eliminating or reducing unwanted sounds (traffic noise or other noise). As such, practical design elements, such as vegetation, noise barriers, topography designs, or reducing source activity can be applied to the soundscape to affect unwanted noise (Brown, 2012; Cerwén, Kreutzfeldt, & Wingren, 2017).

Many studies have examined the restorative effects of positive soundscapes (Aletta, Oberman, & Kang, 2018; Herranz-Pascual et al., 2019; Zhao, Xu, & Ye, 2018). Studies have investigated how the distinct psychological and physiological effects of natural environments (such as green space, and waterfronts) affect the restorative capacity of soundscapes. To understand the mechanism behind such restorative effects, an examination of Attention Restoration Theory (ART; Kaplan, 1995; Kaplan & Kaplan, 1989) and Stress Recovery Theory (SRT; Ulrich, 1983; Ulrich et al., 1991) is beneficial. Both theories assume that environments restore the psycho-physiological energy of urban residents experiencing ego depletion. ART emphasizes attention restoration and reflection and establishes four components of an environment's restorative effects: being away, extent, fascination, and compatibility. It also posits that experiencing environments restores both individuals' psycho-physiological energy and their cognitive resources, including attention and memory. SRT, a representative theory regarding how the natural environment alleviates stress reactions, is also referred to as psycho-evolutionary theory. It proposes that emotional and perceptional reactions in the natural environment could alleviate stress through various psychological and physiological means (Ulrich et al., 1991). Han (2003) tested the validity of self-rating restoration scales by comparing the results of various survey responses across natural and laboratory environments. He determined that an acceptable range of similar results could be obtained regardless of the type of scale that was used. Measures such as perceived restorativeness soundscape scale have been proposed to evaluate the subjective restorative effects of soundscapes in the field. These were tested and verified within particular urban functional areas, such as parks (Payne, 2013; Payne & Guastavino, 2018). Other studies demonstrated that natural environments improved individuals' cognitive functions (Shu & Ma, 2019; Van Dijk-Wesselius, Maas, Hovinga, Van Vugt, & Van den Berg, 2018), fostered stress reduction, and promoted positive emotions (Aletta et al., 2018; Choe, Jorgensen, & Sheffield, 2020; Medvedev, Shepherd, & Hautus, 2015). Many studies have also been conducted on the restorative effects of natural environments from a psychological perspective using questionnaires. Scale-based questionnaires are useful in quantifying a subject's psychological restoration response. However, the use of close-ended questionnaires to conduct evaluations may cause acquiescence and demand characteristics bias, as this method can force participants to focus on the evaluation of specific items (Furnham, 1986). We overcame such limitations by introducing a new set of criteria to determine potential restorative (PR) effects (PR criteria) based on the voluntary emotional expressions of participants regarding urban soundscape experiences.

Other studies have investigated the restorative effects of soundscapes from a physiological perspective. Physiological response indicators, such as heart rate (HR), HR variability (HRV), R-wave amplitude (ΔR), skin conductance level (SCL), respiration rate (RR), respiratory frequency (RF), respiratory depth (RD), and electroencephalography (EEG) have been examined. These studies indicate that natural soundscapes can lead to positive changes in physiological responses (Alvarsson, Wiens, & Nilsson, 2010; Hume & Ahtamad, 2013; Li & Kang, 2019; Medvedev et al., 2015; Yu, Lee, & Luo, 2018). By investigating overall physiological indicators, Li and Kang (2019) determined that soundscapes that include natural sounds reduce the levels of HR, RF, and RD and increase the levels of ΔR, HRV, α-EEG, and β- EEG. A multitude of studies have already been conducted on the restorative effects of natural environments, sufficiently verifying their positive effects (Collins et al., 2020; Huang, Yang, Jane, Li, & Bauer, 2020; Lachowycz & Jones, 2013).

1.2. PR effect of urban environments

In this study, the term "natural environment" includes green areas such as forests, valleys, grasslands, and parks, and waterfronts such as seas, lakes, wetlands, and streams, and is defined as a setting that is contrary to the urban environment. While many studies have examined the restorative effects of natural environments, few have examined the restorative effects of urban environments, despite their potentially frequent occurrence (Krzywicka & Byrka, 2017). Studies have presented urban environments in opposition to natural environments, representing the former as negative stimuli that hinder restorative environmental effects (Park, Lee, Jung, & Swenson, 2020; Tsunetsugu et al., 2013; Yu et al., 2018). Furthermore, most settings used to evaluate urban environments portray unpleasant situational components, including traffic noise, industrial areas, and buildings (Medvedev et al., 2015; Yu et al., 2018). However, some cultural facilities in urban environments, like museums and monasteries, can aid in urban residents' mental recovery (Kaplan, Bardwell, & Slakter, 1993; Ouellette, Kaplan, & Kaplan, 2005; Packer, 2008). Moreover, one study indicated that the HRV response in an urban environment does not differ much from the physiological response in a forest environment; in comparison with office or minibus environments, the urban environment can trigger a physiological restoration effect. (Stigsdotter, Corazon, Sidenius, Kristiansen, & Grahn, 2017). Accordingly, studies have investigated how cultural activities in urban environments, such as concerts, plays, and sporting events, contribute to the health and well-being of urban residents and increase life satisfaction (Chick et al., 2016; Johansson, Konlaan, & Bygren, 2001). Moreover, interesting and attractive urban environments can reduce stress and improve urban residents' moods (Karmanov & Hamel, 2008).

Urban designs generally aim to enhance the beauty, functionality, and sustainability of cities, while considering design factors such as buildings and infrastructure during planning (Carmona, Heath, Tiesdell, & Oc, 2010). As Kaplan (1995) suggested, any environment has the latent potential for restorative qualities, meaning that all design elements should be examined closely. As research into the restorative effects of urban environments has been insufficient, the PR effects of urban soundscapes must be examined by focusing on the diverse functions of urban locations.

1.3. Individual differences regarding restorative effects

Differences in individuals' lifestyles, health, expectations, and sociodemographic characteristics change soundscape perception (Herranz-Pascual, Aspuru, & García, 2010; Jo & Jeon, 2020a). Personality traits, especially emotional stability, affect how individuals evaluate soundscape quality, particularly its perceived pleasantness and eventfulness (Lindborg & Friberg, 2016).

Studies that examine the effect of individual differences on restorative effects focus on factors like noise sensitivity and environmental preference (Lercher, van Kamp, von Lindern, & Botteldooren, 2016; Ojala, Korpela, Tyrväinen, Tiittanen, & Lanki, 2019; Wilkie & Stavridou, 2013). Wilkie and Stavridou (2013) investigated the restorative effects of environments according to individuals' environmental preferences

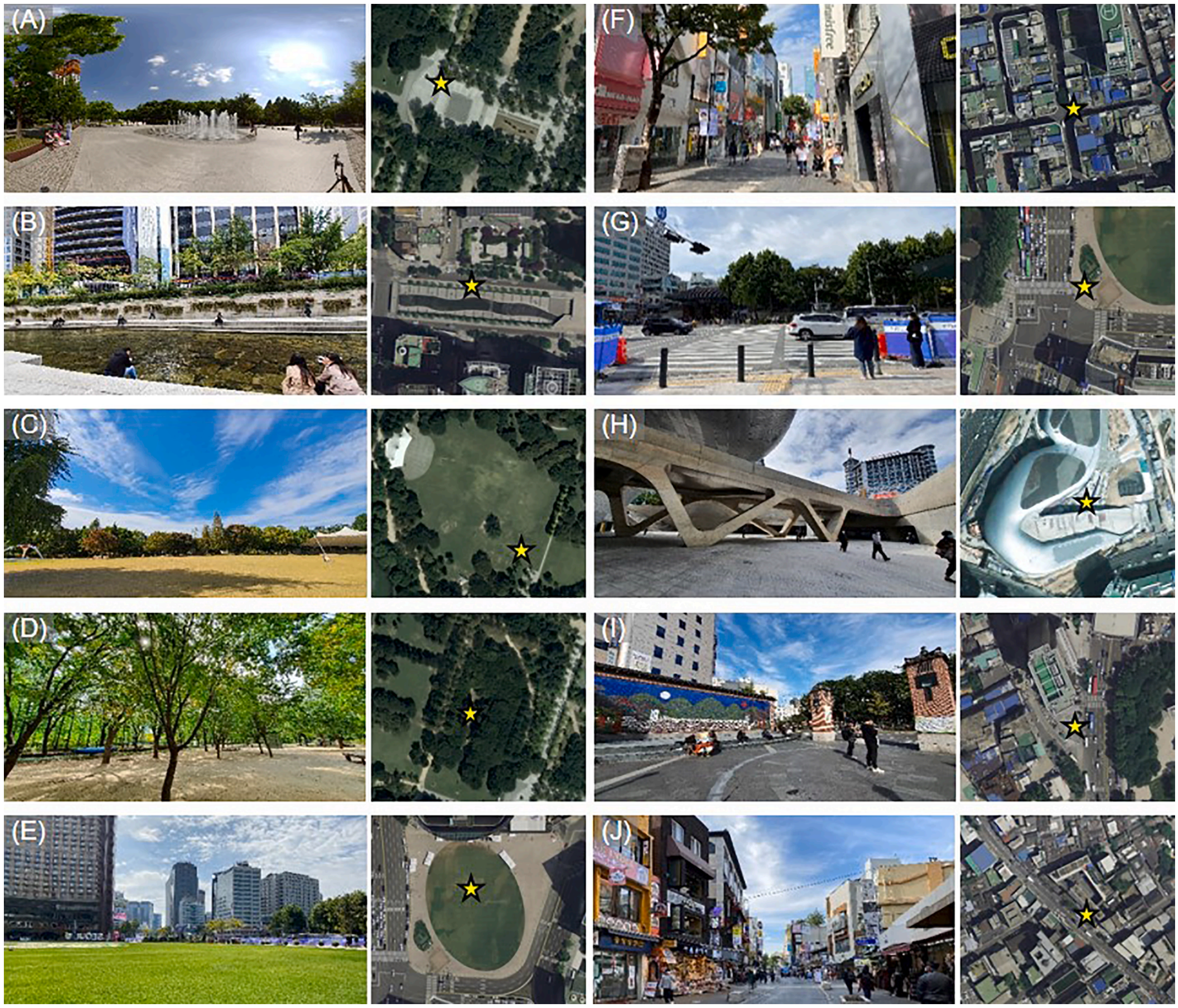

Fig. 1. Site views and locations of the 10 assessment sites. Yellow circles mark the measurement positions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and determined that the PR effect of an environment increased when the participants' experiences were congruent with their preferences. Interestingly, individuals who preferred urban environments perceived a similar level of restorative effect for both natural and urban environments. Ojala et al. (2019) showed that urban-natural orientedness and noise sensitivity triggered differences in psychological restoration and concluded that urban environments cannot restore noise-sensitive and low-urban-oriented persons.

It has also been shown that individuals perceive the affordance of nature differently (Faehnle, Bäcklund, Tyrväinen, Niemelä, & Yli-Pelkonen, 2014). Moreover, the restoration effect varies depending on an individual's life cycle or work environment, and people with health problems tend to favor natural environments (Korpela & Ylén, 2009). The purpose of visiting an environment is an important factor that triggers these individual differences; people who visit a space with the intention of alleviating stress tend to show a greater restoration effect than people who do not (von Lindern, Bauer, Frick, Hunziker, & Hartig, 2013). The restoration effect also differs for each individual depending on their behavioral characteristics. An experience of the natural environment does not have any restoration effect on people with overt behavioral syndromes that include excessive competitiveness, striving for achievement, and aggressiveness (Twedt, Rainey, & Proffitt, 2019).

There are limited studies on restoration effects depending on individual differences in terms of preference, but some studies do examine individual differences in detail, including personal characters and satisfaction of life (Gao, Zhang, Zhu, Gao, & Qiu, 2019; van den Berg, Koole, & van der Wulp, 2003). In particular, no study examines restoration effects among individuals in terms of soundscape. This study is unique in that it investigates both the PR effects of diverse urban soundscapes and the detailed differences between individuals' perceptions of those soundscapes based on personality and temperament.

1.4. Research objectives

This study investigates the PR effects of urban soundscape experiences, focusing on urban environments that fulfill different functions and asking the following research questions:

What influencing factors determine the PR effects of urban soundscapes?

What are the differences between soundscape perceptions in the PR and potential non-restorative (PNR) groups?

How do the restorative effects of urban soundscapes differ according to individual personality?

2. Methods

2.1. Research framework

The research framework of this study is as follow. First, audio-visual data on urban environments were collected. Virtual reality (VR) technology was used to create life-like evaluation environments within a (restricted) laboratory setting. In Step 1, we analyzed the objective characteristics of urban soundscapes, specifically the acoustic and visual characteristics of urban soundscapes as well as those of moving objects. In Step 2, the participants' subjective responses were investigated. Based on the semantic terms used in the narrative interview responses, we examined the relationship of each term to the restoration concept and refined the PR criteria. The subjects were divided into a PR group and a PNR group based on whether they satisfied the criteria. In Step 3, the effect of individual characteristics on restoration were examined, such as the effects of personality, temperament, and life satisfaction on satisfaction with PR criteria. Last, we considered objective, subjective, and individual characteristics to propose a prediction model that satisfies the PR criteria and developed a design methodology to develop practical health-promoting urban soundscape designs.

2.2. PR criteria based on narrative interviews

In this study, establishing the PR criteria was critical to determine the restoration potential of urban soundscapes. The newly established criteria were based on the narrative interview results where participants voluntarily discussed the sites. First, text-mining analysis was performed to extract semantic terms from the narrative interview results. The 60 most frequently-used semantic terms were selected (Yu, Jannasch-Pennell, & DiGangi, 2011). Then, the same 50 participants were asked to respond to the questionnaire items on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) regarding how well each of the 60 words coincided with their thoughts about the concept of restoration. Next, response option 3 (*neither agree nor disagree*), the middle value of the scale, was selected as the PR criterion to classify the semantic terms. Expressions with a value higher than the middle value were included in the list of restoration-related semantic terms (RSTs). Participants who used RSTs to evaluate each site were placed in the PR group, and those who used expressions that were not on the list of RSTs were placed in the PNR group. The PR criteria were applied to the response by each individual participant at each site.

2.3. Audio-visual stimuli and VR reproduction

In this study, the same locations were evaluated as in Jo and Jeon's unpublished research: 10 areas within the Gangbuk region of Seoul City that include a variety of features, such as parks, public spaces, commercial streets, and public squares (Fig. 1). Visual information was recorded at 8 K resolution with an Insta360 Pro, a 360-degree camera with 6 channels. The visual information was collected in video format in a stationary state using a fixed tripod. Auditory information was recorded with a first-order Ambisonic microphone (Soundfield SPS200, Sound Devices). A portable sound recorder (Mixpre-6, Sounddevices, USA) was used to record sound information with an Ambisonic microphone. An A-format first-order Ambisonic (FOA) setup was used for recording. Clapping sounds were used at the start of measurement to synchronize the measured video and audio data (Hong et al., 2019; Jeon & Jo, 2020). Additionally, an omni-directional half-inch microphone (AE 46, GRAS Sound and Vibration) was used to record auditory information synchronously so that the sound pressure level (SPL) in the laboratory environment could be calibrated to be consistent with that at the actual evaluation site. A half-inch microphone was connected to a portable sound-level meter (AS-70, RION, Japan) for measurement. Then, the visual and auditory information of these soundscapes was measured for three minutes. All cameras and microphones were set up at a height of 1.6 m to approximate the height of a person's eyes and ears when standing. Based on these data, we created a VR simulation using the Unity 3D physics engine software that was similar to the real site and was designed to provide all participants with identical stimuli. Previous studies have demonstrated the ecological validity of VR technology in soundscape evaluation (Hong et al., 2019; Kjellgren & Buhrkall, 2010; Maffei, Masullo, Pascale, Ruggiero, & Romero, 2015). The visual information was provided to participants through a head-mounted display (VIVE Pro, HTC) after the Insta360 Pro Stitcher stitched together video clips recorded through its six channels. The edited 360-degree video included the microphone. However, when conducting pre-interviews about the experimental setup with and participants, we confirmed that there was no visual restriction due to the microphone. Audio information was provided to participants through headphones (HD-650, Sennheiser) after an Ambisonic plug-in (sound device) was used to convert the FOA B-format and after the spatial audio SKD Resonance Audio plug-in (Google VR) was used to down-mix the tracks into binaural tracks. Additionally, head-trackers were used to recreate the real-time direction of sounds, which changed according to the individual's head rotation. To calibrate the mean SPL, a head and torso simulator (Type 4100, Brüel & Kjær) recorded the down-mixed binaural tracks to ensure that they were identical to the actual sites. Then, the Adobe Audition software (version 1.5, Adobe) was used to adjust the mean SPL of both channels to be consistent with the three-minute L_{Aeq}, which was measured with a calibration microphone at the actual sites. The views and locations of the 10 assessment sites are shown in Fig. 1.

2.4. Objective evaluation

Multi-sensory perceptions affect the restorative effects of soundscapes (Zhang, Liu, & Li, 2019; Zhao et al., 2018). Therefore, we analyzed acoustic, visual, and object parameters to quantify the objective characteristics of urban soundscapes. First, the acoustic parameters were determined by analyzing the A-weighted SPL (L_{Aeq}), $L_{A10\text{-}A90}$, and $L_{Ceq\text{-}Aeq}$ from the perspective of sound strength, temporal variation, and spectral content. Acoustical parameters were analyzed with post-processing software (01 dB dBTrait Software, 01 dB Metravib, USA) for audio analysis with respect to the three-minute sound source collected with a half-inch microphone. $L_{A10\text{-}A90}$ is a measure of the difference between percentile SPLs and indicates the fluctuation characteristics of soundscapes. Percentile SPLs were measured by setting the timeframe of a three-minute sound source to 125 ms. L_{A10} denotes the noise level that exceeds 10% of the total measuring time and L_{A90} denotes the noise level that exceeds 90% of the total measuring time. $L_{Ceq\text{-}Aeq}$ is a measure of the difference between C-weight SPL and A-weight SPL and demonstrates the low-frequency characteristics of soundscapes.

Second, the visual parameters were determined by calculating green, sky, and gray ratios, which represent what is perceived in an environment in terms of vegetation, the sky, and artificial elements (Kogan, Arenas, Bermejo, Hinalaf, & Turra, 2018; Puyana-Romero, Ciaburro, Brambilla, Garzón, & Maffei, 2019); this was accomplished using the relative ratios of RGB colors determined with the Image Color Summarizer (Krzywinski, 2018). For the evaluation images, the pixel ratio of each RGB color to overall pixels was calculated by converting the evaluation video from a 360-degree video to a 2D video. The number of color clusters was set to 10, and the precision was set to 200 px. The luminance value was calculated using the standard luminance formula of $0.299 \times \text{red} + 0.587 \times \text{green} + 0.114 \times \text{blue}$ (ITU, 2011). Finally, the object parameters were determined by observing the number of moving objects, that is, the number of moving people and vehicles. The three-minute video recorded at each site was divided into six 30-second segments, and the mean number of people and vehicles appearing in each of the six 30-second video clips for each site was calculated.

2.5. Subjective evaluation

2.5.1. Questionnaire and narrative interviews

Our urban soundscape evaluation questionnaire was based on the ISO 12913-2 ISO (2018) and consisted of four parts: 1) sound source identification, 2) perceived affective quality, 3) overall soundscape quality, and 4) individual characteristics. To measure (1), research participants were asked to indicate their responses on a 5-point Likert

Table 1
Summary of participants' individual characteristics.

Demographic variables	Value (number of subjects according to cut-off score)
Age	23.8 ± 3.1
Gender distribution	
Male	25
Female	25
Temperament and character dimensions	
Novelty seeking (NS)	37.6 ± 9.7 (H: 14, M: 22, L: 14)
Harm avoidance (HA)	38.7 ± 9.4 (H: 11, M: 26, L: 13)
Reward dependence (RD)	42.9 ± 7.8 (H: 08, M: 20, L: 22)
Persistence (P)	47.1 ± 10.0
Self-directedness (SD)	44.2 ± 10.0 (H: 14, M: 21, L: 15)
Cooperativeness (C)	55.4 ± 9.1 (H: 14, M: 24, L: 12)
Self-transcendence (ST)	25.5 ± 11.1 (H: 12, M: 14, L: 24)
Satisfaction with Life Scale (SWLS)	23.8 ± 4.8

Note: H = high, M = medium, L = low

scale (1 = *not at all* to 5 = *completely dominates*; all remaining measures in this paragraph used 5-point Likert scales as well) regarding perceived level of sound for audio tracks that contained, for example, traffic noise, sounds of people, or natural sounds. To measure (2), participants were asked to rate their agreement with eight attributes of a site's soundscape (1 = *strongly disagree* to 5 = *strongly agree*): pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, or monotonous. To measure (3), participants were asked to indicate their overall impression of each site's soundscape (1 = *very bad* to 5 = *very good*) and the perceived appropriateness of the soundscape (1 = *not at all* to 5 = *perfectly*). Participants were also asked to indicate the perceived loudness and unpleasantness of each soundscape (1 = *not at all* to 5 = *extremely*) and their willingness to revisit a site (1 = *never* to 5 = *very often*). Participants were also encouraged to express their thoughts and emotions freely and openly about soundscape at the examined site through narrative interviews.

Two categories of individual characteristics were examined for this study: four dimensions of temperament (novelty seeking, harm avoidance, reward dependence, and persistence) and three dimensions of character (self-directedness, cooperativeness, and self-transcendence). Research participants were asked to use a 5-point Likert scale (0 = *definitely false* to 4 = *definitely true*) to respond to the 140 questions of the Temperament and Character Inventory-Revised-Short-Version (TCI-RS) regarding the above temperament and character dimensions (Min, Oh, & Lee, 2007). To investigate the participants' life satisfaction, they were asked to use a 7-point Likert scale (1 = *strongly disagree* to 7 = *strongly agree*) to respond to the five questions of the Satisfaction with Life Scale (SWLS) regarding their perceptions of their lives (Diener, Emmons, Larsen, & Griffin, 1985).

2.5.2. Procedure

A total of 50 (25 male, 25 female) individuals participated in this study. Participants were recruited by distributing notices (posting on a message board and SNS) in the Hanyang university. All experiments were conducted for one month from late January to late February 2020 in a lab environment. Participants visited the lab between 10 am and 5 pm at their convenience to participate in the evaluation. The researchers explained the experiment's purpose before conducting it, and participants were given the opportunity to fully understand the content. Participants gave written consent to participate in accordance with ethical procedures. All 10 evaluation sites were located in the Gangbuk region of Seoul City; the participants were undergraduate and graduate students from a single university located in that region and were, therefore, familiar with the evaluation sites (see Table 1). The participants possessed normal vision and hearing, and their ages ranged from 21 to 41 years (mean = 23.8, standard deviation = 3.1). Participant inclinations and personalities were categorized according to three cut-off scores (High: T score ≥ 55, Medium: 45≤ T score ≤ 55, Low: T score ≤ 45), showing that the participants' personalities and inclinations varied (Min et al., 2007). Additionally, the mean total SWLS score of the participants was 23.8, which is higher than the midpoint of 20 on the SWLS scale, showing that the participants' basic level of life satisfaction was relatively high (Diener et al., 1985). No categorization was done for age, persistence, or SWLS due to a lack of standardized cut-off score. It was particularly difficult to categorize subjects based on age as most of them were in their twenties. Prior studies, such as Diener et al. (1985) also did not categorize distribution across similar levels.

Each participant responded to the survey twice. First, in a laboratory setting, the participants were provided with three minutes of audio-visual stimuli for each of the 10 VR sites (see Section 2.3), with each participant experiencing the sites in the same order. Participants were asked to evaluate sound source identification, perceived affective quality, and overall quality, and complete a narrative interview about all 10 sites. All participant responses were stored on a server in real time using the Google Forms, and participants could take off the VR equipment when responding to the survey and did not have a time limit for their responses. When the subject asked for an explanation of the questionnaire item, the researcher gave an additional explanation to help clarify the understanding. In the interview, they were asked to freely express their thoughts or feelings about the soundscape at each site, and their responses were recorded. Stimuli were repeated if participants requested it. Participant fatigue with VR experiences was considered, and participants were given breaks when requested. After the participants' laboratory evaluations, the TCI-RS and SWLS questionnaires were completed using Google Forms.

Next, participants provided responses about the relationship between restoration and the semantic terms extracted through text-mining from narrative interviews regarding restoration using Google Forms, as described at Section 2.2.

2.6. Statistical analysis

A total of 500 responses were collected for each questionnaire item

Table 2
Summary of objective characteristics according to site.

Site	Acoustic parameter			Visual parameter				Number of objects	
	L_{Aeq}[dB]	$L_{A10\text{-}A90}$ [dB]	$L_{Ceq\text{-}Aeq}$ [dB]	Green ratio [%]	Sky ratio [%]	Gray ratio [%]	Luminance [Cd/m^2]	People[N]	Vehicles[N]
A	80.6	14.7	7.1	31	15	44	95	45	0
B	63.3	4.1	3.6	21	8	33	104	38	0
C	72.5	17.6	19.4	39	28	0	123	19	0
D	69.1	7.0	18.5	37	0	0	97	18	0
E	58.9	10.4	20.3	51	20	19	120	41	45
F	64.7	4.7	7.2	3	9	72	132	60	0
G	62.3	4.7	9.3	6	17	65	122	32	34
H	73.2	5.3	3.7	0	4	96	121	83	0
I	54.8	6.5	16.8	14	10	63	115	38	14
J	78.5	11.6	17.7	7	8	70	129	53	4

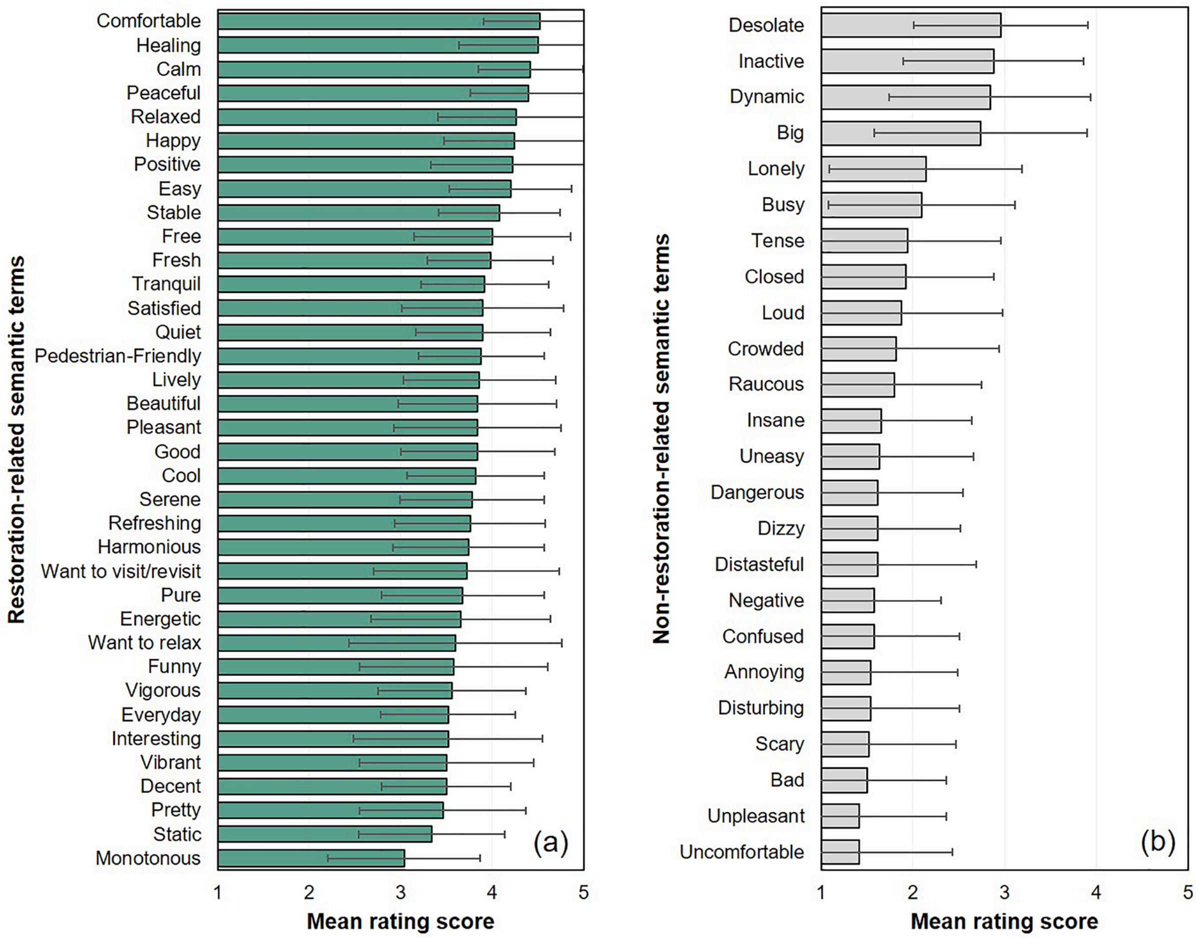

Fig. 2. Mean rating scores of semantic terms related to potential restorative effects based on narrative interviews: (a) restoration-related attributes, (b) non-restoration-related attributes.

(50 participants × 10 sites = 500 responses). Participants were then categorized into two groups, PR or PNR, according to the PR criteria, and the groups' mean rating scores for each questionnaire item were compared. The Mann-Whitney *U* test was conducted because the number of participants per site varied and the assumption of normality was not satisfied. During this process, the mean value of responses for all evaluation sites was compared rather than comparing the value for each site. Next, a logistic regression analysis was performed to predict the PR effects based on a variety of subjective, objective, and individual characteristics. The SPSS software (version 25, IBM) and R language (version 3.5.1, R Development Core Team) were used for analysis.

3. Results

3.1. Objective characteristics of evaluation sites

Each evaluation site's objective soundscape characteristics were analyzed, including acoustic and visual characteristics and the characteristics of moving objects (Table 2). First, examination of the acoustic parameters demonstrated that the range of L_{Aeq} was 54.8–80.6 dB, the range of $L_{A10\text{-}A90}$ was 4.1–17.6 dB, and the range of $L_{Ceq\text{-}Aeq}$ was 3.7–20.3 dB. As the difference between the minimum and maximum values of each parameter is more than 10 dB, these ranges adequately represent the soundscape variation of typical urban environments.

L_{Aeq} was highest at Site A, where there was a large in-ground water fountain and a concentration of human activity. L_{Aeq} was lowest at Site I because, though it is a large public square, the space was not used much because of its poor facilities. The green ratio was highest at Site I, which had a high concentration of vegetation; the sites' green ratios ranged from 0% to 51%. The sky ratio had a lower range of distribution than the green ratio at 0%–28%. This was due to the sites' surroundings, which included buildings or landscape typical of an urban environment. Last, the gray ratio, which is influenced by artificial elements (e.g., buildings and roads), was particularly high at Site H with a wide distribution (0%–96%), as Site H was surrounded by large structures. Spearman's rank correlation analysis demonstrated that the green ratio of sites has a strong negative correlation with the gray ratio ($r_s = -0.94$, $p < 0.01$), confirming that the visual characteristics of gray ratio are the opposite to those of vegetation (Puyana-Romero et al., 2019). Additionally, the distribution of luminance was determined to be 95–132Cd/m^2.

Last, examination of the object parameter showed that this changed according to the function of the urban environment; for sites with commercial streets (Sites F and J), the value was high, with more than 60 moving people. For uncrowded urban parks (Sites C and D), the value was low, with approximately 20 moving people. Overall, this parameter showed large variance, with values ranging from 18 to 83 moving people. Regarding the number of vehicles, the presence of streets in the surrounding area was significant. The value of this parameter was high for sites surrounded by large commercial streets (Sites E and G), with a value of more than 34 vehicles; the overall range of distribution was 0–45 vehicles.

3.2. PR group distribution according to PR criteria

Fig. 2 shows the mean rating scores of the responses for each semantic term and the standard deviations (see Section 2.2). Compliance

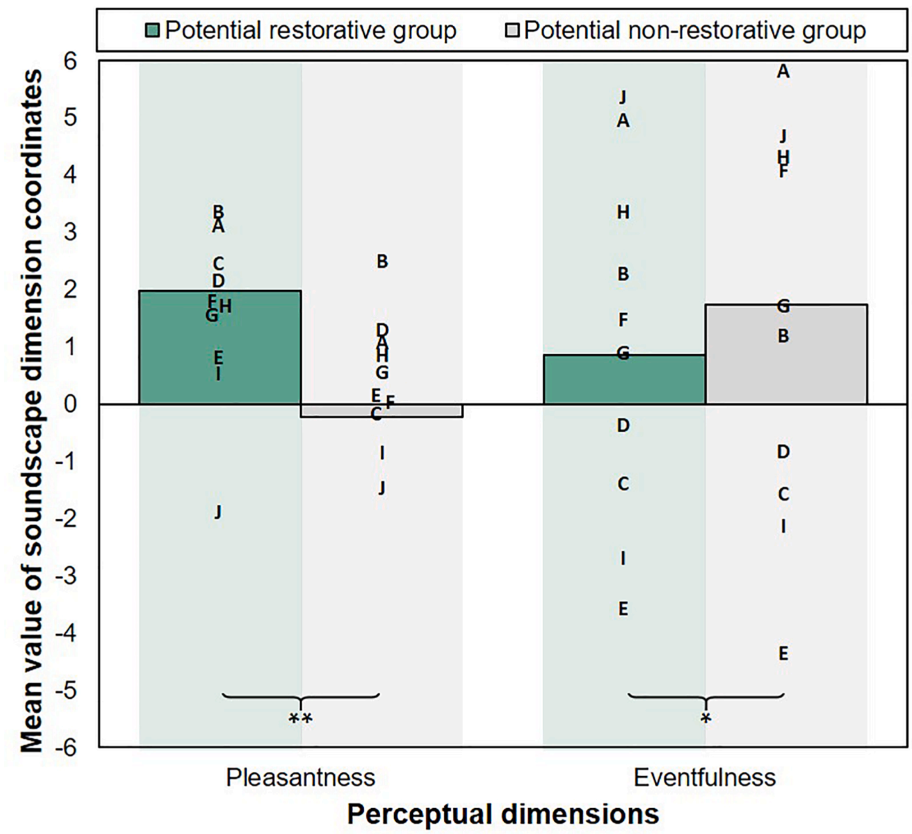

Fig. 3. Mean value of soundscape dimension coordinates by group (letters signify the average value of rating scores according to the site; ** p-value < 0.01, * p-value < 0.05 for Mann-Whitney U).

with the PR criteria is based on whether RSTs were used in the narrative interviews about space. For example, if a participant answered: "It is an urban space that can be healing when walking through it," the word "healing" belonged to RSTs and thus the subject was categorized into the PR group. If a participant answered: "I just want to pass through this space quickly, it is unpleasant, and I do not want to stay long," no word belonging to RSTs was used. The participant was therefore categorized into the PNR group because there was a very low possibility of a restoration effect. However, if a participant used less than five words that belonged to both categories, they were categorized into the group according to the number of words used in each category in the first stage. Then, in the second stage, researchers made a final decision based on the subjective impression of the overall mood of the narrative interview.

When each site's criteria were considered, the PR group participant ratio was higher for sites with vegetation, such as parks, and for sites on a waterfront. This included Sites A–E. For Site A, which had a fountain, children running and playing, and people relaxing in the surrounding area, had the highest ratio (92%). Additionally, while Sites F and J were similarly commercial, PR group participants rated the sites very differently. Site F, which was a modern commercial street with a well-organized environment, had a high PR ratio of 70%. However, Site J, which was a poorly maintained street with no distinction between pedestrian and vehicular zones, had the lowest PR ratio (10%). Sites H and I, both public squares, exhibited a similar trend. Although Site H included only artificial elements, it was a courtyard located within a modern building and was used for events such as exhibitions and fashion shows; the PR ratio for this site was 52%, exceeding the middle value of 50%. Site I was dilapidated and unfrequented with a low PR ratio of 38%. As indicated by the number of vehicles (Table 2), Sites E and F had heavy traffic flows and a wide green space or a large fountain nearby. Both sites had high PR ratios: 70% and 55%, respectively.

3.3. Subjective responses according to PR group

3.3.1. Sound source identification

Regarding traffic noise, the mean score of the PNR group's responses (3.10) was higher than that of the PR group's responses (2.23), demonstrating a statistically significant trend ($U = 15272$, $p < 0.01$). Construction noises, fan noises, sign noises, etc., were sound sources from the noise category; the mean score of the PNR group's responses for this category (2.69) was higher than that of the PR group's responses (1.99), demonstrating a statistically significant trend ($U = 17656$, $p < 0.01$). However, as the mean scores of both groups did not exceed the middle value of 3 (*moderately*) regarding other noises, these noises were not determined to be dominant. In summary, the PNR group was more sensitive to sounds from the noise category. However, the trends for the human-generated and natural sounds differed from those in the noise category. For human-generated sounds, the difference between PR and PNR was not statistically significant ($U = 26107$, $p = 0.42$). For natural sounds, the mean score of the PR group's responses (3.53) was the highest for all sound sources and higher than the mean score of the PNR group's responses (2.84), demonstrating a statistically significant trend ($U = 31790$, $p < 0.01$). In summary, the PR group perceived sound sources from the noise category to a lesser degree but perceived natural sounds to a higher degree.

3.3.2. Perception dimension based on perceived affective quality

To determine the perceptual dimensions of urban soundscapes, we calculated the coordinates along the two dimensions (pleasantness and eventfulness) proposed in ISO 12913-3 ISO (2019) based on the results for eight perceived affective qualities. During this process, the pleasantness value was calculated using "(pleasant − annoying) + cos 45 (calm − chaotic) + cos 45 (vibrant − monotonous)" and the eventfulness value was calculated using "(eventful − uneventful) + cos 45 (chaotic −

Table 3
Spearman's rank correlation between soundscape variables and soundscape perception dimensions by group (** p-value < 0.01, * p-value < 0.05; PR = potential restorative group, PNR = Potential non-restorative group).

Variables	Parameters	Pleasantness		Eventfulness	
		PR	PNR	PR	PNR
Acoustic parameter	L_{Aeq} [dB]	0.30	0.09	0.77**	0.78**
	$L_{A10-A90}$ [dB]	−0.07	−0.37	−0.05	0.00
	$L_{Ceq-Aeq}$ [dB]	−0.42	−0.49	−0.64*	−0.60
Visual parameter	Green ratio [%]	0.26	0.12	−0.53	−0.58
	Sky ratio [%]	−0.04	−0.37	−0.47	−0.36
	Gray ratio [%]	−0.41	−0.26	0.55	0.61
	Luminance [Cd/m^2]	−0.43	−0.69*	0.07	0.10
Numberof objects	People [N]	−0.25	−0.19	0.56	0.58
	Vehicle [N]	−0.77**	−0.44	−0.44	−0.41
Sound source identification	Traffic noise	−0.77**	−0.64*	0.22	0.30
	Other noises	−0.34	0.06	0.17	0.46
	Human sounds	0.32	0.25	0.94**	0.88**
	Natural sounds	0.62	0.25	0.56	−0.10

calm) + cos 45 (vibrant − monotonous)." The mean values are shown in Fig. 3. The PR group positively evaluated the relevant sites and the PNR group's responses generally had a lower positive pleasantness value. Eventfulness and pleasantness exhibited different trends. The mean value of eventfulness of the PR group was lower than that of the PNR group. However, this shows that eventfulness acts as a relatively complicated mechanism regarding restoration because it varied at each site.

To examine the relationship between the dimension of perception (pleasantness–eventfulness) and other soundscape variables (objective characteristics and sound source identifications) for each PR group, Spearman's rank correlation analysis was performed based on the mean values of each evaluation site (Table 3). The PR group's responses regarding pleasantness were significantly related to the audio-visual factors of vehicles. Additionally, eventfulness was related to audio-visual characteristics, with a particularly significant relationship to human-generated sounds. Examination of the PNR group's responses regarding pleasantness revealed that the negative influence of traffic noise was similar to that of the PR group. The relationship between eventfulness and human audio-visual characteristics was similar to that of the PR group. In other words, both PR and PNR groups showed a strong relationship of eventfulness with L_{Aeq} and human sounds.

3.3.3. Overall soundscape quality

This study divided the overall soundscape quality into positive (overall impression, appropriateness, and revisitation) and negative (loudness, unpleasantness), and examined both categories (for mean scores, see Fig. 4). Both groups positively evaluated the sites' overall impression and appropriateness to a certain degree because the mean score of each group's responses was greater than three. Revisitation evaluated the participants' willingness to revisit evaluation sites, and the revisitation variable was a critical factor in determining the PR effects of urban soundscape experiences because of the highly significant difference between the PR and PNR groups' responses. The participants perceived the majority of sites to be relatively peaceful because most of them, except Sites A and J (which had high SPLs), demonstrated mean score values of less than three for loudness and unpleasantness. As a result, we determined that the PNR group, which showed higher sensitivity to noises, evaluated positive soundscape qualities less positively

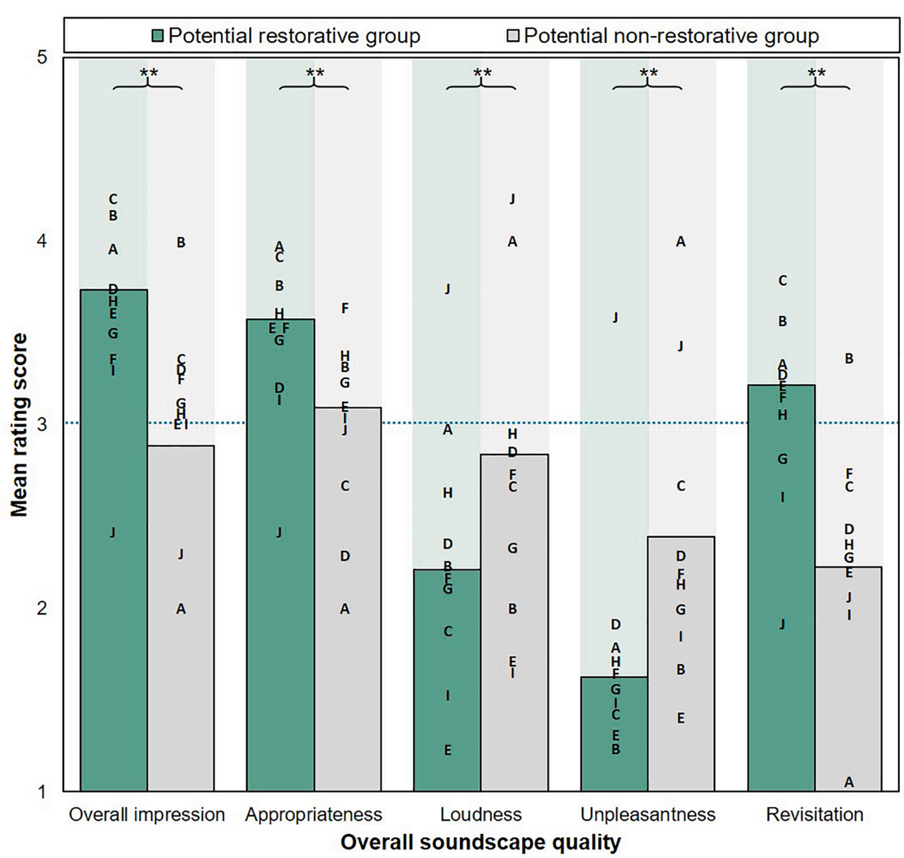

Fig. 4. Mean ratings of factor scores for overall soundscape quality by group (letters signify the average value of rating scores according to the site; ** p-value < 0.01 for Mann-Whitney U).

Table 4
Spearman's rank correlation between soundscape contexts and overall soundscape quality by group (**p-value < 0.01, * p-value < 0.05; PR = potential restorative group, PNR = Potential non-restorative group).

Contexts	Parameters	Overall impression		Appropriateness		Loudness		Unpleasantness		Revisitation	
		PR	PNR	PR	PNR	PR	PNR	PR	PNR	PR	PNR
Acoustic parameter	L_{Aeq} [dB]	0.26	−0.24	0.36	−0.38	0.84**	0.94**	0.67*	0.87**	0.18	−0.12
	$L_{A10\text{-}A90}$ [dB]	0.18	−0.43	0.12	−0.80**	0.10	0.36	0.29	0.61	0.20	−0.49
	$L_{Ceq\text{-}Aeq}$ [dB]	−0.13	−0.08	−0.39	−0.46	−0.47	−0.19	−0.02	0.03	−0.02	−0.19
Visual parameter	Green ratio [%]	0.50	0.09	0.19	−0.65*	−0.37	−0.29	−0.33	−0.03	0.61	−0.08
	Sky ratio [%]	0.14	−0.12	0.30	−0.16	−0.64*	−0.43	−0.52	−0.10	0.23	−0.22
	Gray ratio [%]	−0.62	−0.36	−0.19	0.62	0.36	0.32	0.35	0.04	−0.69*	−0.13
	Luminance [Cd/m^2]	−0.46	0.10	−0.22	0.48	−0.10	0.12	0.04	0.09	−0.38	0.27
Number of objects	People [N]	−0.40	−0.50	0.09	0.49	0.40	0.41	0.27	0.09	−0.39	−0.18
	Vehicles [N]	−0.59	−0.43	−0.59	0.06	−0.51	−0.49	−0.23	−0.50	−0.57	−0.51
Sound source identification	Traffic noise	−0.73**	−0.59	−0.66*	−0.31	0.12	0.26	0.16	0.41	−0.87**	−0.66*
	Other noises	−0.40	−0.38	−0.57	−0.37	0.35	0.55	0.54	0.49	−0.38	−0.35
	Human sounds	0.13	−0.17	0.30	−0.04	0.88**	0.79**	0.47	0.62	0.08	0.01
	Natural sounds	0.67*	0.24	0.47	−0.57	−0.12	−0.07	−0.14	0.24	0.70*	0.03
Perception dimension	Pleasantness	0.88**	0.37	0.82**	0.02	0.18	0.04	−0.22	−0.15	0.89**	0.33
	Eventfulness	−0.06	−0.37	0.16	0.01	0.93**	0.84**	0.59	0.65*	−0.15	−0.18

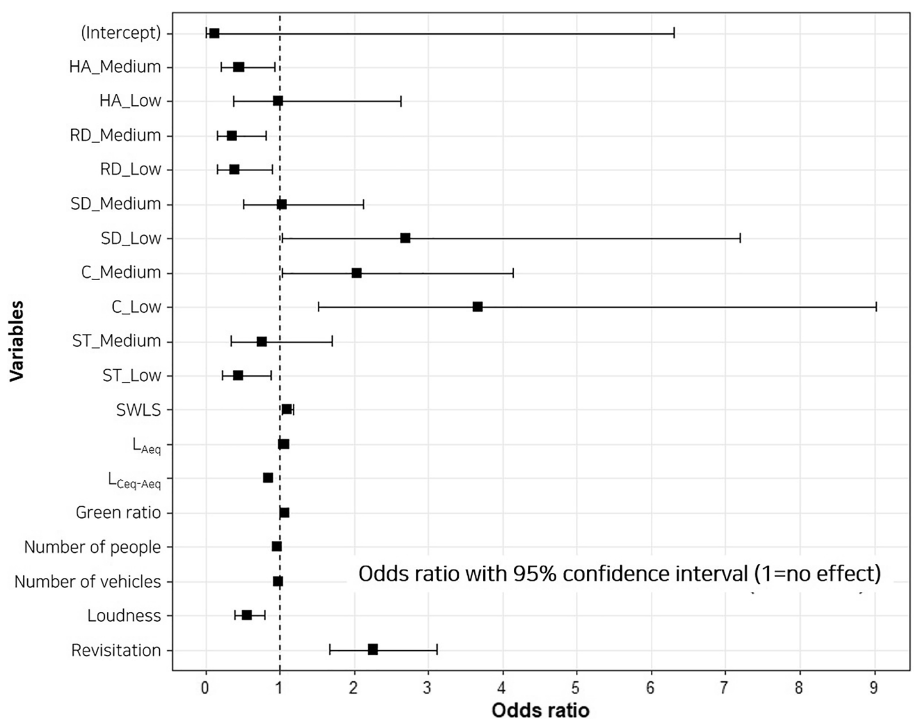

Fig. 5. Summary of logistic regression analysis for potential restorative effect based on various variables (objective parameter, subjective response, and individual characteristics).

and evaluated negative soundscape qualities more negatively.

Analysis of Spearman's rank correlations was performed with the mean score of each evaluation site to examine the relationships between the evaluation variables of overall soundscape quality and soundscape context (objective characteristics, sound source identification, and perception dimensions) for each group (Table 4). First, natural sounds had a positive correlation with overall soundscape quality, implying that natural sounds played a significant role in the positive perception of urban soundscapes. The appropriateness response of PNR was negatively correlated to $L_{A10\text{-}A90}$ and the green ratio. This showed that the temporal variation of soundscapes can have a negative effect on the evaluation of a soundscape's appropriateness, and the visual effect of vegetation does not always have a positive correlation with the appropriateness of soundscapes. Expectation for the soundscape may change according to the visual setting of vegetations (van Renterghem, 2019). Both groups' responses regarding negative soundscape quality, loudness, and unpleasantness, have a strong positive correlation with A-weighted SPL (L_{Aeq}), eventfulness, and human-generated sounds. A comprehensive examination of the above findings showed that the indicators of L_{Aeq} and eventfulness, which rise in value because of human-generated sounds and artificial elements such as traffic noises or gray ratio, had a negative effect on the PR group's evaluation of the overall soundscape quality.

3.4. Prediction model

A logistic regression analysis was conducted to predict the PR effects of diverse urban soundscape experiences on participants (Fig. 5 and Appendix A). The 9 objective parameters, 11 subjective parameters, and 7 individual parameters shown in Tables 1 and 4 were used as independent variables. The subjective parameters included four parameters for sound source identification, five for overall soundscape quality, and two for perceptual dimensions. The individual parameters included one parameter for age, one for SWLS, two for gender (dummy-coded using the group of males as reference), and six dimensions of temperament and character (dummy-coded using the "highest-coded" group as reference). A multicollinearity test was conducted, and variables with a variance inflation factor greater than 10 and with a tolerance$<$0.1 were excluded (gray ratio and $L_{A10\text{-}A90}$). To construct a model with the greatest value of R^2 with the optimal independent variable, stepwise regression was applied, and the resulting logistic model was found to be statistically significant ($p < 0.01$); the accuracy of the overall model was 82.6%, with 85.9% specificity for the PR group and 71.8% sensitivity for the PNR group; the model also had high balanced accuracy (78.9%).

First, regarding objective parameters, an increase in the value of L_{Aeq} by 1 dB and an increase in the green ratio by 1% raised the odds of satisfying the PR criteria by a factor of 1.05 and 1.06, respectively, when other variables were controlled. An increase in the value of $L_{Ceq\text{-}Aeq}$ by 1 dB and the number of people by one additional person raised the odds of not satisfying the criteria by a factor of 1.83 and 1.03, respectively. However, besides $L_{Ceq\text{-}Aeq}$, the odds ratio was not large for the remaining variables. Of the subjective responses, loudness and revisitation were determined to have a significant effect on the satisfaction of the PR criteria. The odds of not satisfying the criteria rose by a factor of 1.77 when loudness increased by 1 point; the odds of the occurrence of PR effects increased by a significant factor of 2.26 when revisitation rose by 1 point. To summarize, while the objective, audio-visual characteristics of an environment can partially affect the PR effects of urban soundscape experiences, the most significant influential factor is individual overall perception, which stems from the urban environmental context. The results showed that evaluation factors regarding people's preferences are highly significant.

The logistic regression analysis found the following personality traits to be significant: harm avoidance (HA) and reward dependence (RD), which are temperament dimensions; and self-directedness (SD), cooperativeness (C), and self-transcendence (ST), which are character dimensions. Regarding temperament, the odds ratio for satisfying PR criteria increased by a factor of 2.23 for participants with moderate levels of HA compared to those with high levels. Second, the odds of satisfying PR criteria increased as levels of RD decreased. Regarding character, the odds of the occurrence of PR effects rose by a factor of 2.69 for participants with low levels of SD compared to those with high levels. Additionally, the odds of satisfying the PR criteria for C_Medium and C_Low were 2.04 and 3.66, respectively, as the levels of C decreased. Additionally, the odds of satisfying the PR criteria were 2.04 and 3.66, respectively, as the levels of C decreased. Last, the odds of satisfying the PR criteria rose by a factor of 2.27 for the group with low levels of ST compared to the group with high levels. The odds of the occurrence of PR effects increased by a factor of 1.10 for every point increase in the value of SWLS, which is a measure of life satisfaction, but the difference was not significant when compared to other individual characteristics. The most influential factor was the level of C.

4. Discussion

4.1. Design strategy for urban soundscapes

This study proposes a soundscape design strategy based on a prediction model for PR effects, which was created using data for diverse soundscape variables. This strategy would provide urban residents with a pleasant and health-promoting environment. Urban environments should be designed to reduce low-frequency acoustic characteristics of soundscapes to increase PR effects. This method is based on the evidence that the objective characteristics of soundscapes, $L_{Ceq\text{-}Aeq}$, had the greatest negative effect on the satisfaction of PR criteria; this finding was similar to that of a previous study (Leventhall, 2004). Moreover, soundscapes must reduce the negative effects of loudness and increase the positive effects of revisitation, which are both subjective response indicators. Accordingly, a method for designing urban environments can be proposed based on the findings given in Tables 3 and 4. First, to reduce loudness, L_{Aeq} should be reduced to create a comparatively tranquil environment (Payne & Bruce, 2019). The tranquil characteristics of soundscapes are known to be a significant factor in decreasing the levels of annoyance and the occurrence of disturbed relaxation and sleep as well as in improving the physiological and psychological well-being of residents (Booi & van den Berg, 2012; Shepherd, Welch, Dirks, & McBride, 2013).

Additionally, in terms of controlling unwanted sound and applying wanted sound, design plans that obtain an optimal soundscape environment where the PR effect can be expected can be categorized as follows (Brown, 2012; Cerwén, Kreutzfeldt, & Wingren, 2017). First, the unwanted sound reduction method can be applied to reduce SPL using vegetation, installing noise screens, or directly eliminating noise sources by restricting certain activities. It is also possible to alter topography in the urban planning stage or utilize materials with significant sound-absorbing power in the execution planning stage. To achieve this, urban areas can be designed such that the radius of activity is separated and protected from noise caused by, for example, vehicles or low-frequency fans (Evensen, Raanaas, & Fyhri, 2016). A stronger method would include local governments controlling traffic and visitors' activities or requiring planning to include access to nearby tranquil areas (Cerwén & Mossbe, 2019). Another method would be to guarantee accessibility to quiet areas within urban environments or to design areas where health-related activities can occur (Lachowycz & Jones, 2013). Guaranteeing access to tranquility is very important to improve residents' health, lifestyle, and economy, but what should be prioritized over a guarantee for access would be the maintenance and enforcement of that access (Cerwén & Mossbe, 2019; Tsaligopoulos, Economou, & Matsinos, 2018).

However, some studies state that there is no significant relationship between tranquility and restoration, and as it has been concluded that the type of sound is more important in determining restoration than the loudness of sound (Payne & Bruce, 2019), it is necessary to consider methodology that utilizes the sound source at an appropriate level. In this sense, wanted sound application methods include audio-visual masking, utilization of sound sculpture and urban furniture, or amplification of natural sound by providing biotope design for birds and other animals.

The design of urban environments must also consider an area's audio-visual interactions to effectively increase the restorative effects because visual factors also significantly affect people's perceptions of soundscapes (Jeon & Jo, 2020; Li & Lau, 2020). As shown in Table 4, providing open views enhances the psychological effect of reducing perceived loudness. Thus, an urban environment design that minimizes artificial elements and provides open views would increase the positive effect that revisitation would have on the occurrence of restorative effects. In particular, an urban design that reduces levels of traffic noise and provides appropriate population density should be encouraged (Jo & Jeon, 2020b; Meng & Kang, 2015).

In existing urban environments where road infrastructure and the organization and assignment of spaces have been decided to a degree, natural sounds can be used to mask other sounds (Galbrun & Calarco, 2014; Rådsten Ekman, 2015). Water sounds with a low level of loudness and a high level of fluctuation strength have a better masking effect (Rådsten Ekman, 2015). Natural stream sounds have a greater masking effect than artificial water sounds, like those of a waterfall or fountain (Galbrun & Calarco, 2014). Previous studies have been conducted on the pleasant and comforting effects of natural sounds (Alvarsson et al., 2010; Jeon, Lee, You, & Kang, 2010), and the potential occurrence of restorative effects was higher for preferred environments (van den Berg, Koole, & van der Wulp, 2003). Studies have especially shown the positive effect of bird sounds on attention restoration and stress recovery (Ratcliffe, Gatersleben, & Sowden, 2013). Water sounds were also determined to be a valuable source of natural sounds for PR effects (Franco, Shanahan, & Fuller, 2017; Zhao et al., 2018). Ultimately, such diverse methods must be used to decrease loudness and increase revisitation to satisfy the PR criteria.

4.2. Effect of individual characteristics

This study aimed to examine the PR effects of urban soundscape experiences from the perspective of individual characteristics. The results of examining the dimensions of temperament and character after dividing the prediction model (Fig. 5) into dimension categories are as follows. Regarding temperament, results show that individuals who are highly cautious and worry frequently (high levels of HA) but are also affectionate and social (high levels of RD) have a greater chance of experiencing effective restoration. Regarding character, results showed that individuals who are immature and easily hurt (low levels of SD), intolerant and inconsiderate of others (low levels of C), and unpretentious (high levels of ST) have a higher chance of experiencing effective restoration. Of the TCI-RS's seven dimensions of personality traits, character was determined to have a greater effect on PR effects than temperament. Thus, the results of the investigation demonstrated that an individual's background has a greater effect on PR effects than the innate temperament of an individual.

Regarding temperament, HA demonstrates the tendencies of individuals to inhibit or stop behaviors when they face or avoid danger (Cloninger, Svrakic, & Przybeck, 1993). These tendencies function as a behavioral inhibition system and are related to serotonin, which is a chemical that acts as a neurotransmitter and is linked to anxiety and depression (Hansenne & Ansseau, 1999). High levels of HA can be associated with high levels of anxiety, and the fact that restorative effects were high in such a group might signify that people with lower levels of HA are not greatly affected by their environment. The temperament dimension of RD is the hereditary tendency to react sensitively to rewards to form social attachments. High levels of RD are known to be associated with low levels of the neurotransmitter norepinephrine (Garvey, Noyes Jr, Cook, & Blum, 1996). Overall, these findings demonstrate that people with high levels of HA and RD are affected by environmental factors. This suggests that feelings like anxiety and depression and the factor of restoration can mutually influence each other. Regarding character, interestingly, C is the most important factor in determining restoration. In general, C means the ability to embrace and empathize with others. The higher the score is, the more generous and empathic one is; the lower the score is, the more difficulty one has in establishing social relationships (Min et al., 2007). As this study evaluates the restoration response of individual subjects as they experience soundscape alone, it shows a greater restoration effect in the low C group participants, who prefer isolation, than those in the high C group, who prefer social experiences and relationships. In other words, in comparison to the participants who feel satisfaction from social relationships, those who prefer individual satisfaction experience a greater restorative effect from soundscape. Therefore, this study implies that one should decide whether to provide an isolated soundscape experience or a soundscape experience where two or more people could share and form social relationships depending on the C characteristic of individuals (Cao & Kang, 2021).

Individuals with low levels of SD are easily influenced by others and are less autonomous (Min et al., 2007). Furthermore, individuals with low levels of C tend to focus on themselves rather than external circumstances. Regarding clinical disease, it has been reported that patients with PTSD have low levels of SD and C (North & Cloninger, 2012). Individuals with these personality traits are more easily influenced by the environment. Because such traits can be linked to the individuals' emotional state, this study predicts that the use of VR and suitable urban soundscape experience systems can have a positive effect as methods of treatment for such individuals.

4.3. Limitations and future research

This study has several limitations. First, the assumption of normality was not satisfied for the participant groups overall, and as the participants were all in their twenties, it was difficult to generalize to all age groups. However, in this study, even though eventfulness and human sounds have shown negative correlation to loudness, soundscape quality cannot be represented by loudness only. As it might have a positive effect in terms of restoration, future studies should investigate this issue. Moreover, even though it is shown that revisitation is an important soundscape factor in determining restoration, from the point of view of design, an academic-practice gap exists in its application. Therefore, future research should study design factors that determine the revisitation of soundscape. Additionally, the relationship between PR criteria and various psycho-physiological responses linked to restoration, such as HR and brain waves, should be examined in addition to objective and subjective indicators (Erfanian, Mitchell, Kang, & Aletta, 2019; Li & Kang, 2019). Last, while we examined individual characteristics in the form of temperament and character, consideration of additional factors regarding the everyday emotional states of participants was insufficient, including for depression, anxiety, and stress. Nonetheless, this study is significant as it 1) expanded the evaluation of PR effects to include urban environments with diverse functions, when previous evaluations only focused on natural environments; 2) evaluated the effects of the participants' individual characteristics with the TCI-RS and SWLS; and 3) established a new set of PR criteria by using responses that were given freely by participants instead of using questionnaires that were designed according to the researchers' intentions. The most important feature of this study is its implications for research, that is, the proposal of a new set of PR criteria based on the narrative interview method.

5. Conclusions

This study investigates PR effects that occur when individuals experience the soundscapes of urban environments, which include a variety of functions. To achieve this, we collected the results of the participants' open responses regarding their perceptions of soundscapes, investigated the connection between terms related to restoration and to semantic terms, and established a new set of PR criteria. To create a prediction model that satisfies the PR criteria, we analyzed the objective characteristics of the audio-visual stimuli of soundscapes, participants' subjective responses regarding their perceptions of soundscapes, and the individual characteristics of participants, including gender, age, personality traits, and life satisfaction. A prediction model with 82.6% accuracy was developed based on the analysis of the above characteristics. The findings of this study are as follows.

We established a new set of PR criteria based on whether the RSTs, extracted through text-mining, were expressed or not.

The participants' overall level of preference regarding soundscapes was found to be a more significant factor in determining the restorative effects of urban soundscapes than objective audio-visual characteristics. Results showed that urban environment designs should be encouraged to increase revisitation and decrease loudness, particularly in low frequency content. Thus, as the overall soundscape quality has connections with various objective characteristics such as the size of sounds, sky or gray ratios, and traffic noise, the relevant design factors (based on Section 4.1) should be considered during the early planning stages of urban environment design.

The PR effects changed according to the character and temperament of individuals as well as their life satisfaction, even when viewing identical spaces. Results showed that a person's character, which is based on their background, has a greater effect on PR effects than their innate temperament. Thus, in terms of restoration, it is desirable to include a diversity of soundscapes during the planning stage in urban environments so that users with various personal traits could feel satisfied.

By using the experiences of urban environments, which have predominantly been evaluated negatively, the findings of this study present a new possibility for restorative potential within such environments. The PR criteria proposed in this study can utilize the potential restoration effect of environmental experience as an innovative methodology in determining restoration while minimizing researcher interventions. The findings provide the basis for sustainable and health-promoting urban soundscape environment designs. Furthermore, in the long term, this study's results can be applied to create services that provide personalized city experiences for restoration.

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Authors' contributions

Conceptualization, J.Y.J. and H.I.J.; Formal analysis, H.I.J.; Funding acquisition, J.Y.J.; Investigation, H.I.J.; Methodology, H.I.J.; Project administration, J.Y.J.; Supervision, J.Y.J.; Visualization, H.I.J.; Writing - original draft, H.I.J.; Writing - review & editing, H.I.J., J.Y.J., K.L.

Declaration of Competing Interest

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

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Appendix A. Prediction model for potential restorative effect

Table A1

Table A1
Detailed description of prediction model for potential restorative effect (**p-value < 0.01, * p-value < 0.05).

Variables	B	Std. Error	p-value		odds ratio	95% confidence interval	
						Lower limit	Upper limit
Objective characteristics							
L_{Aeq}	0.051	0.026	< 0.05	*	1.053	1.001	1.109
$L_{Ceq-Aeq}$	−0.166	0.032	< 0.01	**	0.547	0.793	0.900
Green ratio	0.058	0.012	< 0.01	**	1.059	1.036	1.085
Number of people	−0.031	0.010	< 0.01	**	0.969	0.950	0.988
Number of vehicles	−0.018	0.011	0.09		0.982	0.962	1.003
Subjective response							
Loudness	−0.570	0.175	< 0.01	**	0.566	0.398	0.794
Revisitation	0.815	0.158	< 0.01	**	2.259	1.669	3.107
Personal characteristics							
HA_High					Reference		
HA_Medium	−0.800	0.377	< 0.05	*	0.449	0.211	0.930
HA_Low	−0.016	0.499	0.98		0.984	0.368	2.621
RD_High					Reference		
RD_Medium	−1.026	0.431	< 0.05	*	0.358	0.150	0.818
RD_Low	−0.944	0.435	< 0.05	*	0.389	0.162	0.896
SD_High					Reference		
SD_Medium	0.031	0.365	0.93		1.031	0.503	2.113
SD_Low	0.991	0.493	< 0.05	*	2.694	1.036	7.188
C_High					Reference		
C_Medium	0.714	0.355	< 0.05	*	2.042	1.024	4.131
C_Low	1.297	0.453	< 0.01	**	3.660	1.523	9.030
ST_High					Reference		
ST_Medium	−0.265	0.404	0.51		0.767	0.346	1.695
ST_Low	−0.813	0.353	< 0.05	*	0.443	0.219	0.878
SWLS	0.097	0.036	< 0.01	**	1.102	1.028	1.118

References

Aletta, F., Oberman, T., & Kang, J. (2018). Associations between positive health-related effects and soundscapes perceptual constructs: A systematic review. *International Journal of Environmental Research and Public Health, 15*(11), 2392. https://doi.org/10.3390/ijerph15112392.

Alvarsson, J. J., Wiens, S., & Nilsson, M. E. (2010). Stress recovery during exposure to nature sound and environmental noise. *International Journal of Environmental Research and Public Health, 7*(3), 1036–1046. https://doi.org/10.3390/ijerph7031036.

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. *Lancet, 383*(9925), 1325–1332. https://doi.org/10.1016/S0140-6736(13)61613-X.

Booi, H., & Van den Berg, F. (2012). Quiet areas and the need for quietness in Amsterdam. *International Journal of Environmental Research and Public Health, 9*(4), 1030–1050. https://doi.org/10.3390/ijerph9041030.

Brown, A. L. (2010). Soundscapes and environmental noise management. *Noise Control Engineering Journal, 58*(5), 493–500. https://doi.org/10.3397/1.3484178.

Brown, A. L. (2012). A review of progress in soundscapes and an approach to soundscape planning. International Journal of Acoustics and Vibrations, 17(2), 73–81. 10.20855/ijav.2012.17.2302.

Cao, J., & Kang, J. (2021). The influence of companion factors on soundscape evaluations in urban public spaces. *Sustainable Cities and Society, 69*, Article 102860. https://doi.org/10.1016/j.scs.2021.102860.

Carmona, M., Heath, T., Tiesdell, S., & Oc, T. (2010). *Public places, urban spaces: The dimensions of urban design*. Oxford: Routledge.

Cerwén, G., & Mossberg, F. (2019). Implementation of quiet areas in Sweden. *International Journal of Environmental Research and Public Health, 16*(1), 134. https://doi.org/10.3390/ijerph16010134.

Cerwén, G., Kreutzfeldt, J., & Wingren, C. (2017). Soundscape actions: A tool for noise treatment based on three workshops in landscape architecture. *Frontiers of Architectural Research, 6*(4), 504–518. https://doi.org/10.1016/j.foar.2017.10.002.

Chick, G., Hsu, Y. C., Yeh, C. K., Hsieh, C. M., Bae, S. Y., & Iarmolenko, S. (2016). Cultural consonance in leisure, leisure satisfaction, life satisfaction, and self-rated health in urban Taiwan. *Leisure Sciences, 38*(5), 402–423. https://doi.org/10.1080/01490400.2016.1141734.

Choe, E. Y., Jorgensen, A., & Sheffield, D. (2020). Does a natural environment enhance the effectiveness of Mindfulness-Based Stress Reduction (MBSR)? Examining the mental health and wellbeing, and nature connectedness benefits. *Landscape and Urban Planning, 202*, Article 103886. https://doi.org/10.1016/j.landurbplan.2020.103886.

Cloninger, C. R., Svrakic, D. M., & Przybeck, T. R. (1993). A psychobiological model of temperament and character. *Archives of General Psychiatry, 50*(12), 975–990. https://doi.org/10.1001/archpsyc.1993.01820240059008.

Collins, R. M., Spake, R., Brown, K. A., Ogutu, B. O., Smith, D., & Eigenbrod, F. (2020). A systematic map of research exploring the effect of greenspace on mental health. *Landscape and Urban Planning, 201*, Article 103823. https://doi.org/10.1016/j.landurbplan.2020.103823.

Diener, E. D., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The satisfaction with life scale. *Journal of Personality Assessment, 49*(1), 71–75. https://doi.org/10.1207/s15327752jpa4901_13.

Erfanian, M., Mitchell, A. J., Kang, J., & Aletta, F. (2019). The psychophysiological implications of soundscape: A systematic review of empirical literature and a research agenda. *International Journal of Environmental Research and Public Health, 16*(19), 3533. https://doi.org/10.3390/ijerph16193533.

European Union. (2002). Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official Journal of the European Communities, L, 189(18.07), 2002.

Evensen, K. H., Raanaas, R. K., & Fyhri, A. (2016). Soundscape and perceived suitability for recreation in an urban designated quiet zone. *Urban Forestry & Urban Greening, 20*, 243–248. https://doi.org/10.1016/j.ufug.2016.09.003.

Faehnle, M., Bäcklund, P., Tyrväinen, L., Niemelä, J., & Yli-Pelkonen, V. (2014). How can residents' experiences inform planning of urban green infrastructure? Case Finland. *Landscape and Urban Planning, 130*, 171–183. https://doi.org/10.1016/j.landurbplan.2014.07.012.

Franco, L. S., Shanahan, D. F., & Fuller, R. A. (2017). A review of the benefits of nature experiences: More than meets the eye. *International Journal of Environmental Research and Public Health, 14*(8), 864. https://doi.org/10.3390/ijerph14080864.

Furnham, A. (1986). Response bias, social desirability and dissimulation. *Personality and Individual Differences, 7*(3), 385–400. https://doi.org/10.1016/0191-8869(86)90014-0.

Galbrun, L., & Calarco, F. M. A. (2014). Audio-visual interaction and perceptual assessment of water features used over road traffic noise. *The Journal of the Acoustical Society of America, 136*(5), 2609. https://doi.org/10.1121/1.4897313.

Gao, T., Zhang, T., Zhu, L., Gao, Y., & Qiu, L. (2019). Exploring psychophysiological restoration and individual preference in the different environments based on virtual reality. *International Journal of Environmental Research and Public Health, 16*(17), 3102. https://doi.org/10.3390/ijerph16173102.

Garvey, M. J., Noyes, R., Jr, Cook, B., & Blum, N. (1996). Preliminary confirmation of the proposed link between reward-dependence traits and norepinephrine. *Psychiatry Research, 65*(1), 61–64. https://doi.org/10.1016/0165-1781(96)02954-X.

Han, K. T. (2003). A reliable and valid self-rating measure of the restorative quality of natural environments. *Landscape and Urban Planning, 64*(4), 209–232. https://doi.org/10.1016/S0169-2046(02)00241-4.

Hansenne, M., & Ansseau, M. (1999). Harm avoidance and serotonin. *Biological Psychology, 51*(1), 77–81. https://doi.org/10.1016/S0301-0511(99)00018-6.

Herranz-Pascual, K., Aspuru, I., & García, I. (2010). June). Proposed conceptual model of environmental experience as framework to study the soundscape. In *In Proceedings of INTERNOISE* (pp. 2904–2912).

Herranz-Pascual, K., Aspuru, I., Iraurgi, I., Santander, Á., Eguiguren, J. L., & García, I. (2019). Going beyond quietness: Determining the emotionally restorative effect of acoustic environments in urban open public spaces. *International Journal of Environmental Research and Public Health, 16*(7), 1284. https://doi.org/10.3390/ijerph16071284.

Hong, J. Y., Lam, B., Ong, Z. T., Ooi, K., Gan, W. S., Kang, J., … Tan, S. T. (2019). Quality assessment of acoustic environment reproduction methods for cinematic virtual reality in soundscape applications. *Building and Environment, 149*, 1–14. https://doi.org/10.1016/j.buildenv.2018.12.004.

Huang, Q., Yang, M., Jane, H. A., Li, S., & Bauer, N. (2020). Trees, grass, or concrete? The effects of different types of environments on stress reduction. *Landscape and Urban Planning, 193*, Article 103654. https://doi.org/10.1016/j.landurbplan.2019.103654.

Hume, K., & Ahtamad, M. (2013). Physiological responses to and subjective estimates of soundscape elements. *Applied Acoustics, 74*(2), 275–281. https://doi.org/10.1016/j.apacoust.2011.10.009.

International Organization for Standardization (ISO). (2018). *12913–2: 2018—Acoustics—Soundscape Part 2: Data Collection and Reporting Requirements*. ISO: Geneva, Switzerland.

International Organization for Standardization (ISO). (2019). *12913–3: 2019—Acoustics—Soundscape Part 3: Data Analysis*. ISO: Geneva, Switzerland.

ITU. (2011). *Studio encoding parameters of digital television for standard 4: 3 and wide-screen 16: 9 aspect ratios*. Geneva, Switzerland: ITU.

Jeon, J. Y., & Jo, H. I. (2020). Effects of audio-visual interactions on soundscape and landscape perception and their influence on satisfaction with the urban environment. *Building and Environment, 169*, Article 106544. https://doi.org/10.1016/j.buildenv.2019.106544.

Jeon, J. Y., Lee, P. J., You, J., & Kang, J. (2010). Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. *The Journal of the Acoustical Society of America, 127*(3), 1357–1366. https://doi.org/10.1121/1.3298437.

Jo, H. I., & Jeon, J. Y. (2020a). Effect of the appropriateness of sound environment on urban soundscape assessment. *Building and Environment, 106975*. https://doi.org/10.1016/j.buildenv.2020.106975.

Jo, H. I., & Jeon, J. Y. (2020b). The influence of human behavioral characteristics on soundscape perception in urban parks: Subjective and observational approaches. *Landscape and Urban Planning, 203*, Article 103890. https://doi.org/10.1016/j.landurbplan.2020.103890.

Johansson, S. E., Konlaan, B. B., & Bygren, L. O. (2001). Sustaining habits of attending cultural events and maintenance of health: A longitudinal study. *Health Promotion International, 16*(3), 229–234. https://doi.org/10.1093/heapro/16.3.229.

Kang, J., & Schulte-Fortkamp, B. (Eds.). (2016). *Soundscape and the built environment* (pp. 161–195). Boca Raton, FL, USA: CRC Press.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge, UK: Cambridge University Press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169–182. https://doi.org/10.1016/0272-4944(95)90001-2.

Kaplan, S., Bardwell, L. V., & Slakter, D. B. (1993). The museum as a restorative environment. *Environment and Behavior, 25*(6), 725–742. https://doi.org/10.1177/0013916593256004.

Karmanov, D., & Hamel, R. (2008). Assessing the restorative potential of contemporary urban environment(s): Beyond the nature versus urban dichotomy. *Landscape and Urban Planning, 86*(2), 115–125. https://doi.org/10.1016/j.landurbplan.2008.01.004.

Kjellgren, A., & Buhrkall, H. (2010). A comparison of the restorative effect of a natural environment with that of a simulated natural environment. *Journal of Environmental Psychology, 30*(4), 464–472. https://doi.org/10.1016/j.jenvp.2010.01.011.

Kogan, P., Arenas, J. P., Bermejo, F., Hinalaf, M., & Turra, B. (2018). A Green Soundscape Index (GSI): The potential of assessing the perceived balance between natural sound and traffic noise. *Science of the Total Environment, 642*, 463–472. https://doi.org/10.1016/j.scitotenv.2018.06.023.

Korpela, K. M., & Ylén, M. P. (2009). Effectiveness of favorite-place prescriptions: A field experiment. *American Journal of Preventive Medicine, 36*(5), 435–438. https://doi.org/10.1016/j.amepre.2009.01.022.

Krzywicka, P., & Byrka, K. (2017). Restorative qualities of and preference for natural and urban soundscapes. *Frontiers in Psychology, 8*, 1705. https://doi.org/10.3389/fpsyg.2017.01705.

Krzywinski, M. (2018). Image Color Summarizer: RBG, HSV, LCH & Lab image color statistics and clustering—simple and easy.

Lachowycz, K., & Jones, A. P. (2013). Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework. *Landscape and Urban Planning, 118*, 62–69. https://doi.org/10.1016/j.landurbplan.2012.10.012.

Lercher, P., van Kamp, I., von Lindern, E., & Botteldooren, D. (2016). Perceived soundscapes and health-related quality of life, context, restoration, and personal characteristics. *Soundscape and the Built Environment, 89*. https://doi.org/10.1201/b19145-6.

Leventhall, H. G. (2004). Low frequency noise and annoyance. *Noise Health, 6*(23), 59.

Li, H., & Lau, S. K. (2020). A review of audio-visual interaction on soundscape assessment in urban built environments. *Applied Acoustics, 166*, Article 107372. https://doi.org/10.1016/j.apacoust.2020.107372.

Li, Z., & Kang, J. (2019). Sensitivity analysis of changes in human physiological indicators observed in soundscapes. *Landscape and Urban Planning, 190*, Article 103593. https://doi.org/10.1016/j.landurbplan.2019.103593.

Lindborg, P., & Friberg, A. (2016). Personality traits bias the perceived quality of sonic environments. *Applied Sciences, 6*(12), 405. https://doi.org/10.3390/app6120405.

Maffei, L., Masullo, M., Pascale, A., Ruggiero, G., & Romero, V. P. (2015). On the validity of immersive virtual reality as tool for multisensory evaluation of urban spaces. *Energy Procedia, 78*, 471–476. https://doi.org/10.1016/j.egypro.2015.11.703.

Medvedev, O., Shepherd, D., & Hautus, M. J. (2015). The restorative potential of soundscapes: A physiological investigation. *Applied Acoustics, 96*, 20–26. https://doi.org/10.1016/j.apacoust.2015.03.004.

Meng, Q., & Kang, J. (2015). The influence of crowd density on the sound environment of commercial pedestrian streets. *Science of the Total Environment, 511*, 249–258. https://doi.org/10.1016/j.scitotenv.2014.12.060.

Min, B. B., Oh, H. S., & Lee, J. Y. (2007). *Temperament and Character Inventory-Family Manual*. Seoul: Maumsarang.

Navarrete-Hernandez, P., & Laffan, K. (2019). A greener urban environment: Designing green infrastructure interventions to promote citizens' subjective wellbeing. *Landscape and Urban Planning, 191*, Article 103618. https://doi.org/10.1016/j.landurbplan.2019.103618.

North, C. S., & Cloninger, C. R. (2012). Personality and major depression among directly exposed survivors of the Oklahoma City Bombing. *Depression Research and Treatment, 2012*, Article 204741. https://doi.org/10.1155/2012/204741.

Ojala, A., Korpela, K., Tyrväinen, L., Tiittanen, P., & Lanki, T. (2019). Restorative effects of urban green environments and the role of urban-nature orientedness and noise sensitivity: A field experiment. *Health & Place, 55*, 59–70. https://doi.org/10.1016/j.healthplace.2018.11.004.

Ouellette, P., Kaplan, R., & Kaplan, S. (2005). The monastery as a restorative environment. *Journal of Environmental Psychology, 25*(2), 175–188. https://doi.org/10.1016/j.jenvp.2005.06.001.

Packer, J. (2008). Beyond learning: Exploring visitors' perceptions of the value and benefits of museum experiences. *Curator: The Museum Journal, 51*(1), 33–54. https://doi.org/10.1111/j.2151-6952.2008.tb00293.x.

Park, S. H., Lee, P. J., Jung, T., & Swenson, A. (2020). Effects of the aural and visual experience on psycho-physiological recovery in urban and rural environments. *Applied Acoustics, 169*, Article 107486. https://doi.org/10.1016/j.apacoust.2020.107486.

Payne, S. R. (2013). The production of a perceived restorativeness soundscape scale. *Applied Acoustics, 74*(2), 255–263. https://doi.org/10.1016/j.apacoust.2011.11.005.

Payne, S. R., & Bruce, N. (2019). Exploring the relationship between urban quiet areas and perceived restorative benefits. *International Journal of Environmental Research and Public Health, 16*(9), 1611. https://doi.org/10.3390/ijerph16091611.

Payne, S. R., & Guastavino, C. (2018). Exploring the validity of the Perceived Restorativeness Soundscape Scale: A psycholinguistic approach. *Frontiers in Psychology, 9*, 2224. https://doi.org/10.3389/fpsyg.2018.02224.

Puyana-Romero, V., Ciaburro, G., Brambilla, G., Garzón, C., & Maffei, L. (2019). Representation of the soundscape quality in urban areas through colours. *Noise Mapping, 6*(1), 8–21. https://doi.org/10.1515/noise-2019-0002.

Rådsten Ekman, M. (2015). *Unwanted wanted sounds: Perception of sounds from water structures in urban soundscapes (doctoral dissertation)*. Department of Psychology: Stockholm University.

Raimbault, M., & Dubois, D. (2005). Urban soundscapes: Experiences and knowledge. *Cities, 22*(5), 339–350.

Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). Bird sounds and their contributions to perceived attention restoration and stress recovery. *Journal of Environmental Psychology, 36*, 221–228. https://doi.org/10.1016/j.jenvp.2013.08.004.

Schafer, R. M. (1993). *The soundscape: Our sonic environment and the tuning of the world*. New York: Simon and Schuster.

Shepherd, D., Welch, D., Dirks, K. N., & McBride, D. (2013). Do quiet areas afford greater health-related quality of life than noisy areas? *International Journal of Environmental Research and Public Health, 10*(4), 1284–1303. https://doi.org/10.3390/ijerph10041284.

Shu, S., & Ma, H. (2019). Restorative effects of classroom soundscapes on children's cognitive performance. *International Journal of Environmental Research and Public Health, 16*(2), 293. https://doi.org/10.3390/ijerph16020293.

Southworth, M. (1969). The sonic environment of cities. *Environment and Behavior, 1*(1), 49–70. https://doi.org/10.1177/001391656900100104.

Stansfeld, S., Haines, M., & Brown, B. (2000). Noise and health in the urban environment. *Reviews on Environmental Health, 15*(1–2), 43–82. https://doi.org/10.1515/REVEH.2000.15.1-2.43.

Stigsdotter, U. K., Corazon, S. S., Sidenius, U., Kristiansen, J., & Grahn, P. (2017). It is not all bad for the grey city–A crossover study on physiological and psychological restoration in a forest and an urban environment. *Health & Place, 46*, 145–154. https://doi.org/10.1016/j.healthplace.2017.05.007.

Tsaligopoulos, A., Economou, C., & Matsinos, Y. G. (2018). Identification, prioritization, and assessment of urban quiet areas. In F. Aletta (Ed.), *Handbook of research on perception-driven approaches to urban assessment and design* (pp. 150–180). Hershey, PA: IGI Global. https://doi.org/10.4018/978-1-5225-3637-6.ch007.

Tsunetsugu, Y., Lee, J., Park, B. J., Tyrväinen, L., Kagawa, T., & Miyazaki, Y. (2013). Physiological and psychological effects of viewing urban forest landscapes assessed by multiple measurements. *Landscape and Urban Planning, 113*, 90–93. https://doi.org/10.1016/j.landurbplan.2013.01.014.

Twedt, E., Rainey, R. M., & Proffitt, D. R. (2019). Beyond nature: The roles of visual appeal and individual differences in perceived restorative potential. *Journal of Environmental Psychology, 65*, Article 101322. https://doi.org/10.1016/j.jenvp.2019.101322.

Ulrich, R. S. (1983). Aesthetic and affective response to natural environment. In I. Altman, & J. F. Wohlwill (Eds.), *Behavior and the Natural Environment* (pp. 85–125). Boston: Springer. https://doi.org/10.1007/978-1-4613-3539-9_4.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology, 11*(3), 201–230. https://doi.org/10.1016/S0272-4944(05)80184-7.

Van den Berg, A. E., Koole, S. L., & van der Wulp, N. Y. (2003). Environmental preference and restoration:(How) are they related? *Journal of Environmental Psychology, 23*(2), 135–146. https://doi.org/10.1016/S0272-4944(02)00111-1.

Van Dijk-Wesselius, J. E., Maas, J., Hovinga, D., Van Vugt, M. V. D. B. A., & Van den Berg, A. E. (2018). The impact of greening schoolyards on the appreciation, and physical, cognitive and social-emotional well-being of schoolchildren: A prospective intervention study. *Landscape and Urban Planning, 180*, 15–26. https://doi.org/10.1016/j.landurbplan.2018.08.003.

Van Renterghem, T. (2019). Towards explaining the positive effect of vegetation on the perception of environmental noise. *Urban Forestry & Urban Greening, 40*, 133–144. https://doi.org/10.1016/j.ufug.2018.03.007.

Von Lindern, E., Bauer, N., Frick, J., Hunziker, M., & Hartig, T. (2013). Occupational engagement as a constraint on restoration during leisure time in forest settings. *Landscape and Urban Planning, 118*, 90–97. https://doi.org/10.1016/j.landurbplan.2013.03.001.

Wilkie, S., & Stavridou, A. (2013). Influence of environmental preference and environment type congruence on judgments of restoration potential. *Urban Forestry & Urban Greening, 12*(2), 163–170. https://doi.org/10.1016/j.ufug.2013.01.004.

World Health Organization (WHO). (2018). *Environmental Noise Guidelines for the European Region*. Copenhagen: World Health Organization.

Yu, C. H., Jannasch-Pennell, A., & DiGangi, S. (2011). Compatibility between text mining and qualitative research in the perspectives of grounded theory, content analysis, and reliability. *Qualitative Report, 16*(3), 730–744.

Yu, C. P., Lee, H. Y., & Luo, X. Y. (2018). The effect of virtual reality forest and urban environments on physiological and psychological responses. *Urban Forestry & Urban Greening, 35*, 106–114. https://doi.org/10.1016/j.ufug.2018.08.013.

Zhang, T., Liu, J., & Li, H. (2019). Restorative effects of multi-sensory perception in urban green space: A case study of urban park in Guangzhou, China. *International Journal of Environmental Research and Public Health, 16*(24), 4943. https://doi.org/10.3390/ijerph16244943.

Zhao, J., Xu, W., & Ye, L. (2018). Effects of auditory-visual combinations on perceived restorative potential of urban green space. *Applied Acoustics, 141*, 169–177. https://doi.org/10.1016/j.apacoust.2018.07.00.