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Effects of auditory-visual combinations on perceived restorative potential of urban green space

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ABSTRACT

The research on the restorative capacity of soundscape has grown rapidly in recent decades. Most literature explores this topic using the single medium of soundscape. Their findings perhaps do not provide a cohesive guideline for practical design because a visitor perceives the landscape using the pattern of multi-sensory input, such as visual, auditory, tactile and olfactory. To fill this gap this study conducted an experiment, in which 20 photographs were combined with five sounds, and Short-version Revised Restoration Scale was used to measure the restorative quality of auditory-visual combinations evaluated by 382 college students. The results indicated that: (1) easy accessibility to waterscape and flat topography normally are the promoters for the restorative quality of silent landscape; (2) a landscape containing natural water and a high coverage of plants matches the visual association of a bird singing, adding the birdsong to this landscape will produce higher restorative potential; (3) introducing flowing water sound to the landscape with less still water is a better choice to improve the restorative capacity; (4) adding wind sound to the landscape possessing high coverage of vegetation increases the restorative quality; (5) adding traditional Chinese music to the landscape with less paved areas will promote the mental stress relief of users, and no results were found for the western music.

1. Introduction

Worldwide, poor mental health is a growing problem which human beings have to face. World Health Organization (WHO) proposed “no health without mental health” [1]. In China, the fast changes of social and physical environment and fierce competition lead to mental stress of the general public, and Chinese society is facing increasing challenges with stress-related diseases. According to an investigation conducted in 2013, more than 30 million people in China were suffering from depression, and a more serious fact is that depression and anxiety are widespread among urban residents [2]. Although stress relief is linked to many factors, more and more researchers are convinced of the importance of daily landscape on it [3,4]. Restorative environments have been increasingly considered as the key settings for health promotion in cities [5].

Previous studies mainly focused on the effects of visual environments on mental restoration of users, and most of which suggested that contact with nature would lead to greater psychological well-being, such as better mood [6,7] and lower physiological indexes of stress [8]. However, despite that the sense of sight gathers the most information from the surrounding environments [9], hearing also collects a lot of useful information. Thus some researchers thought that soundscape was an essential component of restorative environment [e.g., 10–12], and the impact of sound on the experience of outdoor places has been received increasing attention in recent years. For example, Annerstedt et al. found that subjects exposed to virtual reality nature (including sound) recovered faster after stress than subjects exposed to virtual reality without sound [13]; Cerwén et al. concluded that, compared to technological or human sounds, natural sounds as being the part of a pleasant and “quiet” experience supported recovery and induced “soft fascination” [10]; sounds perceived as pleasant can reduce skin conductance level for subjects at rest [14]; natural sounds had a positive effect on the restoration of an individuals’ attention [15,16]; Payne demonstrated that the rural soundscape was much better than urban park soundscape, which was more positive than urban soundscape for promoting mental restoration of visitors [17]; and listening to soothing music was shown to reduce stress, blood pressure and post-operative trauma when compared to silence [18–20]. From above, we can see that the features of sound have a great influence on the restorative potential. In general, the natural sounds and music are better than other sounds.

However, the studies related to soundscape’s restoration usually used single medium of soundscape [21], or treated the visual landscape as constant of sound’s background [16]. In fact, sound never exists and works alone in a landscape. The interaction between auditory and

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visual landscape is omnipresent in urban green space, which will produce a comprehensive effect on perceived restorativeness. Thus effects of sounds on restoration not only link to the type of sound, but also depend on the scene presented [22,23].

Although a few experts paid their talents to explore the auditory-visual interaction on restorative potential [24], it is not systematically studied and we have limited understanding on it. For example, Hägerhäll et al. [25] and Hunter et al. [26] extended our understanding of how exposure to natural surroundings of sufficient quality, in terms of both visual and auditory input, could aid the recovery potential and the improvement of well-being, yet put forward little suggestions on how we could specifically do this. Thus it is necessary to add to fine-scaled understanding of key elements and characteristics of visual landscape as well as their interactions with soundscape. More detailed information on which characteristics of green space combining which kind of sound is specifically efficient for stress relief will provide cohesive evidences to guide land/soundscape design.

In spite of the efforts to conserve natural resources, undoubtedly, the originally natural environments will be shrinking year by year with population growth. People are increasingly living in urban areas. The natural environments (including sounds) in cities, such as urban green spaces, are mainly constructed by human power. Existing literature suggests that a poor design links to psychological and physiological discomfort [27]. However, these negative effects can be counteracted through a good design. The restorative capacity of a well-designed urban green space is equal to, or even better than, that of a natural environment [28–30]. Thus, finding the reliable design evidence for the efficiently restorative environment (including visual and auditory landscape) is significant for sustainable development of cities.

2. Aims and overall framework of the study

The main purpose of the present paper is to find reliable evidence to inform landscape design of auditory-visual combination aiming to improve the restorative quality. To achieve this goal, an experiment was performed following the psychophysical manner, where we established quantitative models to describe the relationship between the subject's judgments on restorative capacity and specific objective attributes of a landscape [31,32]. Specifically, 14 landscape characteristics which represent the main features of the landscapes studied in this research and possess the property of designability were picked out by referring to the characteristics identified in the previous literature [33–35] and analyzing the characteristics of these landscapes (see Table 1). The following research questions guide the study:

(1) What are the essential attributes to achieve the mental restorative quality of purely visual landscape?
(2) What are the effects of five sounds (bird singing, flowing water sound, wind sound, western music and traditional Chinese music) on restorative quality of visual landscape, particularly focusing on the interaction between sound and vision?

3. Methods

3.1. Visual landscape

Photographs were used to represent the different visual landscapes. The photographs used in this study were taken at eye-level (about 1.55 m above the ground) on clear days, from 9:00 a.m. to 4:00 p.m. to control for similar lighting conditions in the summer 2014, during which time the vegetation retained a relatively constant appearance. The equipment was a CANON digital camera (EOS 700D) with a focal length 35 mm, and the camera was positioned horizontally to capture the principal characteristics of a scene. The pictures were photographed in the three parks of Yunlong (built in 1958), Pengzu (built in 1976) and Kuishan (built in 2001) located in the city center of Xuzhou, eastern China. The three parks were built at different times and can represent the current situation of urban parks in Xuzhou. In total 20 sample sites were selected (seven in Yunlong and Kuishan, respectively and six in Pengzu) according to representing diversity of visual landscapes. Although more than five photographs were taken on a site, only one photograph with higher representation was selected for each site after removing the photographs with insufficient physical quality. Four examples of the photograph are shown in Fig. 1.

3.2. Soundscapes

Previous works suggested that natural sounds and music were positive for promoting the mental restoration of users [25,37]. The two kinds of sound have the potential to be used in urban green space for improving the restorative quality. Therefore, three natural sounds (birdsong, the sound of flowing water and the sound of wind) and two pieces of music (western music and traditional Chinese music) were selected for our trials. The western music was "Nature and light" (Nature et lumière in French), and the traditional Chinese music was "Calm lake under the moon in autumn" played by a traditional Chinese musical instrument of "Guzheng". The bird was a throstle (*Garrulax canoru*) which is very popular and is often kept as a pet in China. These materials were downloaded from the Internet according to the criteria of clarity and high quality. The flowing water and the wind sound were also downloaded from the Internet but with several versions, respectively. Five postgraduate students were invited to evaluate which

Table 1
Measurement scale of landscape characteristics.

Landscape characteristics	Abbreviation	Scores
Percentage of land covered by vegetation	PLCV	No vegetation = 0; < 35% = 1; 36–70% = 2; 71–100% = 3
Type of land vegetation	TLV	No vegetation = 0; Grasses or(and) shrubs = 1; only trees or tree with grass = 2; mixed vegetation = 3
Configuration of land vegetation	CLV	No vegetation = 0; orderly configuration = 1; semi-natural configuration = 2; natural configuration = 3
Percentage of land covered by water	PLCW	No water = 0; < 35% = 1; 36–70% = 2; 71–100% = 3
Visual naturalness of water	VNW	No water = 0; orderly form = 1; semi-natural form = 2; natural form = 3
Accessibility of water	AW	No water = 0; difficult to access = 1; neutral to access = 2; easy to access = 3
Aquatic plants on water	APW	None = 0; a few = 1; more = 2; almost full cover = 3
Buildings	B	No building = 0; very little = 1; somewhat = 2; much = 3
Paved areas	PA	No paved path or square = 0; very little = 1; somewhat = 2; much = 3
Type of topography	TT	Almost flat = 0; Slightly undulating = 1; Much more undulating = 2, violently undulating = 3
Number of colors	NC	Only one = 0; two = 1; three = 2; four or more = 3
Colour contrast	CC	No contrast = 0; Weak contrast = 1; clear contrast = 2; sharp contrast = 3
Number of landscape elements*	NLE	Only one = 0; two = 1; three = 2; four = 3
View scale	VS	Closed space = 0; slightly open space = 1; semi-open space = 2; open space = 3

*Landscape elements were divided into four categories: building, topographical variation, water body, and plants by referring the manner suggested by the work of Zhao et al. [36].

Fig. 1. Four sample pictures which represent the two lowest (top row) and two highest (bottom row) restorative capacity under the condition of without sound (The number on the top right of each picture indicates the order in assessment of restorative potential).

version was the best to represent the corresponding sound, and the best version was used.

The pairwise of five sounds and 20 photographs was combined using Adobe Premiere software. Thus the 100 (20 × 5) sound-photograph combinations were gathered, which were divided into five groups according to the criterion of unrepeated photographs within each group. The 20 photographs without sound (called silence) were the sixth experimental group.

3.3. Measurement of respondents' mental restoration

The self-rating method of Short-version Revised Restoration Scale (SRRS) developed by Han [38] was used to measure restorative potential of respondents. SRRS consists of eight items spread equally across the four dimensions of emotion, cognition, physiology and behavior (Table 2). Respondents indicated on a 9-point Likert response format how much they agreed with the items, ranging from 1 'totally disagree' to 9 'totally agree'. All items of SRRS were accurately translated into Chinese and tested in a pilot survey by seven postgraduate students. The composite score of physiological response was reversed, because this dimension measures physiological arousal, which is the opposite of restorativeness. The mean value of each item listed in the restoration scale within respondents was calculated. The mean value of eight items was used as the restorative quality of a photograph or photo-sound combination.

Undergraduate students with self-reported normal eyesight and hearing as well as wide discipline background from China University of Mining and Technology (CUMT) were used as respondents for increasing efficiency and reducing cost. This method was widely used by previous researchers of experience-based assessment [e.g., 39–42].

We conducted the main surveys in a classroom which could accommodate a maximum of 80 people in October 2016. The 20 photographs (slides) within a group were randomly projected on a 1.6 × 1.2 m white screen. Before the survey, the participants were told: "imagine you are in the projected scene, please select a scale for each item according to your perception". All slides were shown one by one, and we did not play the next slide until all of the respondents completed the mental restoration scale survey for a slide. The loud speakers are four settings of HIVI (VA6-OS) hanging on the walls of the classroom. The volume of sound attached to a slide was regulated to confirm to be heard comfortably and clearly anywhere in the classroom. At that time, the volume was measured in the center and four corners in the classroom using five volume detectors, respectively. The average score of each detector during the survey was calculated, and the mean of the five detectors was 54.7 dBA. The other five groups' presentations were followed one after another likewise evaluated by different students. The only difference in the silent group was that it was conducted without sounds. The average time for completing a group's evaluation was about 27 min. The number of respondents for 1–6 group was 74 (male 31, female 43; 66 valid questionnaires), 69 (male 32, female 37; 61

Table 2
Short-version Revised Restoration Scale (Imagine you are in the projected scene, please select a scale for each item according to your perception, 1 = 'totally disagree', 9 = 'totally agree').

		Scales
Emotional	Good natured	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
	Relaxed	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
Psychological	My breathing is becoming faster	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
	My hands are sweating	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
Cognitive	I am interesting in the presented scene	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
	I feel attentive to the presented scene	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
Behavioral	I would like to visit here more often	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__
	I would like to stay here longer	1__; 2__; 3__; 4__; 5__; 6__; 7__; 8__; 9__

valid), 65 (male 34, female 31; 58 valid), 57 (male 29, female 28; 54 valid), 71 (male 38, female 33; 62 valid) and 46 (male 30, female 16; 44 valid), respectively. The invalid questionnaires included two or more choices for an item or uncompleted questionnaires.

3.4. Landscape characteristics judgment

Nine landscape architects judged the 14 landscape characteristics of each photograph according to the scales in Table 1, because some landscape characteristics include terminologies such as "configuration of land vegetation", "number of landscape elements", "visual scale", which may be difficult for the general public to understand. This panel included two teachers and seven postgraduates majoring in landscape architecture from CUMT. There was a ten-minute break after the completion of the judgment of ten photographs. The interclass reliability of landscape characteristics scores across the panel was good (Cronbach's Alpha was from 0.741 to 0.913) and could be used with confidence according to the findings of Landis and Koch who indicated that if the Cronbach's Alpha > 0.801, it was almost perfect, and 0.701–0.800, good [43]. Thus the average score of the panel was used as the score for each photograph of a particular landscape characteristic.

3.5. Data analysis

The 20 photographs with the same sound were regrouped. At first, the interclass reliability of restorative scores was tested using SPSS 17.0 software, and the one-way ANOVA was conducted to explore the significance of the effects of each sound on restorative quality of visual landscape. Then, correlation analysis and stepwise multiple linear regression analysis were performed to explore the driving force of landscape characteristics on restorative quality or the effects of soundscapes on restorative quality.

4. Results

4.1. Reliability

The interclass reliabilities of mental restorative scores of six groups of photographs with five sounds and silence were calculated, respectively. Cronbach's Alpha was 0.915 (silence), 0.928 (birdsong), 0.871 (flowing water sound), 0.792 (wind sound), 0.774 (western music), and 0.909 (traditional Chinese music). General speaking, the results showed good internal reliabilities of restorative quality for all groups.

4.2. Overall evaluation of restorative quality

The restorative qualities of auditory-visual combinations and silent photographs were shown in Fig. 2. Based on the average scores, all sounds increased the restorative potential of environments (average score of silence = 6.085; with bird singing = 6.633; flowing water sound = 6.215; wind sound = 6.628; western music = 6.285; traditional Chinese music = 6.238). In addition, the one-way ANOVA showed that there was a significant difference of restoration quality between the six groups (F = 2.358; Sig. = 0.045), which implied that soundscape was an important factor for improving the restorative capacity of environments. However, the pairwise comparisons showed that only the restorative scores of photographs with bird singing or wind sound were significantly higher than the scores of silent photographs (p = 0.012 (bird singing), and p = 0.013(wind sound)), the other three sounds had no significant influences. So the different effects of sounds suggested that the sound's features played an important role for promoting the restorative quality of environments.

4.3. Relationships between landscape characteristics and restorative quality of silent photographs

The research on restorative environment includes not only finding the efficient environment for mental stress recovery, but also understanding which specific features determine recovery potential, which is valuable to guide the environment design. The correlation analysis indicated that the restorative quality of silent landscape increased simultaneously with three characteristics linked to water (percentage of land covered by water, visual naturalness of water, accessibility of water) and more landscape elements (see Table 3).

Although there were complex interactions between the landscape characteristics, the correlation analysis just illustrated the relationship between the restorative quality and individual landscape characteristic. The results are weak and biased in sometimes to guide the landscape design. The multivariate regression analysis, concerning the possible multicollinearity among landscape characteristics, will build the quantitative relationship between the restorative quality and landscape characteristic, and provide more reliable guidance to landscape design [35]. By using the values of the 14 landscape characteristics as the independents and mean restorative scores of silent photographs as the dependent, the significant correlations were further described using the stepwise multiple linear regression analysis (Table 4). The regression analysis illustrated that a landscape containing easy accessibility to water and flat topography was much better for the mental restoration of users.

4.4. Relationships between effects of five sounds on restorative quality and landscape characteristics

A sound's effect on restorative quality was defined that the changes of restoration capacity of a silent environment caused by adding the sound. In this study, the effects of five sounds on restorative capacity were calculated using the following formula.

$$S_{ij} = N_{ij} - N_i$$

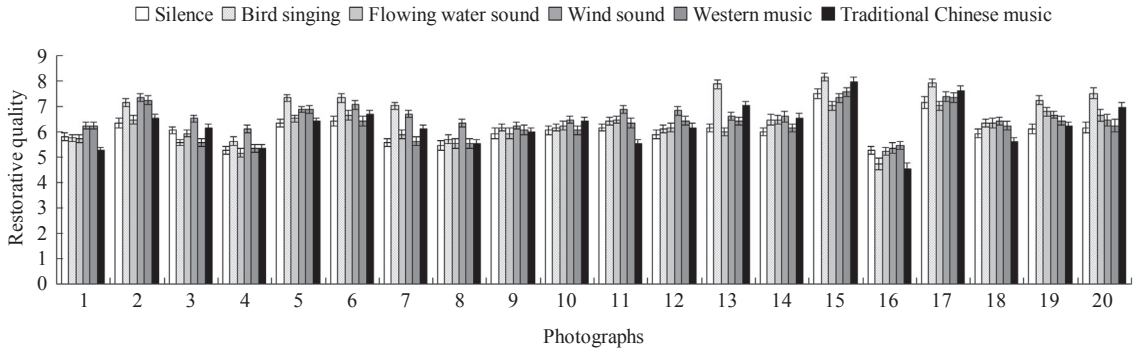

Fig. 2. Mean restoration scores (± standard error) within respondents for 20 pictures with sounds or silence.

Table 3
Correlations between mean restorative quality and landscape characteristics (Spearman).

		PLCV	CLV	TLV	PLCW	VNW	AW	APW	APW	NC	CC	B	PA	NLE	VS
Restoration quality of silent photographs	Coefficient	−0.137	0.145	0.065	0.551*	0.445*	0.587**	0.348	−0.186	0.131	0.172	0.298	0.029	0.552*	−0.198
	Sig. (2-tailed)	0.563	0.543	0.785	0.012	0.049	0.006	0.132	0.433	0.582	0.467	0.203	0.903	0.012	0.403
Effects of bird singing on restoration quality	Coefficient	0.279	0.679**	−0.410	0.614**	0.699**	0.611**	0.659**	0.390	−0.186	−0.187	−0.122	−0.591**	0.529*	−0.107
	Sig. (2-tailed)	0.234	0.001	0.073	0.004	0.001	0.004	0.002	0.089	0.432	0.430	0.609	0.006	0.016	0.652
Effects of flowing water sound on restoration quality	Coefficient	0.407	−0.232	0.265	−0.638**	−0.563**	−0.634**	−0.456*	−0.274	−0.021	0.048	−0.183	0.174	−0.559*	−0.364
	Sig. (2-tailed)	0.075	0.326	0.258	0.002	0.010	0.003	0.043	0.243	0.930	0.842	0.440	0.464	0.010	0.115
Effects of wind sound on Restoration quality	Coefficient	0.477*	−0.117	0.029	−0.347	−0.226	−0.340	−0.109	−0.024	−0.225	−0.376	−0.268	−0.150	−0.347	−0.224
	Sig. (2-tailed)	0.034	0.623	0.903	0.134	0.338	0.143	0.647	0.921	0.340	0.102	0.253	0.528	0.134	0.342
Effects of western music on restoration quality	Coefficient	0.239	−0.004	0.313	0.018	−0.067	0.030	−0.064	−0.061	0.262	−0.285	−0.100	−0.048	−0.173	−0.126
	Sig. (2-tailed)	0.311	0.988	0.179	0.939	0.780	0.902	0.787	0.798	0.265	0.222	0.674	0.840	0.465	0.597
Effects of Traditional Chinese music on restoration quality	Coefficient	0.359	0.590**	−0.502*	0.525*	0.623**	0.530*	0.588**	0.242	−0.447*	−0.339	−0.045	−0.646**	0.529*	−0.308
	Sig. (2-tailed)	0.120	0.006	0.024	0.017	0.003	0.016	0.006	0.304	0.048	0.144	0.849	0.002	0.017	0.186
PLCV	Coefficient		0.106	−0.120	−0.323	−0.108	−0.211	0.130	−0.015	−0.073	−0.244	−0.258	−0.530*	−0.113	−0.672**
	Sig. (2-tailed)		0.655	0.614	0.165	0.649	0.372	0.585	0.949	0.759	0.300	0.271	0.016	0.635	0.001
CLV	Coefficient			−0.366	0.651**	0.668**	0.635**	0.580**	0.534*	−0.341	−0.154	−0.359	−0.563**	−0.452*	−0.064
	Sig. (2-tailed)			0.113	0.002	0.001	0.003	0.007	0.015	0.141	0.518	0.120	0.010	0.046	0.788
TLV	Coefficient				−0.371	−0.537*	−0.353	−0.565**	−0.551*	0.132	0.206	−0.007	0.477*	−0.550*	−0.189
	Sig. (2-tailed)				0.108	0.015	0.126	0.009	0.012	0.578	0.382	0.977	0.033	0.012	0.425
PLCW	Coefficient					0.918**	0.966**	0.723**	0.455*	−0.037	−0.014	0.152	−0.387	0.791**	0.375
	Sig. (2−tailed)					0.000	0.000	0.000	0.044	0.876	0.954	0.523	0.092	0.000	0.104
VNW	Coefficient						0.929**	0.916**	0.648**	0.059	0.054	0.237	−0.526*	0.890**	0.254
	Sig. (2-tailed)						0.000	0.000	0.002	0.806	0.823	0.313	0.017	0.000	0.280
AW	Coefficient							0.825**	0.478*	0.074	0.040	0.138	−0.364	0.819**	0.265
	Sig. (2-tailed)							0.000	0.033	0.755	0.868	0.560	0.115	0.000	0.259
APW	Coefficient								0.684**	0.220	0.086	0.206	−0.493*	0.835**	0.066
	Sig. (2-tailed)								0.001	0.352	0.718	0.385	0.027	0.000	0.784
TT	Coefficient									0.220	0.260	0.210	−0.398	−0.595**	−0.342
	Sig. (2-tailed)									0.352	−0.268	−0.374	−0.083	−0.006	−0.140
NC	Coefficient										0.508*	0.597**	0.293	0.239	0.205
	Sig. (2-tailed)										0.022	0.005	0.210	0.311	0.386
CC	Coefficient											0.491*	0.294	0.254	0.144
	Sig. (2-tailed)											0.028	0.208	0.279	0.545
B	Coefficient												0.117	0.449*	0.351
	Sig. (2-tailed)												0.622	0.047	0.130
PA	Coefficient													−0.433	0.086
	Sig. (2-tailed)													0.057	0.719
NLE	Coefficient														0.202
	Sig. (2-tailed)														0.394

PLCV: percentage of land covered by vegetation; CLV: configuration of land vegetation; TLV: type of land vegetation; PLCW: percentage of land covered by water; VNW: visual naturalness of water; AW: accessibility of water; APW: aquatic plants on water; TT: type of topography; NC: number of colors; CC: colour contrast; B: buildings; PA: paved areas; NLE: number of landscape elements.
* Significance at the 0.05 level; ** Significance at the 0.01 level.

Table 4
Significant predictors for restorative quality of silent photographs and the effects of five sounds on restoration quality emerging from stepwise multiple linear regression analysis, respectively.

Dependent	Independent	Unstandardized Beta	Standardized Beta	T	Significance	Collinearity statistics	
						Tolerance	VIF
Restorative quality of silent photographs (R^2 = 0.627; adjusted R^2 = 0.583)	(constant)	6.398		37.588	0.000		
	Accessibility of water	0.417	0.876	5.192	0.000	0.772	1.296
	Type of topography	−0.548	−0.604	−3.580	0.002	0.772	1.296
Effects of bird singing on restoration quality (R^2 = 0.616; adjusted R^2 = 0.571)	(constant)	−0.414		−1.321	0.204		
	Visual naturalness of water	0.427	0.738	4.886	0.000	0.988	1.012
	Percentage of land covered by vegetation	0.325	0.359	2.374	0.003	0.988	1.012
Effects of flowing water sound on restoration quality (R^2 = 0.407; adjusted R^2 = 0.374)	(constant)	0.178		3.358	0.004		
	Percentage of land covered by water	−0.148	−0.638	−3.512	0.002	1.000	1.000
Effects of wind sound on restoration quality (R^2 = 0.227; adjusted R^2 = 0.184)	(constant)	0.047		0.210	0.836		
	Percentage of land covered by vegetation	0.234	0.477	2.300	0.034	1.000	1.000
Effects of traditional Chinese music on restoration quality (R^2 = 0.418; adjusted R^2 = 0.385)	(constant)	0.687		4.114	0.001		
	Paved areas	−0.324	−0.646	−3.594	0.002	1.000	1.000

where S_{ij}: the effect of *j*th sound on restorative capacity of *i*th picture; N_{ij}: restorative capacity of *i*th picture with *j*th sound; and N_i: restorative capacity of *i*th picture without sound.

The correlation analysis indicated that the effect of birdsong on restorative quality increased simultaneously with configurative naturalness of land vegetation and all characteristics linked to water (percentage of land covered by water, visual naturalness of water, accessibility of water, aquatic plants on water), and decreased with more paved areas (Table 3). The effect of the flowing water sound on restoration quality decreased with all characteristics linked to water and more landscape elements. The effect of the wind sound increased with higher coverage of land vegetation. The effect of traditional Chinese music increased with configurative naturalness of land vegetation, more landscape elements and all characteristics linked to water, and decreased with complex vegetation structure, more colors and more paved areas. No significant correlation was found between the effect of western music and landscape characteristics.

The stepwise multiple linear regression analysis showed that visual naturalness of water and percentage of land covered by vegetation were the two reliable predictors for the effect of birdsong on restoration quality; percentage of land covered by water, percentage of land covered by vegetation and paved area are the predictors for the effect of flowing water sound, wind sound and traditional Chinese music on restoration, respectively; no predictor was found for the effect of western music, which is consistent with the result of correlation analysis (Table 4).

In order to accept the models shown in Table 4, the normality of the residuals, analysis of variance and multi-collinearity were tested. This was accomplished by using the Kolmogorov-Smimo test, in which the residuals followed a normal distribution (Kolmogorov-Smirnov Z = 0.515, 0.473, 0.603, 0.521, 0.614, p = 0.954, 0.978, 0.860, 0.949, 0.846 for silence, the effects of a bird singing, the flowing water sound, wind sound and traditional Chinese music, respectively). Variance analysis results revealed a linear correlation between the landscape characteristics and the restorative quality (F = 17.257, $p < 0.001$ (silence); F = 13.658, $p < 0.001$ (bird singing); F = 12.333, $p = 0.002$ (flowing water sound); F = 5.292, $p = 0.034$ (wind sound); F = 12.916, $p = 0.002$ (traditional Chinese music)). By referring to values in Menard [44] and Arriaza et al. [33] (value of tolerance < 0.2 or VIF > 10, which indicates a problem), our models also had no problem with multi-collinearity (the minimal value of tolerance = 0.772 > 0.2 and the maximal VIF = 1.296 < 10)). Thus, our models were accepted.

5. Discussion

5.1. Visual landscape's restorative capacity

Kaplan argues that stress can be caused by the human perception of inadequate resources [45]. Water is the essential source of all life in the world. The importance of water for relieving the mental stress is evidenced by the present study (Tables 3 and 4), which is also supported by the findings of previous researchers, such as Velarde et al. [4], Burmil et al. [46], Völker and Kistemann [47], who indicated that blue space (water body) enhanced human health and well-beings. The landscape containing water is considered to be "peaceful", "traditional", "worth-preserving" and "preferable" [48]. Water plays an important role in the perception of naturalness [49], which has been demonstrated as one of the key elements for improving the restorative potential of environments [42,50,51]. Furthermore, water also has spiritual symbolism, for example, water forms part of the essential rituals involving birth, marriage or death [52]; Buddhist doctrine thinks that some kind of water (called holy water) can heal all diseases. Therefore, regarding the cultural aspects, water is also a very important factor for people's health. The regression analysis suggests that accessibility of water is the first important predictor for restoration potential of a visual landscape, which implies that touching water is much better than just viewing it. Water can afford many kinds of activities such as boating, sailing or canoeing, cycling or jogging around the water, swimming, playing in water, and fishing, which have been demonstrated a positive health effects for the prevention of serious diseases by physiological exercise and mental stress relief [53–56].

Although numerous previous studies suggest that natural environments are better for reducing mental stress than man-made elements [6,57,58]. In this study the second predictor (type of topography) (Table 4) implies an environment with somewhat human maintenance being better for restoration. In fact, some kinds of nature would make people feel fear, for instance, the dense dark forest may appear to be a hiding place for potential attackers [59], such as the picture of Fig. 1(4) used in this study, which is evaluated with the second lowest restorative quality. Human beings are biologically prepared to respond negatively to things that would have been a threat to our lives [60]. This shows that we are likely to benefit from the management and maintenance of natural landscape.

5.2. Visual association of soundscape and the restorative capacity of auditory-visual combinations

Previous works suggest that natural sounds are better for improving the mental stress recovery than man-made sounds [10,16]. When hearing natural sounds, listeners may be made aware of the presence of life-giving elements of environment. For example, Mammides et al. [61] and Yoo et al. [62] found that bird songs correlated with the number of species in the field survey, and singing by several species was more positive than singing by a single species [63], furthermore Ratcliffe et al. [21] indicated that bird sounds could be symbols for times of year associated with resources. So it is possible that natural sounds may have restorative potential through their associations with vitality and biodiversity, perhaps linking to the concept of survival [64]. However, this study shows that not all natural sounds are better than man-made sounds. The bird singing and wind sound significantly improve the restorative quality, but the flowing water and man-made sounds (western and traditional Chinese music) do not. This is possibly explained by the degree of matching between a sound triggering the imagination of particular environments and the landscapes shown by a photograph. Shaw et al. indicated that individuals' imagined restorative environments built up from non-visual perceptions according to the instinct from evolution and personal symbolism in the form of memories of one's past [65]. The bird singing may trigger associations with natural environments and activities in nature [21,66]. In Table 4, the two predictors of the effect of bird singing on restorative quality (visual naturalness of water and percentage of land covered by vegetation) generally describe such a scene. Supporting this, Ratcliffe et al. [67] said *"birdsong was the sound most commonly associated with participants' restorative experiences in nature"*.

The wind itself cannot make a sound. It must interact with other objects for a sound. In urban green space the vegetation is the most common object. Therefore, a higher percentage of land covered by vegetation is much better to improve the restorative quality of wind sound (see Table 4). On the other hand, wind can promote the pollination of anemophilous plants, thereby increasing the food supply of the environment, which will relieve people's unconscious anxiety.

The flowing water sound indicates a scene including moving water. Seven out of 20 photographs in our study contain water body, but all of them are still water such as a pond or a lake, which leads to the visual association of flowing water sound being incongruent with the landscape showed by the photographs. Thus we can say that percentage of land covered by water being a negative predictor for the effects of flowing water sound is reasonable: the more the water, the lower the matching degree of visual association of flowing water sound and visual landscape. Although previous works indicated that the sound of water has great power to induce states of relaxation [68], the present study suggests that only introducing the sound of water to a proper environment would fully achieve the restorative potential of the environment.

During the long evolutionary history human beings live in natural environment, natural sounds are likely to carry some useful information of habitat, which will help our ancestors choose a right habitat which can support them survival and reproduction. Therefore, they are sensitive to the natural sounds and have a similar visual association of a natural sound. However, the man-made sounds such as music are cultural products. The associations between the sounds and scenes are more dependent on the demographic variables such as age, educational level, especially cultural background. This can be explained as no predictor is found for the effect of the selected western music on restorative quality. The traditional Chinese music describes the natural scenery of West Lake in Hangzhou, eastern China, which is very famous, and most Chinese people, especially those with high education such as the college students, can understand the meaning of this music. Thus the respondents in our study think this music should be played in a natural environment (Table 4 shows the paved areas are a negative predictor for the effect of traditional Chinese music).

5.3. Application for sound/landscape design

In order to increase the restorative capacity of urban green space, it is indispensable to focus on the properties of visual landscape. Firstly, setting up a waterscape in green space and enhancing its accessibility can improve its restorative potential by building a hydrophilic platform, cutting the obstacles between users and water such as dense shore plants, upright bank-protected wall, muddy border of water and land, constructing some infrastructures to encourage the activities linked to water. Secondly, creating a flat topography for urban green space is necessary, which will increase the perceived safety of users and the possibility of carrying on activities.

For the soundscape design aiming to improve the restorative potential of urban green space, understanding its association with vision is necessary. Then, some sounds can be introduced to a landscape by creating some elements to produce an appropriate sound such as creating habitats and nests to attract birds, building streams, planting specific trees on high and windy topography. Alternatively, we should create a proper visual landscape based on the sound of the site. For this case study, the results provide some guidelines for soundscape design: the bird singing should be introduced to a landscape possessing high coverage of plants and natural water; the flowing water sound should be set in an environment with less still water; setting up some sounding devices in a place with dense trees or planting many trees in a windy place is much better to increase the restorative capacity; and at least in China, it is a better choice to play the traditional Chinese music using a hidden loud speaker in a natural environment.

5.4. Limitations and future research

At first, as most previous works do [40,42,69], the present study does not take the demographic variables of respondents into account. The undergraduate respondents in our study are relatively demographically homogeneous except for gender. Some researchers suggest that there is no significant difference of landscape preferences between undergraduate students and the general public [70] and that students can substitute for the public in landscape assessment [71,72]. However, the results for mental restoration assessment have not yet been tested on people from different demographics. Thus, related research which uses respondents from a wider demographic range is needed in order to increase the generalizability of the findings.

Secondly, the present study explores the effects of five sounds on restorative quality of visual landscape individually. However, a real landscape usually contains several sounds simultaneously. There are complex interactions among the sounds. What are the effects of the coexistence of several sounds on perceived restorativeness? Our study does not provide the answer. This limits the practical values of our results. Therefore, the interactions of several sounds in a real environment make the research on soundscape's restoration more difficult and complicate the soundscape design. However, it is an interesting and important research topic.

Finally, human beings have five senses. Our study indicates that adding some kind of sound to visual landscape will change its restorative quality significantly. Although some literature declares that photographs have representational validity for restorative environment research [66,71], our results do not support it. Then we can speculate that the mental restoration is not also simply linked to the visual landscape and soundscape. The olfactory, tactile and gustatory experiences and their interactions have an essential influence on perceived restorativeness. Examining the other senses was never the aim of this study. Therefore, a study which includes the effects of all five senses and their interactions on restorative capacity is recommended in the future.

6. Conclusions

This study explores five sound's effects on restorative quality and the driving forces of 14 landscape characteristics on these effects. The results indicate that, for purely visual landscape, easy accessibility to waterscape and flat topography normally imply better mental fatigue recovery for the respondents; the matching degree of visual association of a sound with visual landscape is an important factor to improve the sound's restorative capacity, and choosing or creating a proper visual environment to meet the visual association of a sound is the basic method of landscape design of auditory-visual combination aiming to enhance the potential of mental recovery. Specifically, a landscape containing natural water and high coverage of plants is the proper environment for birdsong; less still water in a landscape is much better for improving the restorative capacity of flowing water sound; introducing wind sound to a landscape with dense vegetation will benefit its restorative effect; and a landscape with less paved areas will be the right environment in which traditional Chinese music is encouraged to play. In spite of some limitations in the study, these results provide some valuable guidelines for land/soundscape design.

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