The effects of environmental sensitivity and noise sensitivity on soundscape evaluation

Weifu Gao [a], Jian Kang [a,b], Hui Ma [a*], Chao Wang [a]

[a] School of Architecture, Tianjin University, Tianjin, 300072, China

[b] UCL Institute for Environmental Design and Engineering, The Bartlett, University College London, London, UK

[*] Corresponding author：

Hui Ma,

Professor,

School of Architecture, Tianjin University, Tianjin, 300072, China,

E-mail address: mahui@tju.edu.cn

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Abstract

The perception of sound is a complex process that is influenced by not only the physical characteristics of the sound, but also individual characteristics of people. This study aimed to determine whether noise sensitivity and environmental sensitivity have a significant effect on people's soundscape evaluations, including sound source identification, perceived affective quality, and overall quality. Sixty participants aged 19–36 years were exposed to audiovisual stimuli derived from 10 commonly encountered urban scenes and assessed the soundscape quality. The study revealed that noise sensitivity did not significantly affect the evaluation of the soundscapes, whereas environmental sensitivity had a significant impact. Specifically, the full scale of environmental sensitivity had a significant effect on soundscape appropriateness, and the aesthetic sensitivity (AES) subscale of environmental sensitivity had a significant effect on perceived natural sound dominance, soundscape pleasantness, and overall impressions. The physical sensitivity (PHS) subscale significantly affected soundscape pleasantness, overall impressions, and perceived loudness. Moreover, an interaction effect between site and environmental sensitivity was observed in the evaluation of soundscape pleasantness and overall impressions; in sites dominated by natural environments, individuals with higher environmental sensitivity tended to perceive higher levels of soundscape pleasantness. Conversely, in sites dominated by built environments, individuals with higher environmental sensitivity tended to perceive lower levels of soundscape pleasantness. Similar patterns were observed in the overall impression evaluations. These findings can help policymakers and urban planning practitioners to recognise the diverse needs of various people and highlight the need for targeted soundscape design based on user sensitivity.

Key words: soundscape; noise sensitivity; environmental sensitivity; urban; built environment; natural environment

1. Introduction

Sound is a ubiquitous element of environments and has a significant impact on how people perceive their surroundings. As research on acoustic environment perception advances, the focus is shifting from noise reduction to more effective use of existing environmental resources to create comfortable and healthy acoustic environments [1, 2]. This shift is reflected in the concept of the soundscape, which emphasises the way people perceive and understand the acoustic environment in the context in which it is heard [3]. Research has shown that soundscape perception is heavily influenced by the characteristics of the physical environment, such as the dominant sound source [4-6], physical acoustic metrics [7-9], and psychoacoustic metrics [10-13]. However, it has also been found that not everyone perceives and understands the acoustic environment in the same way, and that individual factors such as demographics [14-18], mental health, personal traits, and preferences [18-22] can also affect soundscape perception. These personal factors can explain some of the differences in acoustic perception; however, knowledge and understanding of individual differences in this area are still limited, and further research is needed to expand our understanding of the personal factors that affect soundscape perception.

Previous research has shown that noise sensitivity is a stable trait that is partially influenced by genetics [23-25] and increases an individual's susceptibility to noise, which can affect their responses to it [20, 26-28]. Consequently, researchers have developed self-report scales to measure noise sensitivity and distinguish between those who are more and less susceptible to noise [29-32]. This allows for the quantification of the role of noise sensitivity in subjective noise annoyance evaluation. It has been found that the difference in annoyance between individuals with high and low noise sensitivity is equivalent to a difference in noise exposure of DNL-11 dB, and that noise sensitivity explains more of the variance in annoyance evaluation than other individual variables, such as demographics [17]. In terms of community response to noise, noise sensitivity is thought to be a better predictor than noise exposure [33]. However, in addition to the negative effects of sound environments, soundscape research has focused on the positive effects of certain types of environments, such as those with relaxing natural sounds or engaging human activities, which can provide mental and physiological benefits [34-37]. Despite this, research on the relationship between noise sensitivity and soundscape perception in positive sound environments is insufficient. It is unclear whether everyone has the same evaluation of a positive sound environment, or whether noise sensitivity is an appropriate predictor of soundscape perception.

Environmental Sensitivity is a common, heritable, and evolutionarily conserved individual trait that describes variations among individuals in their sensitivity to environmental stimuli, encompassing both negative and positive stimuli [38]. It is generally understood that environmental sensitivity is a broader concept than noise sensitivity, as it encompasses responses to a wider range of environmental stimuli, including positive stimuli, in addition to negative stimuli such as noise [39]. Environmental sensitivity also encompasses an individual's ability to process and modulate sensory information, which includes responses to various environmental cues, including visual, tactile, olfactory, and auditory stimuli [40]. This aligns well with the concept of the soundscape, which considers human sound perception in different contexts. Because of this, environmental sensitivity has been found to be particularly useful in explaining differences in the perception of positive environmental stimuli. In the realm of neuroscience, research utilizing functional MRI (fMRI) has discovered that individuals with varying environmental sensitivities exhibit differences in subtle environmental awareness and emotional responses, in aspects such as perceptual task responses, emotional stimulus responses, and brain activity differences during a resting state [41]. In the field of education, environmental sensitivity is considered to potentially impact students' learning levels and educational outcomes. For instance, students with high environmental sensitivity may be more susceptible to influences from factors such as family environment and peer relationships [42]. In psychology, studies have found that people's sensitivity to environmental stimuli is multidimensional including elements such as aesthetic, physical, and psychological sensitivity [39, 43-45]. In addition, some dimensions are associated with negative emotionality, as well as psychological traits such as anxiety and depression, while others are linked to positive affect and self-esteem [40]. Despite the importance of environmental sensitivity in explaining differences in the perception of positive environmental stimuli, no research has yet examined its effects on soundscape perception, particularly in positive acoustic environments. It remains unclear whether environmental sensitivity, which includes measures of responses to positive stimuli, is a more effective predictor of soundscape perception than noise sensitivity.

Therefore, the present study aims to enhance our understanding of the variations in people's perceptions of soundscapes by manipulating audiovisual environmental variables in a controlled laboratory setting. Participants were categorised based on their levels of noise sensitivity and environmental sensitivity, after which it was investigated whether individuals with high levels of these sensitivities evaluated soundscapes differently than those with low levels. Additionally, this study explores the implications of these findings for personalised soundscape practices in smart cities. The detailed theoretical framework of this study is illustrated in Fig 1 [3, 46], and the specific research questions addressed were as follows:

1. What is the relationship between noise sensitivity and soundscape evaluation?

2. Does environmental sensitivity affect soundscape evaluation? Which of its subscales have important roles in soundscape evaluation?

3. Do people with high noise sensitivity or high environmental sensitivity respond to soundscapes in the same way in different sites?

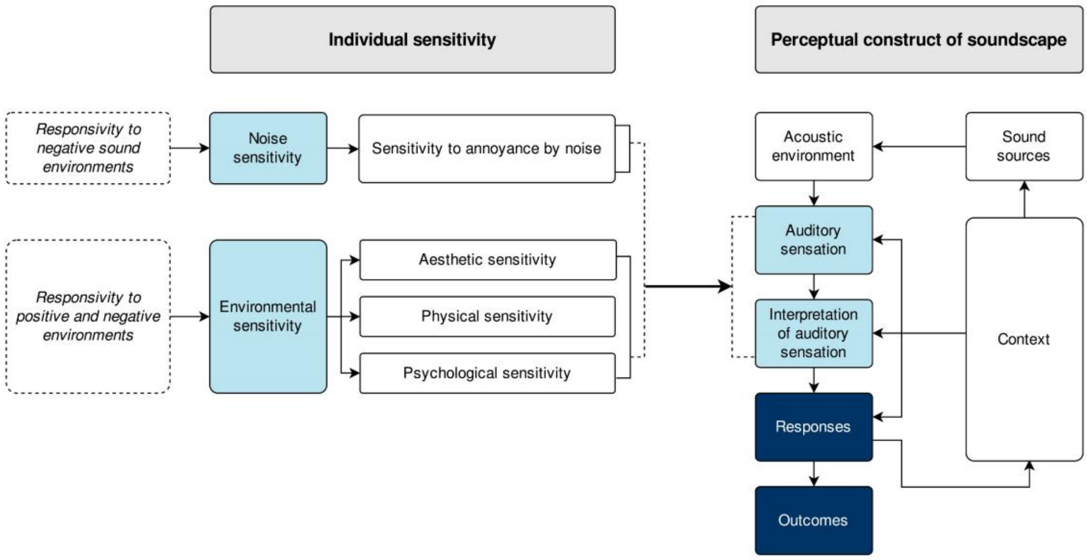

Fig. 1. A theoretical framework describing the relationships between individual sensitivities and perceptual construct of soundscape.

2. Methods

2.1. Participants

Sixty participants (32 males and 28 females) ranging in age from 19 to 36 years (mean age: 25.1 years, SD: 3.36 years) were recruited via university campus ads. All participants self-reported normal hearing and eyesight. To determine whether the participants in the study were more representative of highly sensitive or less sensitive individuals, the distributions of the Noise Sensitivity Scale and Environmental Sensitivity Scale were compared to a representative sample of the Chinese population from a previous study conducted by Han et al. and Li et al. [47,48] To assess noise sensitivity, the simplified Chinese version of the Weinstein Noise Sensitivity Scale

(WNSS) with 15 items was employed as it is able to delve deeply into the multifaceted impacts of noise on individual quality of life and has been proven to possess high reliability and validity in numerous studies [49]. To measure environmental sensitivity, we used the Highly Sensitive Person Scale (HSPS), which comprises 27 items and was originally proposed by Aron and Aron et al [39]. as it has demonstrated good measurement validity and reliability across multiple cultures and samples, accurately capturing individual sensitivity responses to environmental stimuli [50-52]. For the Chinese translation of HSPS, the study engaged two professionals proficient in English to conduct a rigorous translation and back-translation process to ensure the accuracy of the Chinese version of the HSPS scale. Its consistency and comprehensibility in the Chinese translation were further validated through comparison with the research of Li et al. and a pre-test involving eight adults [48]. Moreover, numerous subsequent studies have demonstrated the multidimensionality of the scale [44], and the present study used subscales of environmental sensitivity derived from a factor analysis conducted by Li et al. on a Chinese population sample [48]. The subscales include aesthetic sensitivity (AES), physical sensitivity (PHS), and psychological sensitivity (PSS). Figure 2 displays the distribution of scores for both noise and environmental sensitivity among the participants.

An independent samples t-test was conducted, and the results indicated that the distribution of sensitivity scales among participants in this experiment was not significantly different from that in the larger Chinese population sample from previous surveys ($p > 0.05$) [47]. Participants were then divided into high- and low-level groups based on median scores on the different scales, and the scores on the scales for each subgroup are shown in Table 1.

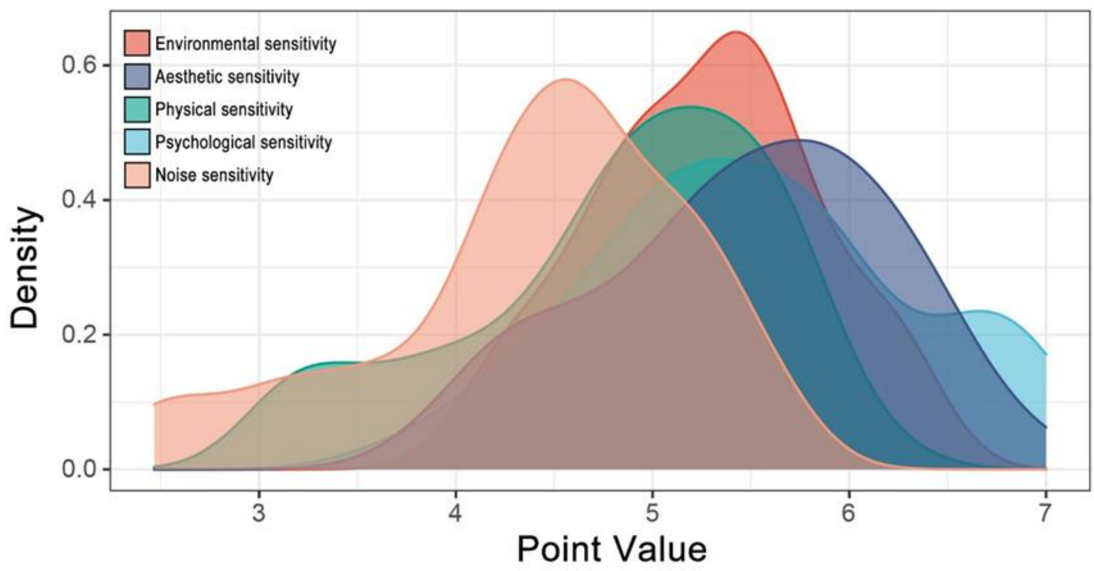

Fig. 2. Distribution of participants' sensitivity scores in the laboratory experiment.

Table. 1. Scale scores of the participants with high and low sensitivity.

Variable	Noise Sensitivity	Environmental Sensitivity	Aesthetic Sensitivity	Physical Sensitivity	Psychological Sensitivity
			Mean ± *SD*		
High Level	4.80 ± 0.33	5.57 ± 0.31	5.91 ± 0.34	5.29 ± 0.28	6.00 ± 0.49
Low Level	3.59 ± 0.64	4.64 ± 0.34	4.70 ± 0.47	4.05 ± 0.60	4.70 ± 0.45
Total	4.19 ± 0.80	5.11 ± 0.57	5.31 ± 0.74	4.66 ± 0.78	5.35 ± 0.81

Note: SD = standard deviation; Participants were divided into high- and low-level groups based on median scores.

2.2. Stimulus Material

2.2.1. Site Selection

To examine the varied perceptions of soundscapes across individuals with different levels of noise and environmental sensitivity, 10 frequently visited scenes from the Tianjin urban area were selected. These scenes were chosen to encompass a broad range of morphological functions and acoustic environments, and Figure 3 provides further details regarding this selection. The scenes included 1) a pocket square located by the road, 2) a pocket square in a residential area, 3) a commercial street, 4) Quanyechang Square, 5) Minyuan Square, 6) Central Park, 7) Haihe Park, 8) Shuixi

Park, 9) a lakeside square in Shuixi Park, and 10) Canal Park. The order of presentation of the scenes was based on the mean soundscape pleasantness evaluation scores from lowest to highest.

Fig. 3. Views and locations of the 10 evaluated sites.

2.2.2. Audiovisual recording

Audiovisual recordings and objective acoustic measurements were taken at ten selected sites during sunny weather, with average temperatures ranging between 19 °C and 28 °C. Visual information was captured using a Canon 5D camera in 4K video format, whereas auditory information was captured using a Sennheiser AMBEO four-channel VR microphone and a ZOOM F6 portable four-channel recorder in panoramic first-order A-format. The visual and auditory information for each soundscape was recorded for a duration of three minutes. To simulate the height of an individual's eyes and ears when standing, the cameras and microphones were positioned at a height of 1.6 m. A Norsonic 140 sound level meter was utilised to measure the sound pressure level for calibrating the laboratory acoustic environment to correspond to that of the actual site. Table 2 presents the three-minute equivalent sound pressure levels of the background sound at each site.

Table.2. Sound pressure levels of the acoustic environments in the 10 evaluated sites.

ID	Site	$L_{Aeq, 3min}$ (dB)
1	A pocket square by the road	63.3
2	A pocket square in a residential area	50.6

3	A commercial street	63.4
4	Quanyechang Square	78.0
5	Minyuan Square	72.8
6	Central Park	59.7
7	Haihe Park	57.4
8	Shuixi Park	49.3
9	A lakeside square in Shuixi Park	47.3
10	Canal Park	63.4

2.2.3. Audiovisual reproduction

To ensure high ecological validity in a controlled setting, high-resolution video and panoramic sound were used to reproduce the recorded audiovisual stimuli in a semi-anechoic chamber. Visual information was reproduced using a JIMI 4K projector. For ambient sound stimulus, we used the ZOOM Ambisonics Player to encode the recorded panoramic sound information, converted the A-format recordings to B-format, and then we exported the panoramic sound files to four-channel surround sound files by decoding them with the Reaper editor and using four loudspeakers (Genelec 8030C) to generate four-channel surround sound. Finally, the average sound pressure level of each experimental scene was adjusted such that the three-minute equivalent sound pressure level at the participant's location was consistent with that in the actual site measurements. The audiovisual reproduction system setup is shown in Figure 4.

Fig. 4. Setup of audiovisual reproduction system.

2.3. Procedures

The experiment consisted of two sections. In the first section, the participants were randomly presented with 10 audiovisual stimuli and asked to respond to each stimulus for a period of three minutes. Following this, they were required to complete the soundscape perception section of the evaluation form. The participants were given the opportunity to seek clarification on any questionnaire item, and the researcher provided immediate explanations. The participants were allowed to take breaks as needed. After evaluating the soundscapes of all scenes, participants were requested to complete the second section of the survey, which focused on their personal characteristics and included the WNSS and HSPS. The entire experiment lasted for approximately 45 minutes.

2.4. Measures

2.4.1. Sound source identification

For sound source identification, using a Likert scale ranging from 1 (not at all) to 5 (completely dominant) to score the responses to the questions: ‘To what extent do you currently hear the following four sound types: traffic noise (cars, buses, trains, airplanes, etc.), human sounds (conversations, laughter, children playing, footsteps, etc.), natural sounds (birds, water, wind, etc.), and other noises (sirens, construction, industry, etc.)?’ The questionnaire items on sound source identification were based on the data collection methods described in Annex C of ISO 12913-2 relying on its scientific and systematic framework for soundscape perception assessment, ensuring the comparability and standardization of the research [53-55].

2.4.2. Perceived affective quality

To measure the perceived affective quality, 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, and monotonous. We then calculated the coordinates along the two dimensions (pleasantness and eventfulness) proposed in ISO 12913-3, based on the results for the eight perceived affective qualities. In this process, the calculation for the pleasantness value employed the formula "(pleasant − annoying) + cos 45° · (calm − chaotic) + cos 45° · (vibrant − monotonous)". Similarly, the eventfulness value was determined through the formula "(eventful − uneventful) + cos 45° · (chaotic − calm) + cos 45° · (vibrant − monotonous)" [56].

2.4.3. Overall Quality

Regarding the overall quality, three items were included: overall impressions, perceived loudness, and soundscape appropriateness. To measure overall impressions, participants were asked to provide their impressions at each site with the specific question "Overall, how would you describe the present surrounding environment?" (1 = very bad to 5 = very good). The question used to measure perceived loudness was "How loud is it here?" (1 = not at all to 5 = extremely). Finally, the question used to measure soundscape appropriateness was "Overall, to what extent is the present surrounding sound environment appropriate to the present place?" (1 = not at all to 5 = perfectly) [53, 57].

3. Results

A linear mixed model analysis with repeated model options was used to analyse the effects of individual sensitivity grouping variables on soundscape evaluations in different environments. Specifically, the participants were divided into two groups based on the median noise sensitivity and environmental sensitivity (full scale and subscale) scores, and the mean scores of each group for each soundscape evaluation item were compared. Additionally, because previous studies have shown that the environmental sensitivity factor is influenced by the type of environmental stimulus, the interaction effect of 'individual group variable × site' was also analysed in addition to the main effect of 'individual group variable' on soundscape evaluations. Prior to the deployment of the linear mixed-effects model for analysis, a preliminary examination of the data was carried out to ensure its alignment with all model assumptions. This step involved verifying the independence and normality of all model residuals, along with confirming equal variance across the groups, all of which were confirmed to be accurate.

3.1. Effect of noise sensitivity

The results of the experiment indicated that there were no significant differences between the soundscape evaluation scores for the higher and lower noise sensitivity groups. Table 3 shows that the two groups did not differ significantly in terms of the perceived dominance of the four sound source categories, including traffic noise ($F = 0.77$, $p > 0.05$), human sounds ($F = 0.20$, $p > 0.05$), natural sounds ($F = 1.77$, $p > 0.05$), and other noise ($F = 1.29$, $p > 0.05$), as well as in perceived affective quality (pleasantness $F = 2.53$, $p > 0.05$, eventfulness $F = 2.34$, $p > 0.05$), and overall quality (overall impression $F = 0.81$, $p > 0.05$, loudness $F = 0.00$, $p > 0.05$, appropriateness $F = 2.03$, $p > 0.05$) in the soundscape evaluation. Thus, these findings suggest that noise sensitivity did not have a significant impact on any of the soundscape evaluation items (Table 3).

Table.3. Analysis of linear mixed model for soundscape evaluations.

Variable	Sound source identification								Perceived affective quality				Overall quality					
	Traffic Noise		Human Sounds		Natural Sounds		Other Noise		Pleasantness		Eventfulness		Overall impression		Loudness		Appropriateness	
	F	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*	*F*	*Sig.*
Noise Sensitivity	0.77	0.38	0.20	0.66	1.77	0.18	1.29	0.26	2.53	0.11	2.34	0.13	0.81	0.37	0.00	0.99	2.03	0.16
Environmental Sensitivity	0.44	0.51	0.00	0.99	0.10	0.76	0.50	0.48	0.13	0.71	0.00	0.99	1.77	0.18	0.09	0.77	31.86	**0.00****
Aesthetic Sensitivity	0.12	0.73	0.75	0.39	5.27	**0.02***	2.26	0.13	28.38	**0.00****	1.22	0.27	8.92	**0.00****	2.80	0.10	1.57	0.21
Physical Sensitivity	0.54	0.46	0.24	0.63	0.72	0.40	0.25	0.62	30.38	**0.00****	0.67	0.41	12.75	**0.00****	12.46	**0.00****	0.77	0.38
Psychological Sensitivity	0.01	0.91	0.09	0.76	0.00	0.97	0.05	0.83	0.00	0.98	0.19	0.66	1.30	0.26	0.04	0.85	0.00	0.97
Site	184.25	**0.00****	236.61	**0.00****	225.83	**0.00****	44.41	**0.00****	158.75	**0.00****	196.56	**0.00****	80.72	**0.00****	82.99	**0.00****	4.49	**0.00****
NS * Site	1.41	0.19	0.69	0.72	1.10	0.37	1.32	0.23	0.77	0.64	0.64	0.76	0.50	0.87	1.19	0.31	0.75	0.66
ES * Site	0.87	0.55	1.54	0.14	1.21	0.29	1.53	0.14	2.13	**0.03***	0.49	0.48	2.98	**0.00****	1.69	0.10	1.18	0.32
AES * Site	1.20	0.30	0.62	0.78	1.80	0.08	0.93	0.50	0.63	0.77	1.29	0.25	1.79	0.08	1.45	0.18	1.01	0.43
PHS * Site	1.18	0.32	0.38	0.94	0.93	0.50	0.44	0.51	0.96	0.48	1.48	0.16	1.42	0.19	2.36	0.13	0.69	0.71
PSS * Site	1.54	0.14	0.25	0.99	0.60	0.80	0.71	0.70	1.88	0.17	1.67	0.10	1.10	0.38	1.69	0.10	0.75	0.66

Note: NS=Noise Sensitivity, ES=Environmental Sensitivity, AES=Aesthetic Sensitivity, PHS=Physical Sensitivity, PSS=Psychological Sensitivity; $*p < 0.05$, $**p < 0.01$.

3.2. Effect of environmental sensitivity

This study yielded some noteworthy findings regarding the influence of environmental sensitivity on soundscape evaluations. Specifically, in terms of its effect on perceived sound source dominance, the results indicated a significant association between the AES subscale and the perceived dominance of natural sounds ($F = 5.27$, $p < 0.05$) (Table 3). As shown in Figure 5, individuals with higher AES scores tended to perceive natural sounds as more dominant ($M = 2.74$ and $SD = 1.46$ for the high-AES group, and $M = 2.59$ and $SD = 1.48$ for the low-AES group). However, this study did not identify any significant relationship between AES and the perceived dominance of other sound sources.

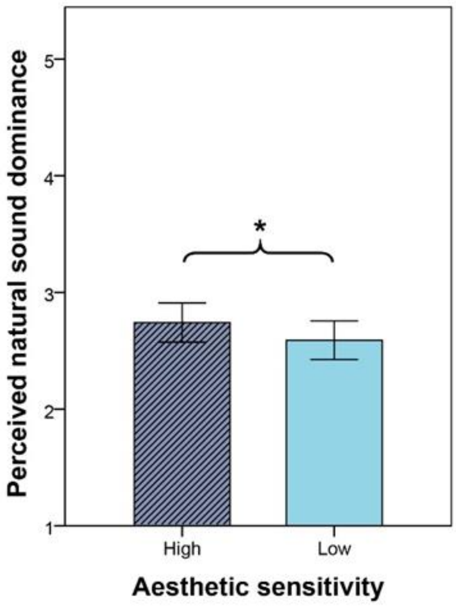

Fig. 5. Mean perceived natural sound dominance scores of aesthetic sensitivity subgroups.

Nonetheless, a significant effect on the perceived affective quality of the soundscape was observed. The study found statistically significant differences in the mean scores of soundscape pleasantness between the groups according to the AES subscale ($F = 28.38$, $p < 0.01$) as well as the PHS subscale ($F = 30.38$, $p < 0.01$). Figure

6 shows that the mean soundscape pleasantness value of the high-AES group (M = 1.47, SD = 4.53) was significantly higher than that of the low-AES group (M = 0.22, SD = 4.05). The PHS subgroups also demonstrated statistically significant differences in their mean scores for soundscape pleasantness. Specifically, the high-PHS group (M = 0.29, SD = 4.47) had lower scores than the low-PHS group (M = 1.38, SD = 4.12). However, no significant variations were observed among the subgroups for any grouping variable in the assessment of soundscape eventfulness.

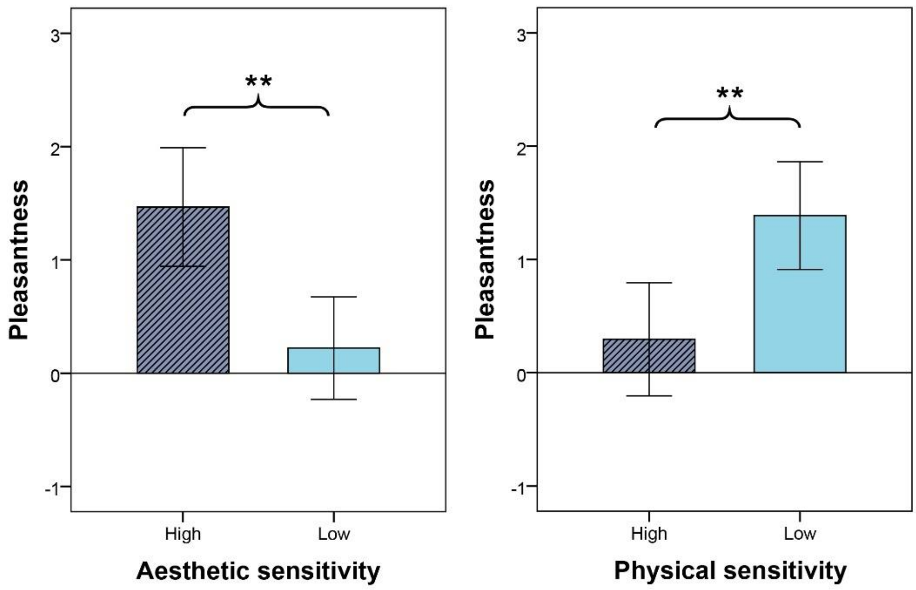

Fig. 6. Mean soundscape pleasantness scores of aesthetic sensitivity and physical sensitivity subgroups.

Furthermore, it was discovered that environmental sensitivity significantly influenced the assessment of the overall quality. As depicted in Figure 7, the analysis revealed statistically significant differences between the AES subgroups ($F = 8.92$, $p < 0.01$, see Table 3) in their overall impressions. Subgroups with higher AES scores tended to have higher scores overall impression scores (M = 3.36 and SD = 1.19 for the group with high AES and M = 3.06 and SD = 1.12 for the group with low AES). The study also revealed a significant difference in overall impression scores among the PHS subgroups ($F = 12.75$, $p < 0.01$). Unlike the AES effect, participants with higher PHS scores rated lower in the overall impression evaluation (M = 3.13, SD = 1.17 for the high-PHS group; M = 3.29, SD = 1.15 for the low-PHS group). In loudness ratings, PHS subgroups differed significantly in mean scores (F = 12.46, p < 0.01); those with higher PHS perceived the environment as significantly louder (M = 2.75 and SD = 1.22 for the high-PHS group and M = 2.47 and SD = 1.23 for the low-PHS group). Individuals with higher scores for full environmental sensitivity tended to provide higher appropriateness ratings (M = 4.06, SD = 0.95) than those with lower scores (M = 3.57, SD = 1.06). This difference was found to be statistically significant (F = 31.86, p < 0.01).

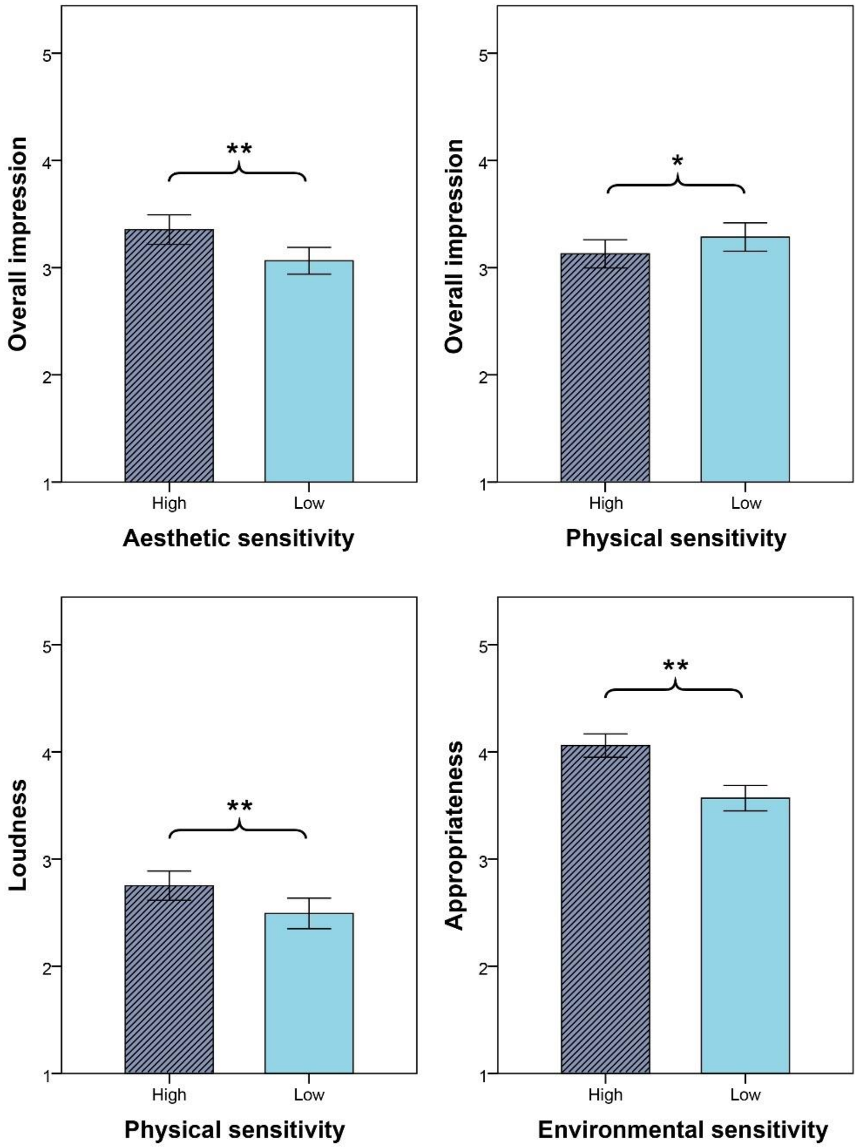

Fig. 7. Mean soundscape overall quality scores of sensitivity subgroups.

3.3. Effect of individual sensitivity among different evaluated sites

Linear mixed model analysis revealed that the site had a significant influence on people's soundscape evaluation results. All soundscape evaluation items showed significant differences between sites (see Table 3). To gain a comprehensive understanding of whether the effect of individual sensitivity varied across different sites, a detailed analysis of the interaction between site characteristics and individual sensitivities was conducted.

The results of this study demonstrated that the impact of environmental sensitivity on soundscape pleasantness evaluation varied across different sites. The analysis of the interaction effect indicated a statistically significant result ($F = 2.13$, $p < 0.05$). As Figure 8 illustrates, in certain sites with higher soundscape pleasantness scores (primarily dominated by natural elements and settings), individuals with a high degree of environmental sensitivity tended to rate the soundscapes as more pleasant than those with lower sensitivity. However, in some sites with lower soundscape pleasantness scores (where the built environment dominated and natural elements were less prevalent), the trend was reversed, with individuals possessing a higher environmental sensitivity rating the soundscape as less pleasant.

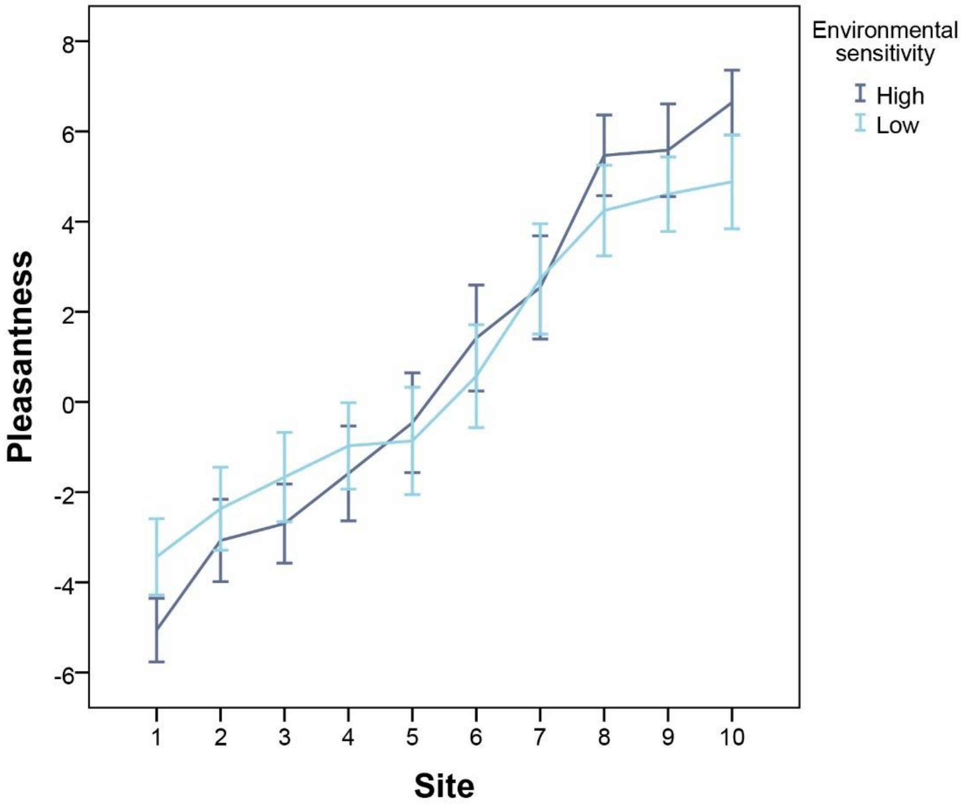

Fig. 8. Mean soundscape pleasantness scores of environmental sensitivity subgroups by evaluated site.

Moreover, the findings indicated a significant interaction effect between environmental sensitivity and site on the overall soundscape impression evaluation ($F = 2.98$, $p < 0.01$). As depicted in Figure 9, the impact of environmental sensitivity was not uniform across all sites, with the results indicating that individuals with high environmental sensitivity tended to have higher overall impression ratings at most evaluated sites. However, at Sites 1 and 4, the effect of environmental sensitivity was the opposite of that observed at the other locations.

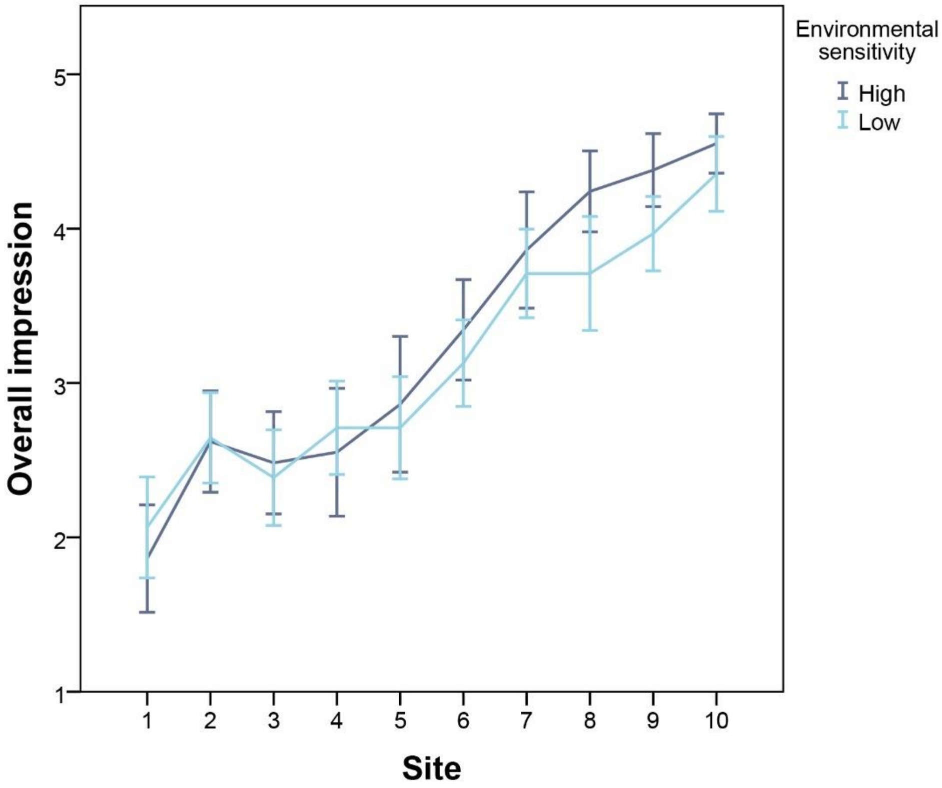

Fig. 9. Mean soundscape overall impression scores of environmental sensitivity subgroups by evaluated site.

4. Discussion

4.1. Interpretations of the results

This study investigated the potential influence of noise sensitivity and environmental sensitivity on soundscape evaluations in various urban environments. The findings indicated that environmental sensitivity significantly impacts certain aspects of soundscape evaluations, whereas noise sensitivity was not found to be a reliable predictor of soundscape evaluations. In previous studies, noise sensitivity was considered as a vulnerability to environmental noise stimuli, and people who were highly sensitive to noise tended to be less adaptable to their environment and had health problems [23, 31]. Many studies have found that noise sensitivity is negatively correlated with soundscape pleasantness evaluation [58]. However, it is important to note that these studies often focus on negative or neutral environments. In contrast, our experimental results showed no statistically significant differences in the ratings of any soundscape evaluation items between participants with high and low noise sensitivity in response to different environmental stimuli. These findings are consistent with those of previous research by Kemp et al., which showed that noise sensitivity was not a strong predictor of noise annoyance in high-quality environments [59]. One possible explanation for this is that noise sensitivity primarily measures differences in people's perceptions of negative stimuli, such as noise, and may not effectively capture differences in people's perceptions of positive environmental stimuli.

Regarding the effect of environmental sensitivity in sound source identification, previous studies have suggested that individuals with higher levels of environmental sensitivity may be more aware of various sound sources and may perceive some types of sound sources as more dominant [60]. The results of our study showed that only the aesthetic sensitivity subscale was related to the perceived dominance of natural sounds. One possible explanation for this is that individuals with a greater degree of aesthetic sensitivity tend to allocate more attention to sounds in their surrounding environment that elicit pleasurable responses, such as natural sounds. Considering the intimate association between the perceived dominance of sound sources and the perceived affective quality of soundscapes, it is imperative to conduct additional research to comprehensively understand the correlation between environmental sensitivity and sound source identification.

Regarding the effect of environmental sensitivity on the perceived affective quality of soundscapes, the results suggest that aesthetic sensitivity and physical sensitivity play a significant role in the evaluation. One potential explanation for this finding is that individuals with higher aesthetic sensitivity may be more attuned to the different depths of perceptual processing of positive environmental stimuli, which may lead to stronger emotional responses and empathic abilities. This implies that individuals with higher aesthetic sensitivity may have different responses to the environment and may experience greater pleasantness or comfort from positive environmental stimuli than those with lower levels of sensitivity. This finding is consistent with previous research on environmental sensitivity, which has linked higher levels of aesthetic sensitivity with positive outcomes, such as subjective well-being [61], greater attention to detail, enhanced communication skills [62], and improved mood [63]. Additionally, individuals with higher aesthetic sensitivity have been found to have higher levels of extraversion and openness, which may also contribute to their stronger emotional responses to positive environmental stimuli [64]. In contrast, a significant inverse effect with regard to physical sensitivity was also observed. This can likely be attributed to the fact that high physical sensitivity represents a higher sensitivity to negative environmental stimuli. This is supported by the findings of other studies showing that physical sensitivity is associated with symptoms of stress and ill health [65], social phobia [66], anxiety, depression [62], job stress, and unhappiness at work [67]. Furthermore, our experimental findings corroborated the multidimensional aspects of environmental sensitivity. That is, individuals who exhibit heightened reactivity to adverse environmental stimuli may not necessarily manifest similar reactivity to positive stimuli, as the two forms of sensitivity are distinct and unrelated to one another. In this study, aesthetic sensitivity denotes sensitivity to positive environmental stimuli, whereas physical sensitivity refers to sensitivity to negative environmental stimuli. The existence of diverse dimensions of environmental sensitivity, as well as the reality that these dimensions possess particular ranges of applicability, necessitates the prioritisation of utilising and exploring environmental sensitivity sub-dimensions in future research, with the aim of enhancing the precision of soundscape perception prediction models.

The study also revealed that aesthetic sensitivity and physical sensitivity significantly impact the overall impression of the environment. Our analysis indicated a strong correlation between soundscape pleasantness and overall impression. Therefore, this phenomenon may be attributable to an underlying factor similar to the effects of aesthetic sensitivity and physical sensitivity on soundscape pleasantness. An additional explanation could be that the overall impression of the environment includes other sensory factors in addition to sound. physical sensitivity significantly affects loudness in different environments. Furthermore, physical sensitivity refers to the ability to perceive and respond to negative environmental stimuli such as loud noises or uncomfortable temperatures. In the case of loud noises, this heightened sensitivity allows individuals to detect and respond to these stimuli more intensely than those with lower physical sensitivity levels. This heightened perception of loudness can make them more sensitive to loud noises, which may cause discomfort or distress when exposed to loud sounds [40]. Furthermore, the specific impact of environmental sensitivity on appropriateness is another important topic of discussion. When we experience a scene, our visual and auditory senses collaborate to provide a comprehensive picture of what is happening around us. For example, when we see a tree and hear its leaves rustling in the wind, our brain integrates these two sensory inputs to create a coherent perception of the tree and its surroundings. People with high environmental sensitivity may possess heightened awareness of their surroundings, making them more sensitive to the subtle details of the environment, including the sounds and sights that constitute a scene. This increased awareness may enable them to integrate the visual and auditory aspects of a scene more easily, resulting in a more cohesive perception. However, further research is required to validate this theory.

Finally, the interaction effect between environmental sensitivity and site on soundscape pleasantness and overall impression is consistent with the findings of Baumeister et al. Environmental sensitivity encompasses a variety of dimensions, such that people with higher environmental sensitivity may process this sensory information more deeply or produce stronger emotional responses to different types of environmental stimuli, whether positive or negative [68]. In our experiment, the type of environment was varied, incorporating both natural and built environments with both pleasant and unpleasant features, so no significant main effects were found in the evaluation of environmental sensitivity on the mean soundscape pleasantness of all scenes or on the overall impression.

4.2. Applications

One of the significant applications of this study is the ability to consider individual sensitivity factors when designing soundscapes. Different individuals have varying levels of environmental sensitivity, which can strongly correlate with positive or negative perceptions and mood changes. By identifying people's sensitivity levels to positive or negative soundscape elements, personalised soundscapes can be designed to help them recover from stress. To achieve this, designers and planners can divide different areas into outdoor spaces, such as parks and green spaces, in various ways to meet the diverse needs of people. By doing so, more appropriate, enjoyable, and balanced soundscapes can be created. Specifically, for people with heightened sensitivity to positive soundscape aspects, designers can create a tranquil and pleasant setting by using natural sounds, such as water features, bird melodies, and wind chimes. Alternatively, designers may utilise soothing music, such as classical music or natural sounds, which have been demonstrated to have a calming influence on mood and relaxation. In addition, designers can build secluded sections inside spaces where people can enjoy the sounds of nature or engage in calm hobbies. For those with a higher sensitivity to negative soundscape elements, such as traffic or construction noise, designers can utilise white noise or other sound-masking techniques to decrease their impact. To prevent or lessen the impact of undesirable noise, designers may also employ physical barriers such as walls, plants, and water features. In addition, designers can supply noise-cancelling headphones or other sound-blocking devices to people who are especially sensitive to unwanted sounds.

Additionally, these findings regarding environmental sensitivity and soundscape evaluation have practical implications for the development of personalised and effective psychotherapeutic interventions through natural environmental exposure. By incorporating natural sounds and reducing negative soundscape elements, psychotherapy sessions can offer calmer and more therapeutic experiences for individuals with different sensitivities. For instance, individuals who are highly sensitive to negative soundscape elements such as noise may benefit from psychotherapy sessions held in quiet and calm environments. In contrast, individuals with high aesthetic sensitivity may internalise positive stimuli more profoundly and reliably apply environmental intervention strategies for stress relief and mood regulation [40].

4.3. Limitations and future research

This study provides empirical evidence of the causal relationship between individual sensitivity and soundscape evaluation by using control variables in a laboratory setting. To enhance the generalisability of the findings, future studies should investigate the impact of personal sensitivity on soundscape evaluations in real-life situations. While our choice of a 3-minute audiovisual stimulus, based on preliminary tests and existing literature [34, 69], aimed to balance participant immersion and fatigue, the lack of a fixed standard for stimulus length in soundscape research and the potential for varied results with different durations present some limitations. Future research could further explore and validate the impact of audiovisual stimulus length on experimental outcomes to enhance the applicability of findings in the field. Furthermore, soundscape research emphasizes people's perception of sound within a specific context, which includes visual stimuli. In the experiment of this study, consistent visual stimuli were used to control the impact of visual factors on all participants. Nevertheless, we believe that further analysis of the impact of visual factors is valuable, as existing research has found that visual stimuli indeed affect soundscape perception [70], and it is currently unknown whether groups with different sensitivities will have their auditory perception affected due to different experiences of visual stimuli. Therefore, future research on the impact of visual stimuli is essential. In addition, recent research has shown a growing interest in examining people's long-term perceptions of soundscapes. These investigations aim to understand how individuals' attitudes towards specific soundscapes are developed and sustained over prolonged periods [71, 72]. Future research could examine the role of individual sensitivity in long-term soundscape perception, contributing to a more comprehensive understanding of how individuals shape and maintain their attitudes towards the surrounding soundscapes.

5. Conclusion

Based on the results of an inclusive soundscape exposure laboratory experiment, this study provides evidence for the effects of individual sensitivity factors on soundscape evaluation. The conclusions are as follows.

1) Noise sensitivity was not found to have a significant impact on soundscape evaluations.

2) The full scale of environmental sensitivity had a significant effect on soundscape appropriateness; the aesthetic sensitivity subscale of environmental sensitivity had a significant effect on perceived natural sound dominance, soundscape pleasantness, and overall impressions; and the physical sensitivity subscale had a significant effect on soundscape pleasantness, overall impressions, and perceived loudness.

3) The evaluation of soundscape pleasantness and overall impressions revealed a significant interaction effect between the site and environmental sensitivity. Specifically, higher levels of soundscape pleasantness were reported by individuals with greater environmental sensitivity in natural-environment-dominated sites, whereas lower levels were reported in built-environment-dominated sites. These patterns were consistent with the evaluation of overall impressions.

These findings provide empirical support for theories about the influence of personal characteristics on the perception of acoustic environments and can inform the development of interventions and strategies for improving soundscapes.

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7. References

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