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Impacts of nature and built acoustic-visual environments on human's multidimensional mood states: A cross-continent experiment

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ABSTRACT

New and complex acoustic-visual environments are emerging in contemporary highdensity cities. The independent and interactive effects of acoustic and visual environments on human's mood states have been rarely investigated in that context. This study examined the extent to which 12 pairs of four acoustic environments and three visual environments influence multiple-dimensional mood states, including emotion, attention, and stress. Sixty-eight local participants from Illinois, USA, and 69 nonlocal participants from Hong Kong SAR, China, were randomly assigned to watch and listen to one of 12 videos. The participants' mood states were measured before and after the exposure. Two-way ANOVA analysis controlling for baseline mood and gender, and pairwise comparisons yield four major findings after. First, the acoustic and visual environments have significant independent and interactive effects on mood states. Second, the acoustic environments have stronger effects on mood states than the visual environments. Third, in general, effects of acoustic-visual environments are more positive and stronger for local participants than for nonlocal participants. Fourth, evidence suggests a universal restorative effect that grows from exposure to natural acoustic-visual environments. This study provides new and specific evidence to support planning and design of healthy high-density cities.

1. Introduction

The mood states that people experience can be categorized in three dimensions: emotion, attention, and stress (Steyer & Schwenkmezger, 1997). Each dimension has positive and negative aspects. Positive mood states can significantly promote human health and cognitive performance (e.g., Baños et al., 2012; Bryan, Mathur, & Sullivan, 1996; Pressman & Cohen, 2005). Positive moods are also linked with lower morbidity, decrease symptoms of illness, reduced pain (Pressman & Cohen, 2005), more creative problem solving (Bryan et al., 1996; Isen, Daubman, & Nowicki, 1987), and higher levels of life satisfaction (Chang, Chang, & Kamble, 2019). Negative mood states, however, are precursors to a variety of severe health problems, including cardiovascular diseases (Correia, Peters, Levy, Melly, & Dominici, 2013), disorders of the immune system (for a review, see Kuo, 2015), reductions in cognitive functioning (Tang et al., 2017), aggressive behavior (Poon, Teng, Wong, & Chen, 2016), depression (Yu, Lee, & Luo, 2018), and suicide (Nepon, Belik, Bolton, & Sareen, 2010; Jiang et al., 2021).

The mood states people experience can be influenced by physical environments in positive or negative ways. Exposure to natural settings, especially green spaces, for instance, can enhance positive emotion (e.g., Hartig, Mang, & Evans, 1991; Hartig, Evans, Jamner, Davis, & Gärling, 2003), promote attention restoration (e.g., Berman, Jonides, & Kaplan, 2008; Kaplan, 1995; Kaplan & Kaplan, 1989; Sullivan et al., 2014), and reduce mental stress (e.g. Memari, Pazhouhanfar, & Grahn, 2021; Park, Lee, Jung, & Swenson, 2020; Ulrich et al., 1991). Less green settings, however, which are often characterized by a variety of anthropogenic sounds, and complex visual stimuli, can have adverse impacts on mood states (Hartig et al., 2003; Van Renterghem & Botteldooren, 2016). Among the environmental stimuli that have the greatest impact on

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people, two are dominant: visual and acoustic stimuli (Preis, Kocinski, Hafke-Dys, & Wrzosek, 2015).

Complex acoustic-visual environments are emerging in high-density cities across the world. Around 55% of the global population now lives in urban areas, and this percentage is predicted to increase to 68% by 2050 (United Nations, 2018). Such rapid urbanization has led to a scarcity of open spaces and considerable juxtaposition of diverse acoustic and visual stimuli in high-density cities. Compared with suburban and rural residents, people who live in high-density urban areas are more likely to experience a diversity of acoustic-visual environments (Jahncke, Eriksson, & Naula, 2015), and they are more likely to experience new and complex combinations of acoustic-visual environments (Jo & Jeon, 2020). The recent development of electronic technology and wide use of portable electronic devices allow people a variety of opportunities to experience manipulated acoustic-visual environments no matter their location (Jiang, Schmillen, & Sullivan, 2018). Such electronic devices may include noise-canceling earphones or headsets, laptop or tablet computers, electronic sound box, projectors, virtual reality, and augmented reality devices (Jahncke et al., 2015; Jiang, Schmillen, & Sullivan, 2018; Jo & Jeon, 2020).

Another characteristic of open spaces in high-density cities is a mix of residents and nonlocal people – who temporarily travel from other regions, countries, or continent with a distinctively different natural, geometrical, and cultural context. In many high-density cities, such as New York, Chicago, London, Shanghai, and Hong Kong, a large portion of the people found in public open spaces are nonlocals. In spite of this diversity, however, most studies have focused on measuring the effects of urban environments only on local people (e.g., Deng et al., 2020; Gidlöf-Gunnarsson & Öhrström, 2007; Zhao, Xu, & Ye, 2018). And yet we know that locals and non-locals may have different responses to particular urban environments (e.g., Craig, Conniff, & Galan-Diaz, 2012, pp. 1–9; Kaplan & Herbert, 1987; Yang & Kang, 2005). Thus, it is necessary to examine responses of both local and nonlocal individuals to various acoustic and visual stimuli in urban open spaces. In this study, we do exactly that by comparing the extent to which variations in acoustic-visual environments impact mood states of local and non-local people.

1.1. Supporting theories

We suggest that impacts of urban environment on three aspects of mood states –attention, stress, and emotion – might largely be explained by some combination of the five theories and mechanisms described below.

First, Attention Restoration Theory posits that our top-down attention, which becomes depleted through mentally demanding tasks associated with everyday life, can be restored through exposure to natural settings (Kaplan, 1995; Sullivan & Li, 2021). Natural visual and acoustic elements, such as trees, water, tweeting birds, and breeze, are softly fascinating. These stimuli engage our bottom-up attention, thus allowing our top-down attention a chance to recover from the mental fatigue associated modern life (Kaplan, 1995).

Second, Stress Reduction Theory posits that exposure to nature promotes recovery from stress because positive mental responses to unthreatening natural settings and elements are deeply rooted in our genes through millions of years of evolution (Ulrich et al., 1991). This psychological response is immediate, unconscious, and spontaneous, and it is accompanied by increased positive feelings (Ulrich et al., 1991).

Third, Appleton's Prospect-refuge Theory (Appleton, 1975) suggest that humans often experience unconscious positive mood responses to safe and fertile environments and experience negative mood responses to dangerous or barren settings. Prospect-refuge Theory has a great deal of overlap with the biophilia hypothesis, which posits humans possess an innate tendency to seek and prefer connections with nature (Wilson, 1984).

Fourth, the theory of information processing in landscape settings posits that making efficient and accurate comprehension of an environment is a foundational capacity that supported our ancestors' survival and prosperity (Kaplan, 1987; Kaplan, Kaplan, & Ryan, 1998). There is ample evidence that humans make rapid mental responses to landscapes and that these responses include changes of mood states (Kaplan & Kaplan, 1989). Change in mood states was likely critical to facilitate our species' ability to make immediate assessments of landscapes that might have posed resources or threats – or a combination of resources and threats (Kaplan, 1987).

Finally, although a combination of the five senses is involved in the perception of environments, the vast majority of information about landscapes is acquired by seeing and hearing (Treichler, 1967). Thus, visual and acoustic stimuli are the two major sources of information that people perceive from their surroundings (Preis et al., 2015). Moreover, visual information affects acoustic perception of anthropogenic and natural sounds, and acoustic information affects visual perception of various visual elements (Jeon & Jo, 2020; Preis et al., 2015; Xu & Wu, 2021). From this perspective, a combination of visual and acoustic environments might have interactive impacts on human's mood states, and different combinations of visual and acoustic environments might have varying effects on the mood states that people experience.

1.2. Impacts of environments on mood states

1.2.1. Impacts of visual environments on mood states

Studies examining the impact of visual environments on mental health have been much more frequently conducted than similar studies focusing on acoustic environments (Jo, Song, & Miyazaki, 2019). Many studies, on the one hand, report that viewing green spaces, without accompanying nature sounds, can improve mood states by eliciting positive emotions (Jiang, He, Chen, Larsen, & Wang, 2020), facilitating attention restoration (Jiang et al., 2020; Wang, Rodiek, Wu, Chen, & Li, 2016) and stress reduction (Chang et al., 2021; Jiang et al., 2014; Jiang, Li, Larsen, & Sullivan, 2016). Viewing settings devoid of vegetation – also without any accompanying sound – on the other hand, can adversely impact the mood states that people experience (e.g., Chang et al., 2021; Jiang et al., 2016; Wang et al., 2016). In general, compared to viewing green settings, viewing landscapes that lack vegetation is associated with higher levels of negative mood states (Ulrich, 1979).

1.2.2. Impacts of acoustic environments on mood states

The sounds we are exposed to also independently affect our mood states. The acoustic experience of a setting is the experience formed by a sound or a combination of sounds, which can be categorized as natural (e.g., wind, birdsongs, and trickling water) or anthropogenic (e.g., traffic noise, construction noise, and mechanical noise). Compared to exposure to a setting without sound, exposure to a setting with natural sounds can have a positive influence on attention restoration and promote positive moods (Benfield, Taff, Newman, & Smyth, 2014; Jo, Song, & Miyazaki, 2019). Anthropogenic sounds in cities, however, can have adverse impact on the mood states that people experience. Exposure to mechanical sounds (e.g., trains, construction, and airport sounds) has been associated with higher levels of negative moods and an elevated risk of cardiovascular disease (Correia et al., 2013); and traffic noise exposure is associated with negative mental health symptoms and psychological disorders such as depression and anxiety, and increase stress hormone levels, which have been shown to be associated with inflammatory and oxidative stress pathways (Hahad, Prochaska, Daiber, & Muenzel, 2019).

1.2.3. Interactive impacts of visual and acoustic environments on mood states

The interactive impact of acoustic-visual environments on mental health is an emerging area of research and only a few studies have been published that examined these interactions with respect to mood states (e.g., Deng et al., 2020; Jahncke et al., 2015; Hong et al., 2021; Park et al., 2020). The interaction between acoustic and visual elements can predict attentional restoration (Jahncke et al., 2015), happiness or distress (Hong & Jeon, 2013, 2014), and stress reduction (Annerstedt et al., 2013). The extent to which the source of the sound is visible also impacts ratings of pleasantness and appropriateness of natural sounds in residential areas (Hong et al., 2017). Adding natural sounds to natural visual landscapes has been shown to facilitate greater mental restoration or stress reduction that grow from exposure to urban green spaces (Deng et al., 2020; Zhao et al., 2018). Nevertheless, these studies examined the impacts of acoustic and visual stimuli on emotion, attention, or stress, separately. Thus, we do not know the extent to which there is an interaction effect associated with acoustic and visual stimuli on mood states. Finally, most of studies of independent and interactive effects of acoustic and visual environments have engaged only local individuals, which ignores the significant portion of public space users in high-density cities who are nonlocal people.

1.3. Critical gaps in our knowledge

We find three critical gaps in our knowledge related to the impact of acoustic and visual landscapes on mood states that are addressed below.

First, the impacts of main and interactive effects of acoustic and visual environments on mood states are largely unknown in the context of high-density cities. The juxtaposition of a great variety of acoustic and visual stimuli in cities is becoming a common, or even dominating phenomenon due to high residential density and a diversity of land uses and associated human activities. Although the impacts acoustic or visual stimuli on moods have been examined separately, there are some indications of synergistic effects of acoustic and visual stimuli (Franco, Shanahan, & Fuller, 2017; Regenbogen, Johansson, Andersson, Olsson, & Lundstrom, 2016). Thus, knowing both the independent and interactive effects of acoustic-visual stimuli on mood states in the context of high-density cities is an important gap in our knowledge.

Second, we know little about the impacts of acoustic-visual stimuli on multidimensional mood states relative to emotion, attention, and stress. Separate findings related to individual aspects of mood states are valuable. Still, such findings may prevent us from understanding the comprehensive impacts of such combined stimuli on broader measures of mental health. More comprehensive measures of mood states should provide policy makers, planners, designers, and public health professionals' better guidelines for creating healthy places.

Third, to the best of our knowledge, no studies have examined impacts of acoustic and/or visual environments on mood states of local and nonlocal participants. Most findings from previous studies have been based on participation of local people (e.g., Liu, Kang, Behm, & Luo, 2014; Preis et al., 2015). This is a gap in our knowledge that has consequences for many users of public spaces in high-density cities because so many users of these spaces are likely non-local individuals. Both local and nonlocal people's responses to acoustic-visual environments should be considered in the research design.

1.4. Research questions

To address these gaps, we examined the extent to which 12 combinations of four acoustic and three visual environments influenced local and nonlocal participants' multidimensional mood states. We explored two central questions. To what extend do:

(1) Various combinations of acoustic and visual environments in high-density cities independently and interactively impact multidimensional mood states in people?
(2) Differences in mood states emerge from the presentation of visual stimuli that are seen as local to some participants and non-local to others[1]?

2. Methods

To address these questions, we conducted two randomized laboratory experiments. Parallel experiments were conducted in Illinois, USA and Hong Kong Special Administrative Region, China. Methods are introduced below in four parts: laboratory setting and participants, materials and instruments, procedure, and statistical analysis.

2.1. Laboratory setting and participants

2.1.1. Laboratory setting

Identical experimental procedures were conducted both in Illinois in 2014 and Hong Kong in 2015. Each experiment received an Internal Research Board (IRB) approval from a university in Illinois and a university in Hong Kong, respectively. The laboratory conditions were strictly controlled in both places. These conditions included a standard office room with a rectangular area of 15 m^2, white walls, typical overhead lighting conditions, and a comfortable temperature of 23 °C. A 22-inch LED monitor with noise-canceling over-the-ear headphones was used to play the video and audio stimuli. The distance between the screen and the participants' eyes was maintained at approximately 0.5 m, a comfortable distance for most desktop computer users.

2.1.2. Participants

Participants were also recruited both from Illinois and Hong Kong through two universities' bulk email systems and flyers posted in various public spaces both on and off campus. Other than wearing glasses or contact lenses, none of the participants reported having a diagnosed eyesight or hearing problem. We have recruited 174 adult participants in total and 140 participants finished the experiment, including 69 from Illinois and 71 from Hong Kong. In the Illinois experiment, data of one participant with a missing questionnaire was excluded. In the Hong Kong experiment, data of one participant from the USA and one statistical outlier (Mean ± 3Standard deviation) was used as outlier filters) were excluded. Our statistical analysis includes data of 68 participants from Illinois (49 women, 19 men) and 69 participants from Hong Kong (40 women, 29 men).

2.2. Materials and instruments

2.2.1. Twelve combinations of visual & acoustic environments

Twelve environmental conditions of visual-acoustic stimuli were used in the two identical experiments conducted in Illinois and Hong Kong (Fig. 1). Three common types of urban spaces—urban parks, urban streets, and office plazas—in Chicago, Illinois, USA, were selected as the visual environments for this study. Outstanding landmarks or elements with significant cultural characteristics were excluded to minimize cultural and historical distinction. Two-dimensional videos shot by an investigator were used as surrogates of these visual environments. To enhance representativeness, five sites of each type of setting were recorded with a video camera mounted on a tripod at a fixed height during the summer of 2014 (Fig. 2). The camera height was set to 160 cm to approximate the eye-level view of adults of average height. We

[1] We compared the impact of visual stimuli on changes in mood states after controlling for baseline mood state for the IL and HK samples but did not make a similar comparison for acoustic stimuli because we could not be sure that the acoustic stimuli we presented would be understood as either local or non-local.

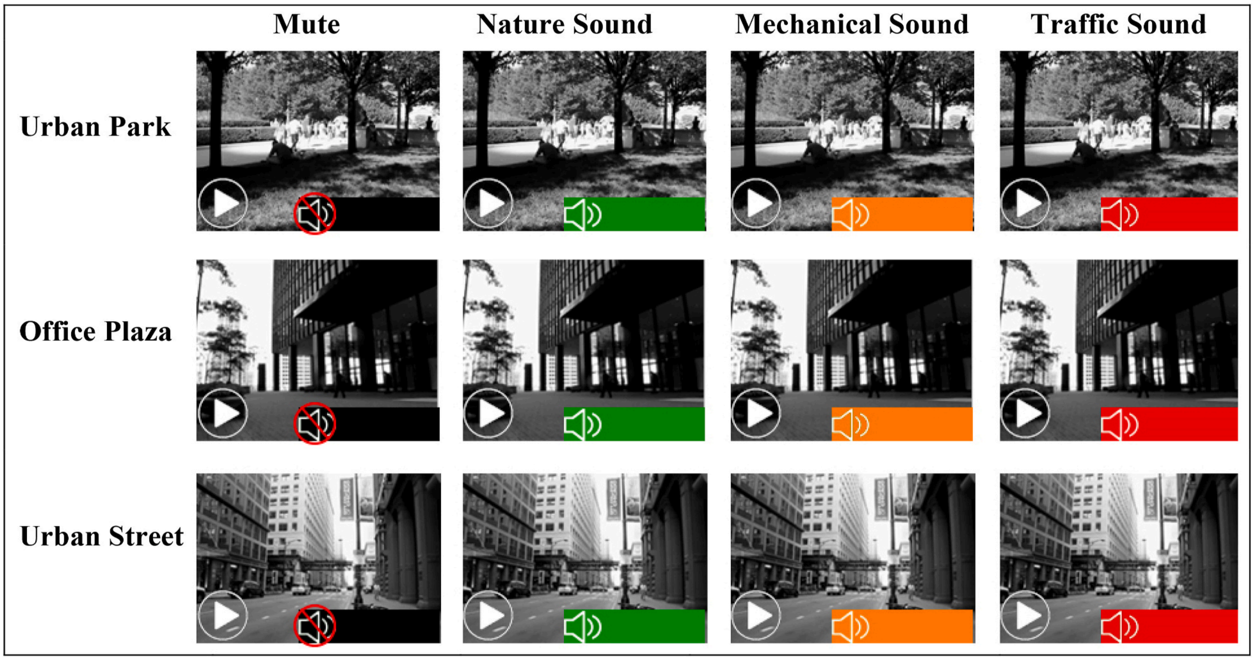

Fig. 1. Twelve videos consisting of three types of acoustic environments and three visual settings were employed as the treatments to which participants were randomly assigned in the experiment.

created three videos—one each representing urban parks, office plazas, and urban streets. To enhance the content validity of this work, each 5-min video consisted of 60-s scenes from five different settings. Thus, the urban park video showed five different urban parks in Chicago, and each park was shown for 60-s. We followed the same procedure for the videos focused on office plazas and urban streets, and all sounds were removed from the three videos.

We used the software *Audition* to produce three tracks of acoustic stimuli used in the experiments. The audio tracks consisted of nature, traffic, and mechanical sounds, and each of these sounds was downloaded from an online library of audio materials (www.sounddogs.com). For the nature audio track, we downloaded sounds of tweeting birds, wind, and trickling water as separate files and mixed them in parallel layers. For the mechanical audio track, we downloaded a single file containing sounds from a ventilation system, electronic devices, and construction sites. For the traffic audio track, we downloaded a single file containing the sounds of automobiles and other vehicles on urban streets. The traffic sound file did not contain any perceivable human voices or other sounds with cultural or regional significance.

The three resulting acoustic stimuli (nature, mechanical, and traffic) were then normalized to the same volume and used to prepare 5-min audio files. To create realistic acoustic stimuli that one is likely to hear in the city, each audio file consisted of one major sound along with two minor sounds. The major sound was expressed at 70% of the volume level, and each of the two minor sounds were expressed at 15% of the volume level. Thus, the nature sound audio file consisted of 70% nature sounds, 15% mechanical sounds, and 15% traffic sounds; the mechanical sound file consisted of 70% mechanical sounds, 15% nature sounds, and 15% traffic sounds, and the traffic sound file consisted of 70% traffic sounds, 15% nature sounds, and 15% mechanical sounds.

In addition to the three urban sound files, we created one mute audio file. Therefore, the four acoustic environments (mute, nature, mechanical, and traffic) were included in the experiment. Each of the four audio files was combined with each of the three silent videos to yield 12 combinations of acoustic-visual environments (Fig. 1). The 12 experimental videos can be seen and heard at: https://www.youtube.com/playlist?list=PLjTb6W6cJcnt5FxtSiF5OGs_0fPPVYHzA.

2.2.2. Measuring multidimensional mood states

To examine the effects of acoustic and visual environments on mood states, we used the short version of the Multi-Dimensional Mood Questionnaire (MDMQ) which measures a participant's self-reported mood states and has been used in wide variety of studies (e.g., Mealey & Theis, 1995; Wilhelm & Schoebi, 2007). The MDMQ covers three dimensions—emotion, attention, and stress—and each is measured using five items (see Table 1). Participants responded to 15 items using a six-point Likert Scale ranging from (1) definitely not, (2) not, (3) not really, (4) a little, (5) very much, and (6) extremely. Some of the items were presented in positive terms and others in negative terms. Thus, we reverse coded the negative items so that high scores for each item indicated positive mood. The sum of all 15 items was taken as a participant's general mood state, and its value ranged from 15 to 90.

2.3. Procedure

We used following steps to ensure random assignment with an equal number of participants for each of 12 acoustic-visual treatments in Illinois and Hong Kong. We sought six participants per acoustic-visual treatment, for a total of 72 participants. Using Microsoft Excel, we created a column that included an identifier for each potential participant within each treatment category. Next, we generated 72 random numbers in the second column. We then sorted that second column in descending order thus creating a random sequence of acoustic-visual treatment. The participants were randomly assigned to one of the 12 treatments as they came to the laboratory to participate in the experiment. Because some of the participants did not complete the experiment, in fact more than 72 participants were recruited in each experiment.

When a participant entered the laboratory room, an investigator guided them to first rest for 5 min. Then, the investigator asked the participant to read and sign a consent form. After signing the consent form, participants were asked to fill out the short MDMQ questionnaire for the first time (Mood^{1st}). Later, the participants were randomly assigned to watch and listen to a video set to a normal level on the LED monitor while wearing noise-canceling over-the-ear headphones. Each participant was exposed to only one acoustic-video treatment. Immediately after watching the acoustic-video treatment, participants were

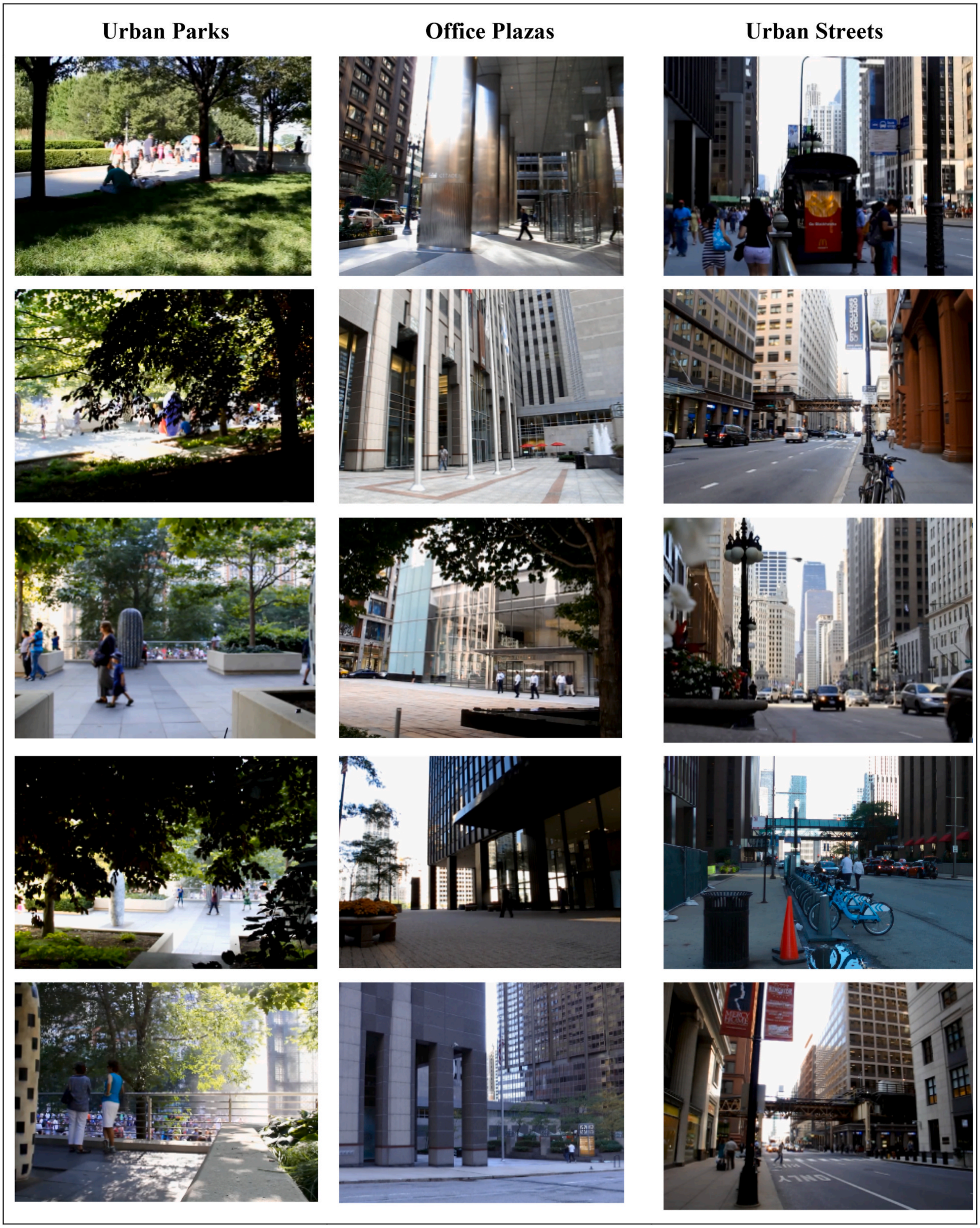

Fig. 2. Each of the three visual settings (e.g., Urban Parks, Office Plazas, and Urban Streets) include video clips taken from five different sites. This sampling of settings was designed to enhance construct validity.

asked to complete the short MDMQ questionnaire for the second time (Mood^{2nd}), and information about gender and country of residence was also collected. It took about 20 min for each participant to complete the enrollment process and experimental procedure (Fig. 3).

2.4. Statistical analysis

Mood change was calculated as the percentage of mood change derived by taking the score obtained after watching the video and subtracting the initial mood score: Mood Change (%) = (Mood^{2nd} -

Table 1
The Multi-Dimensional Mood Questionnaire includes three categories: Emotion, Attention, and Stress. Each category was assessed by asking participants to respond to the prompt "Right now, I feel:" using a six-point Likert Scale ranging from (1) definitely not, (2) not, (3) not really, (4) a little, (5) very much, and (6) extremely. Several of the items were presented in a positive manner, others in a negative manner. We reverse coded all the negative items.

Category	Items
Emotion	Content
	Bad
	Great
	Uncomfortable
	Superb
Attention	Rested
	Worn-out
	Tired
	Energetic
	Highly activated
Stress	Restless
	Composed
	Uneasy
	Relaxed
	Absolutely calm

$Mood^{1st}$)/$Mood^{1st}$ * 100. To test the impact of variations in acoustic and visual environments on the participants' mood changes, we performed multiple statistical analyses using SPSS 25.0. The four acoustic environments and three visual environments were considered categorical independent variables, and the percentage of mood change was considered a continuous dependent variable. Descriptive statistics were used to express the effect level of each combination of acoustic and visual environment on mood. Two-way Analysis of Variance (ANOVA) was used to examine the main effects of acoustic and visual environments and their interactions on mood states while controlling for mood baseline and gender as covariates. We employed a Least Significant Difference (LSD) test to assess pairwise comparisons among treatments. We analyzed the data as a whole, and individually for the Illinois and Hong Kong experiments.

3. Results

3.1. Analysis of combined data from two experiments

We ask, first, did the acoustic and visual environments impact mood states? To answer this question, we subtracted the baseline mood state scores from the mood state scores obtained after participants saw the videos (Table 2 provides the descriptive statistics for each condition). As can be seen in Table 3 and Fig. 4, the acoustic and visual environments have significantly different impacts on changes in mood states. For the acoustic environments, *Nature Sound* yields the most positive change in mood states for all participants, whereas *Traffic Sound* yields the most negative change in mood states. The two other sound conditions (Mute and Traffic Sound) also produce negative mood states. All visual environments – *Urban Park*, *Office Plaza*, and *Urban Street* – yield negative changes in mood states.

Were these changes statistically significant? Yes, results of two-way ANOVA demonstrate these changes in mood state are statistically significant (adjusted $R^2 = 0.34$; $p < .001$). That is, acoustic environments (F (3, 123) = 10.96, $p < .001$, η_p^2 (effect size) = .21) and visual environments (F (2, 123) = 3.26, $p < .05$, $\eta_p^2 = .05$) both have significant effects on changes in mood states. Moreover, there is a significant interactive effect between acoustic and visual environments (F (6, 123) = 3.52, $p <$ .01, $\eta_p^2 = .15$). As can be seen by comparing the top and bottom rows in Fig. 4, although nature sounds have positive impacts overall and when combined with urban parks and office plazas, they have a negative impact on mood states when combined with urban streets. Indeed, each of the sounds we tested interacts with the visual settings to such an extent that simply knowing the sound does not provide a reliable estimate of changes in mood states. As the bottom row in Table 4

Table 2
Descriptive statistic of impacts of acoustic and visual environments on changes in mood states in the combined assessment of Illinois & Hong Kong participants.

Acoustic Environment	Visual Environment	Mean	Std. Deviation	N
Nature Sound	Urban Park	14.5	16.4	13
	Office Plaza	2.4	23.4	11
	Urban Street	−3.2	19.0	11
	Total	5.1	20.5	35
Mute	Urban Park	0.9	13.2	7
	Office Plaza	−0.4	6.5	12
	Urban Street	−23.9	16.2	10
	Total	−8.2	16.5	29
Mechanical Sound	Urban Park	−18.2	29.3	11
	Office Plaza	−0.3	13.7	12
	Urban Street	−10.7	22.0	15
	Total	−9.6	22.8	38
Traffic Sound	Urban Park	−16.7	20.3	14
	Office Plaza	−24.7	16.2	9
	Urban Street	−17.1	13.5	12
	Total	−18.9	17.0	35
Total	Urban Park	−5.3	24.9	45
	Office Plaza	−4.6	18.5	44
	Urban Street	−13.3	19.2	48
	Total	−7.9	21.2	137

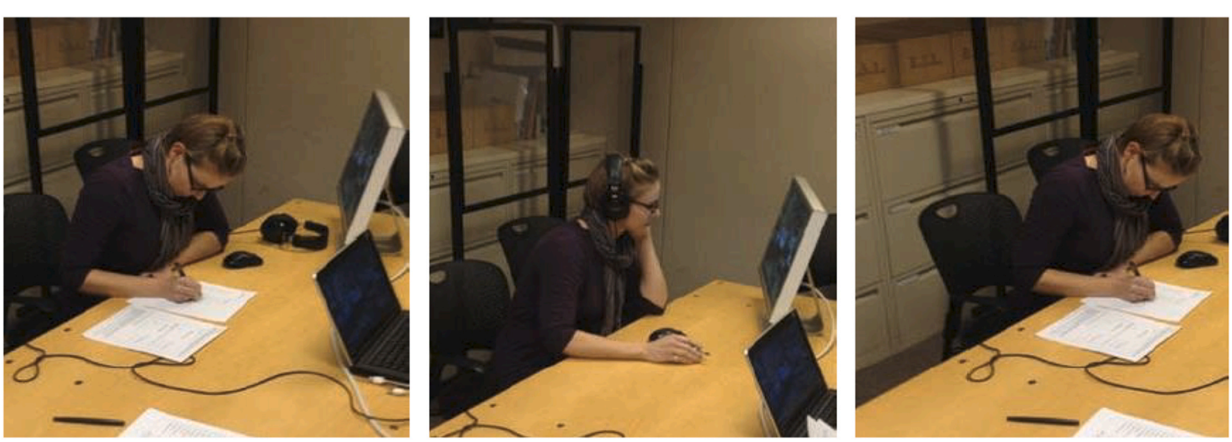

Fig. 3. Images taken during the experimental procedure showing the participant taking the initial Multi-Dimensional Mood Questionnaire (MDMQ) (left), watching and listening to one of the video treatments (middle) and completing the MDMQ for a second time (right).

Table 3
Summary of two-way analysis of variance (Illinois & Hong Kong).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	24,621.94	13	1894.00	6.34***	.000	.40
Intercept	3742.08	1	3742.08	12.53**	.001	.09
Baseline Mood	6296.48	1	6296.48	21.09***	.000	.15
Gender	23.55	1	23.55	.08	.779	.00
Acoustic Environment	9818.81	3	3272.94	10.96***	.000	.21
Visual Environment	1949.14	2	974.57	3.26*	.042	.05
Acoustic Environment x Visual Environment	6300.69	6	1050.11	3.52**	.003	.15
Error	36,724.91	123	298.58			
Total	69,885.51	137				
Corrected Total	61,346.85	136				

a. *R* Squared = 0.40 (Adjusted *R* Squared = 0.34); ${}^{ł}p < .10$, ${}^{*}p < .05$, ${}^{**}p < .01$, ${}^{***}p < .001$.

demonstrates, the interaction between acoustic and visual environments results in dramatically different changes in mood states.

How do the four acoustic environments and three visual environments relate one another (see Table 4)? To answer this question, we made multiple pairwise comparisons among the acoustic and visual

Table 4
Pairwise comparisons of changes in mood states among acoustic environments (Illinois & Hong Kong).

Pairwise Comparison	Mean Difference	Std. Error	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Nature Sound vs Mute	10.99*	4.42	2.24	19.73
Nature Sound vs Mechanical Sound	13.74**	4.09	5.64	21.83
Nature Sound vs Traffic Sound	23.79***	4.18	15.52	32.06
Mute vs Mechanical Sound	2.75	4.35	−5.85	11.35
Mute vs Traffic Sound	12.80**	4.44	4.02	21.59
Mechanical Sound vs Traffic Sound	10.06*	4.10	1.93	18.18

${}^{ł}p < .10$, ${}^{*}p < .05$, ${}^{**}p < .01$, ${}^{***}p < .001$.

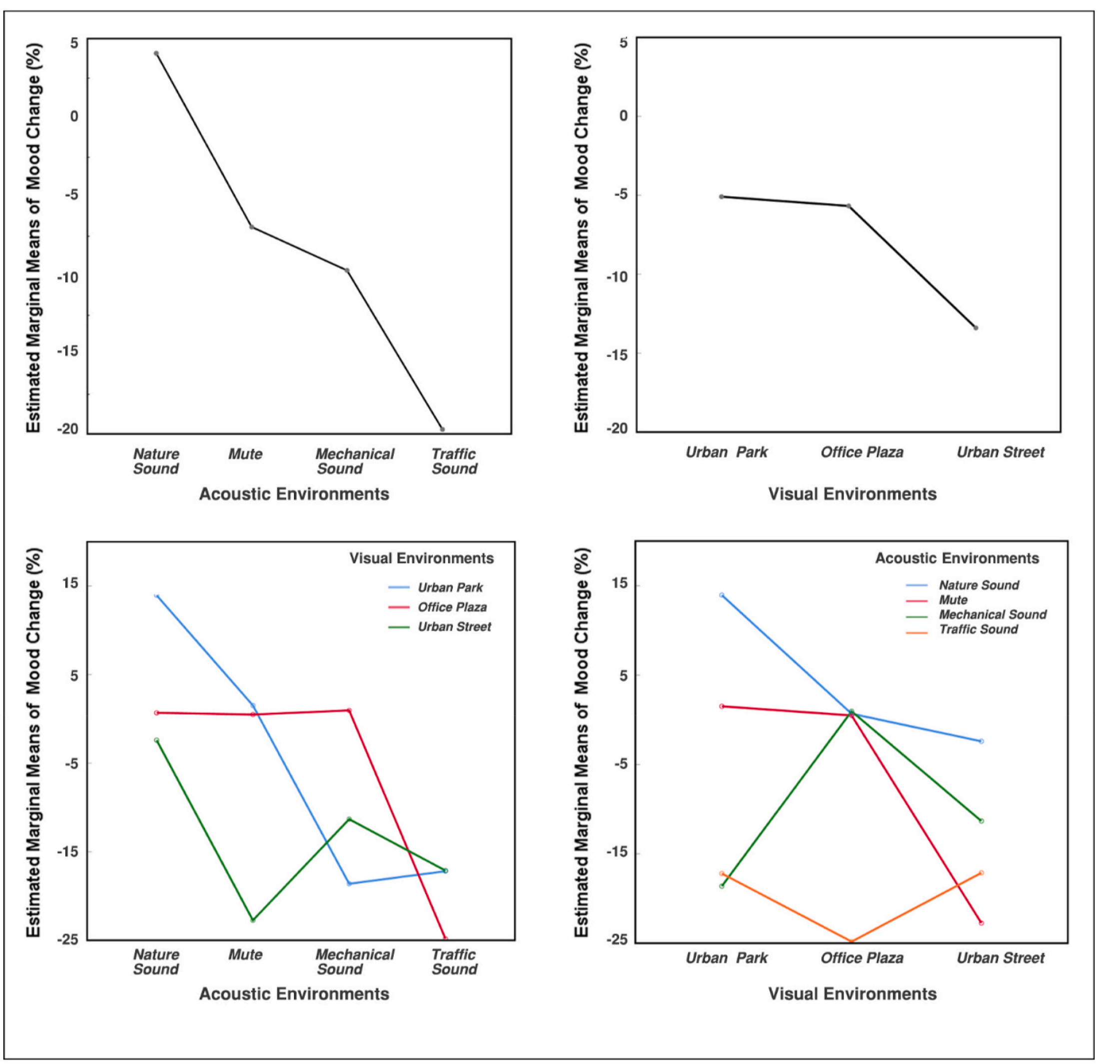

Fig. 4. Plot of two-way analysis of variance (combined data from two experiments). The top row shows the main effects for acoustic and visual environments. The bottom row shows the interactive effects for both environments.

environments and found that the effects of *Nature Sound* are significantly greater than that of the *Mute* ($p < .05$), *Mechanical* ($p < .01$) and *Traffic Sound* ($p < .001$) conditions. Notice that the effects of *Nature Sound* on mood states are always positive and are significantly greater than those of the other three acoustic conditions. *Traffic Sound* contribute to significantly more negative mood status than the *Mute* ($p < .01$), and *Mechanical Sound* ($p < .05$) condition. Among the visual environments, *Urban Park* ($p < .05$) and *Office Plaza* ($p < .05$) yield significantly greater positive changes in mood states than did *Urban Street* (Table 5).

Which combination of acoustic and visual environments have the greatest impact on changes in mood states? To address this question, we conducted pairwise comparisons between each pair of 12 videos on participant's change in mood states (Table 6). Results show a clear pattern. In general, treatments with more natural acoustic-visual content yield more positive effects on mood states. In contrast, videos with more anthropogenic acoustic-visual content yield more negative effects on mood states. *Nature Sound & Urban Park* yield more positive effects on mood states than any other treatment. *Traffic Sound & Urban Street* and *Traffic Sound & Office Plaza* yield the most negative effects on mood states.

3.2. Analysis of data from each location

An independent *t*-test comparing the baseline mood scores between the Illinois (Mean (M) = 46.7, Standard deviation (SD) = 8.3) and Hong Kong (M = 52.8, SD = 9.00) participants shows a significant difference between the two groups at the beginning of the experiment ($t = -4.48$, $p < .001$). This finding is reinforced by a one-way analysis of covariance in which change in mood states between the Illinois and Hong Kong participants is compared while controlling for baseline mood as a covariate. Here again, we find that the two groups of participants differ in terms of mood change (F (1,134) = 5.72, $p < .05$). Thus, we report the results of the Illinois and Hong Kong experiments independently below.

3.2.1. Results from Illinois

For the Illinois participants, descriptive statistics of the four acoustic environments and three visual environments are shown in Table 7. Among the acoustic environments, *Nature Sound* (M = 11.3, SD = 18.8) and *Mechanical Sound* (M = 2.3, SD = 14.1) yield positive changes in mood states, whereas *Mute* (M = −7.8, SD = 16.9) and *Traffic Sound* (M = −14.4, SD = 9.9) yield negative changes in mood states. Among the three visual environments, *Urban Park* (M = 5.3, SD = 15.6) yield positive mood changes, whereas *Office Plaza* (M = −1.1, SD = 17.6) and *Urban Street* (M = −9.4, SD = 18.3) yield negative mood changes.

As can be seen in Table 8 and Fig. 5, the results of a two-way ANOVA indicate that the entire model is statistically significant (adjusted R^2 = 0.57; $p < .001$. Both acoustic environments (F (3, 54) = 13.31, $p < .001$, $\eta_p^2 = .43$) and visual environments (F (2, 54) = 8.69, $p < .01$, and $\eta_p^2 = .24$) have significant effects on changes in mood states. Moreover, a significant interaction is evident between the acoustic and visual environments (F (6, 54) = 2.67, $p < .05$, $\eta_p^2 = .23$).

Table 5
Pairwise comparisons of changes in mood states among visual environments (Illinois & Hong Kong).

Pairwise Comparison	Mean Difference	Std. Error	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Urban Park vs Office Plaza	0.58	3.75	−6.84	8.01
Urban Park vs Urban Street	8.31*	3.68	1.03	15.59
Office Plaza vs Urban Street	7.73*	3.64	0.52	14.93

$^{ł}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

The results of pairwise comparisons indicate that *Nature Sound* has significantly more positive effects on changes in mood states than the *Mute* ($p < .01$) or *Traffic Sound* ($p < .001$) condition, and marginally more positive effects than the *Mechanical Sound condition* ($p < .10$). The *Mute* ($p < .05$) and *Mechanical Sound* ($p < .001$) conditions have significantly more positive effects on changes in mood states than *Traffic Sound*. *Mechanical Sound* yields marginally more positive effects than the *Mute* condition ($p < .10$, Table 9). Pairwise comparisons between the visual environments indicate that *Urban Park* has a significantly greater effect on changes in mood states than *Urban Street* ($p < .001$) and *Office Plaza* ($p < .05$), and that *Office Plaza* yields marginally better effects than *Urban Street* ($p < .10$, Table 10).

3.2.2. Results from Hong Kong

For the Hong Kong participants, descriptive statistics of the four acoustic environments and the three visual environments from Hong Kong are shown in Table 11. All acoustic environments yield negative effects on changes in mood states (*Nature Sound: M* = −1.5, SD = 20.8; *Mute*: M = −8.7, SD = 16.8; *Mechanical Noise: M* = −20.2, SD = 24.2; *Traffic Noise*: M = −22.6, SD = 20.8). All visual environments also produce negative effects on changes in mood states (*Urban Park: M* = −16.4, SD = 28.0; *Office Plaza: M* = −8.5, SD = 19.1; *Urban Street: M* = −16.6, SD = 19.7).

As can be seen in Table 12 and Fig. 5, the results of the two-way ANOVA indicate that the entire model is statistically significant (adjusted R^2 = 0.24; $p < .01$). Although the acoustic environments have significant effects on changes in mood states (F (3, 55) = 4.24, $p < .01$, $\eta_p^2 = .19$), the visual environments do not (F (2, 55) = 0.90, $p > .10$, $\eta_p^2 = .03$). Significant interaction effects can be seen between the acoustic and the visual environments (F (6, 55) = 2.72, $p < .05$, $\eta_p^2 = .23$).

We further examined the effects of each pair of the four acoustic environments on mood changes. Multiple pairwise comparisons indicate that *Nature Sound* has significantly more positive effects on changes in mood states than the *Mechanical Sound* ($p < .01$) or *Traffic Sound* ($p < .01$). The *Mute* condition has marginally more positive effect on changes in mood states than *Traffic Sound* ($p < .10$, Table 13). The differences between the other pairs of acoustic environments are not significant. No significant differences are found between any pair of visual environments.

3.2.3. Local vs non-local reactions

Did the Illinois participants, who saw images that were gathered in Illinois, react differently to those images than did their Hong Kong counterparts, for whom the images were clearly not local? To address the question, we conducted two-way ANOVAs for the Illinois and Hong Kong samples while controlling for baseline mood states (Table 8 for Illinois and 12 for Hong Kong samples, Fig. 5 for both samples). We found the two groups did react differently to the visual environments. The video gathered in Illinois had a significant impact on changes in mood states for the Illinois participants (F = 0.9, p = .001, $\eta_p^2 = .24$). But these same video images had no measurable impact on the mood states of the Hong Kong participants (F = 0.9, p = .41, $\eta_p^2 = .03$). In general, the visual environments have more positive and stronger effects for local participants than for nonlocal participants. These findings suggest that visitors to high density cities will be impacted more by the sounds they hear than the visual conditions they encounter.

4. Discussion

4.1. Summary of major findings

There are five major findings in this study. First, the acoustic and visual stimuli employed in this study had significant, independent, and interactive effects on changes in mood states. Second, natural stimuli, either acoustic or visual, had the most positive effects on changes in mood states. Third, acoustic stimuli had stronger effects on changes in

Table 6
Pairwise comparisons between each pair of 12 treatments on changes in mood states for all participants.

	Nature sound-urban park	Nature sound-office plaza	Nature sound-urban street	Mute-urban park	Mute-office plaza	Mute-urban street	Mechanical sound-urban park	Mechanical sound-office plaza	Mechanical sound-urban street	Traffic sound-urban park	Traffic sound-office plaza	Traffic sound-urban street
Nature sound-urban park	-	12.1	17.7*	13.6	14.8*	38.3***	32.6***	14.7*	25.1***	31.1***	39.1***	31.6***
Nature sound-office plaza	-12.1	-	5.6	1.5	2.7	26.3**	20.5*	2.7	13.0ǂ	19.0*	27.0**	19.5*
Nature sound-urban street	-17.7*	-5.6	-	-4.1	-2.8	20.7*	15.0	-2.9	7.5	13.5ǂ	21.5*	13.9ǂ
Mute-urban park	-13.6	-1.5	4.1	-	1.3	24.8**	19.1*	1.2	11.5	17.5*	25.6**	18.0*
Mute-office plaza	-14.8*	-2.7	2.8	-1.3	-	23.5**	17.8*	-0.1	10.3	16.3*	24.3**	16.7*
Mute-urban street	-38.3***	-26.3**	-20.7*	-24.8**	-23.5**	-	-5.7	-23.6**	-13.2ǂ	-7.2	0.78	-6.8
Mechanical sound-urban park	-32.6***	-20.5*	-15.0	-19.1*	-17.8*	5.7	-	-17.9*	-7.5	-1.5	6.5	-1.1
Mechanical sound-office plaza	-14.7*	-2.7	2.9	-1.2	0.08	23.6**	17.9*	-	10.4	16.4*	24.4**	16.8*
Mechanical sound-urban street	-25.1***	-13.0ǂ	-7.5	-11.5	-10.3	13.2ǂ	7.5	-10.4	-	6.0	14.0ǂ	6.5
Traffic sound-urban park	-31.1***	-19.0*	-13.5ǂ	-17.5*	-16.3*	7.2	1.5	-16.4*	-6.0	-	8.0	0.4
Traffic sound-office plaza	-39.1***	-27.0**	-21.5*	-25.6**	-24.3**	-0.8	-6.5	-24.4**	-14.0ǂ	-8.0	-	-7.6
Traffic sound-urban street	-31.6***	-19.5*	-13.9ǂ	-18.0*	-16.7*	6.8	1.1	-16.8*	-6.5	-0.4	7.6	-

The numbers in the table are the mean difference in changes in mood state scores between the two treatment videos being compared. The mean difference was calculated by subtracting the value of a column unit from the value of a row unit. ǂ $p < .10$, *$p < .05$, ** $p < .01$, *** $p < .001$.

Mean difference is positive with $p < .001$
Mean difference is positive with $p < .01$
Mean difference is positive with $p < .05$
Mean difference is positive with $p < .10$
Mean difference is positive with $p \geq .10$
Mean difference is negative with $p \geq .10$
Mean difference is negative with $p < .10$
Mean difference is negative with $p < .05$
Mean difference is negative with $p < .01$
Mean difference is negative with $p < .001$

Table 7
Descriptive statistic of impacts of acoustic and visual environments on changes in mood states (Illinois).

Acoustic Environment	Visual Environment	Mean	Std. Deviation	N
Nature Sound	Urban Park	20.5	17.5	6
	Office Plaza	11.5	26.1	6
	Urban Street	2.0	3.1	6
	Total	11.3	18.8	18
Mute	Urban Park	5.9	5.7	5
	Office Plaza	−0.8	3.1	6
	Urban Street	−29.9	10.5	5
	Total	−7.8	16.9	16
Mechanical Sound	Urban Park	1.1	14.5	6
	Office Plaza	0.9	9.4	6
	Urban Street	4.9	19.0	6
	Total	2.3	14.1	18
Traffic Sound	Urban Park	−6.1	8.6	6
	Office Plaza	−19.0	9.6	5
	Urban Street	−19.7	3.9	5
	Total	−14.4	9.9	16
Total	Urban Park	5.3	15.6	23
	Office Plaza	−1.1	17.6	23
	Urban Street	−9.4	18.3	22
	Total	−1.6	18.0	68

mood states than visual stimuli. Fourth, in general, effects of the visual environments were more positive and stronger for local participants than for nonlocal participants. Finally, the *Nature Sound & Urban Park* treatment was the only treatment that had a positive effect for local and non-local participants.

Table 8
Summary of two-way analysis of variance (Illinois).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14,147.18	13	1088.24	7.86***	.000	.65
Intercept	1877.96	1	1877.96	13.57**	.001	.20
Baseline Mood	2165.75	1	2165.75	15.65***	.000	.22
Gender	1.05	1	1.05	0.01	.931	.00
Acoustic Environment	5524.51	3	1841.50	13.31***	.000	.43
Visual Environment	2405.92	2	1202.96	8.69**	.001	.24
Acoustic Environment x Visual Environment	2213.88	6	368.98	2.67*	.024	.23
Error	7473.10	54	138.39			
Total	21,795.43	68				
Corrected Total	21,620.28	67				

R Squared = 0.65 (Adjusted R Squared = 0.57); ǂ$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

4.2. Interpretation of major findings

4.2.1. Main and interactive effects of acoustic and visual environments on the mood states

We found that the acoustic and visual stimuli both had significant main effects on multidimensional mood states. Previous studies have focused on the effects of visual environments on mood states (e.g., Chang et al., 2021; Jo, Song, & Miyazaki, 2019; Ulrich, 1979; Wang et al., 2016), but much less work has examined on the effects of acoustic environments on mood (e.g., Benfield et al., 2014; Wooller, Barton, Gladwell, & Micklewright, 2016). The findings presented here suggest

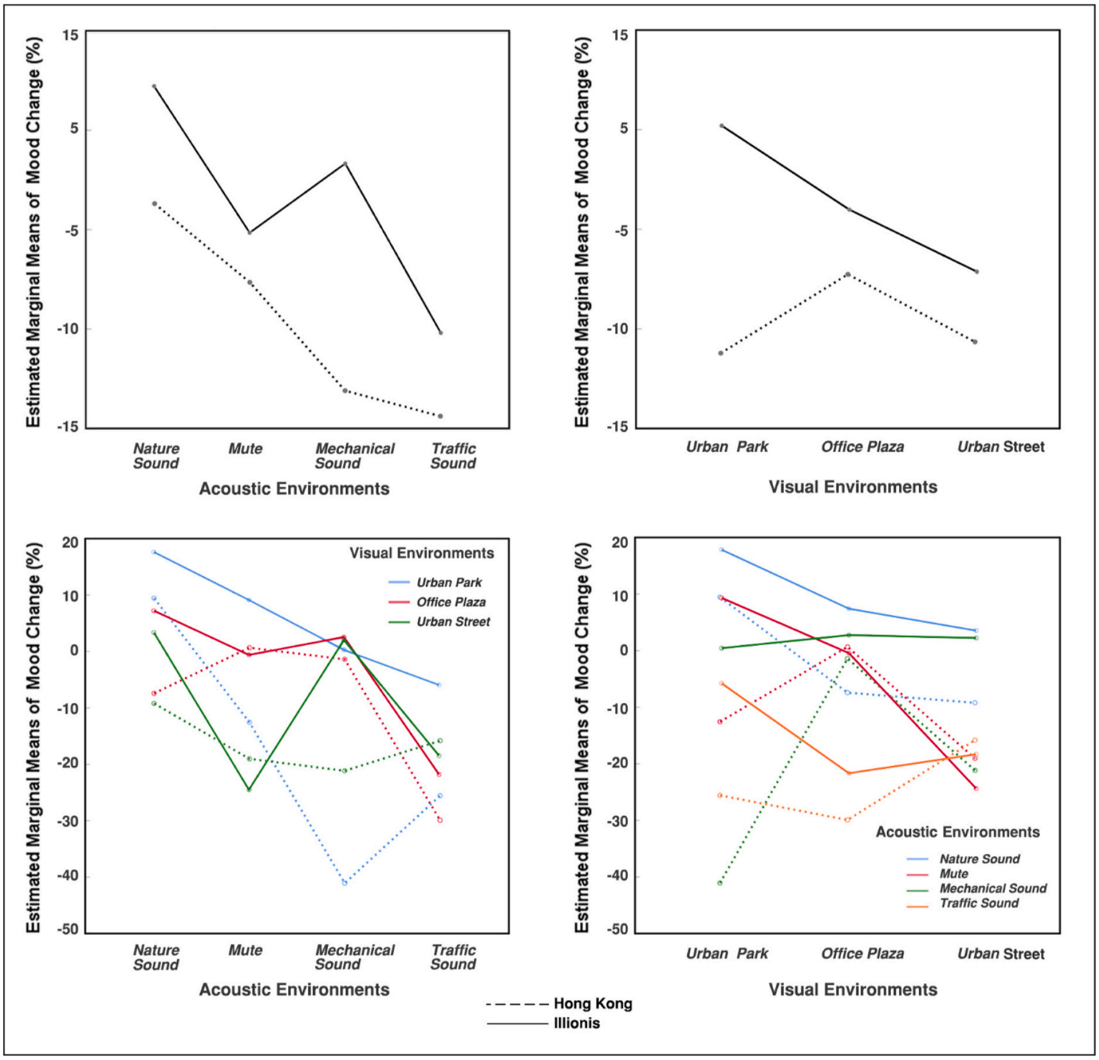

Fig. 5. Plot of two-way analysis of variance (for Illinois and Hong Kong, respectively). The top row shows the main effects for acoustic and visual environments. The bottom row shows the interactive effects for both environments.

Table 9
Pairwise comparisons of changes in mood states among acoustic environments (Illinois).

Pairwise Comparison	Mean Difference	Std. Error	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Nature Sound vs Mute	14.79**	4.23	6.30	23.27
Nature Sound vs Mechanical Sound	7.81ⱡ	3.97	-.15	15.77
Nature Sound vs Traffic Sound	24.89***	4.08	16.71	33.08
Mute vs Mechanical Sound	−6.98 ⱡ	4.16	−15.31	1.35
Mute vs Traffic Sound	10.11*	4.26	1.56	18.65
Mechanical Sound vs Traffic Sound	17.08***	4.05	8.96	25.21

ⱡ$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

that we value the power of acoustic environments on influencing the mood states that people experience.

We also found interactive effects of acoustic and visual stimuli on the mood states. Comparing the two main effects, the interactive effect had a similar or even greater impact. Moreover, the interactive effect was significant for parallel experiments conducted in Illinois and Hong Kong. These findings can enrich our understanding of some previous studies (e.g., Jahncke et al., 2015; Li & Lau, 2020; Pheasant, Horoshenkov, Watts, & Barrett, 2008), because our treatments examined more levels of the acoustic and visual stimuli, because we measured multidimensional mood states, and because the participants were not limited to local individuals.

The significant interactive effect can be explained through linking

Table 10
Pairwise comparisons of changes in mood states among visual environments (Illinois).

Pairwise Comparison	Mean Difference	Std. Error	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Urban Park vs Office Plaza	8.45*	3.49	1.45	15.46
Urban Park vs Urban Street	14.71***	3.55	7.58	21.83
Office Plaza vs Urban Street	6.26 ⱡ	3.60	−0.96	13.48

ⱡ$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 11
Descriptive statistic of impacts of acoustic and visual environments on changes in mood states (Hong Kong).

Acoustic Environment	Visual Environment	Mean	Std. Deviation	N
Nature Sound	Urban Park	9.3	14.8	7
	Office Plaza	−8.6	15.8	5
	Urban Street	−9.4	28.3	5
	Total	−1.5	20.8	17
Mute	Urban Park	−11.6	21.9	2
	Office Plaza	0.04	9.2	6
	Urban Street	−18.0	19.8	5
	Total	−8.7	16.8	13
Mechanical Sound	Urban Park	−41.3	25.5	5
	Office Plaza	−1.5	17.9	6
	Urban Street	−21.0	17.9	9
	Total	−20.2	24.2	20
Traffic Sound	Urban Park	−24.6	23.3	8
	Office Plaza	−31.7	21.4	4
	Urban Street	−15.2	17.8	7
	Total	−22.6	20.8	19
Total	Urban Park	−16.4	28.0	22
	Office Plaza	−8.5	19.1	21
	Urban Street	−16.6	19.7	26
	Total	−14.1	22.5	69

Table 12
Summary of two-way analysis of variance (Hong Kong).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13,135.09	13	1010.39	2.62**	.007	.38
Intercept	1.25	1	1.25	0.00	.955	.00
Baseline Mood	450.19	1	450.19	1.17	.285	.02
Gender	27.43	1	27.43	0.07	.791	.00
Acoustic Environment	4916.51	3	1638.84	4.24**	.009	.19
Visual Environment	696.00	2	348.00	0.90	.412	.03
Acoustic Environment x Visual Environment	6316.86	6	1052.81	2.72*	.022	.23
Error	21,250.06	55	386.36			
Total	48,090.08	69				
Corrected Total	34,385.15	68				

R Squared = 0.38 (Adjusted *R* Squared = 0.24); ƚ$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

Table 13
Pairwise comparisons of changes in mood states among acoustic environments (Hong Kong).

Pairwise Comparison	Mean Difference	Std. Error	95% Confidence Interval for Difference	
			Lower Bound	Upper Bound
Nature Sound vs Mute	7.92	7.83	−7.77	23.61
Nature Sound vs Mechanical Sound	18.82**	6.63	5.52	32.11
Nature Sound vs Traffic Sound	21.38**	6.76	7.83	34.93
Mute vs Mechanical Sound	10.90	7.62	−4.37	26.17
Mute vs Traffic Sound	13.46 ƚ	7.72	−2.02	28.94
Mechanical Sound vs Traffic Sound	2.57	6.54	−10.55	15.68

ƚ$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

human perception of information with mood states (Kaplan & Kaplan, 1989). For humans, no matter where they live, information is a human need that is “inescapable, essential, and pervasive” (Kaplan et al., 1998, p. 7). An environment with coherent and legible features is critical for humans to understand their surroundings and keep oriented (Kaplan, 1987). A poor comprehension of one’s surroundings might stimulate negative mood states, such as feeling fatigued, stressed, or anxious, because a setting that is difficult to understand is likely to be perceived as unsupportive or risky. For the same reason, a setting that is easy to understand might stimulate positive mood states, such as a sense of energy, calmness, and relaxation (Kaplan, 1987). Therefore, different combinations of acoustic and visual environments might have positive or negative impacts on human’s perception and understanding of a particular setting and that understanding is likely to have implications for one’s mood state.

4.2.2. *Positive effects of nature features on the mood states*

Among all of the stimuli we examined in this study, environments with a greater presence of natural features, either acoustic or visual stimuli, had stronger positive effects on mood states than environments with a greater presence of features that were mostly anthropogenic.

Indeed, the positive effects of natural sounds on various aspects of participant’s moods has been frequently reported (e.g., Benfield et al., 2014; Jahncke et al., 2015; Park & Swenson, 2020). The findings presented here, however, are a bit more nuanced. Instead of presenting a single track of pure natural, mechanical or traffic sounds, each of our acoustic stimuli included a mix of sounds: 70% of the sound came from the predominant source (e.g., natural sounds of birds, water, wind) and 30% came from the two other acoustic stimuli (e.g., 15% from mechanical sounds and 15% from traffic sounds). We adopted this procedure because it is almost impossible to experience pure nature sounds without any anthropogenic sounds in urban areas. It seems to us that a stimulus of pure nature sounds would reduce the generalizability of findings from such studies because it would be nearly impossible to find urban settings in which one experiences pure natural acoustic stimuli.

In this study, nature sounds made positive effects on mood states when a low portion of anthropogenic sounds (mechanical and traffic sounds) was added to the nature sounds. The finding suggests that the introduction of nature sounds in existing urban areas can help improve visitors’ mood states of people even anthropogenic sounds are not full avoidable.

4.2.3. *Stronger effects of acoustic environments than visual environments*

In this study, acoustic environments yielded stronger effects on mood states than did visual environments. This finding is supported by reports from several previous studies. For example, one study found greater impact of acoustic compared to visual environments on perceived comfort (Preis et al., 2015). Another study reported acoustic environments had a greater impact on office workers’ psychological restoration than did visual environments (Ma & Shu, 2018). Other researchers have reported that acoustic environments may be more important than visual environments in creating virtual environments that can significantly reduce the mental stress that people feel (Hedblom et al., 2019). Most of these studies, however, did not measure multidimensional mood states as we did in this study. Thus, another contribution of this study is to provide additional data resulting from multiple measures of mood states, that replicate and extend these previous findings. Taken together, this growing body of work suggests that designers, planners, engineers, and municipal officials may have underestimated the powerful impacts of acoustic stimuli on the mood states that people experience.

The significant effects of acoustic environments is reinforced by the results presented above related to the muted videos. In this study, three muted videos generally yielded negative effects on mood changes, which were demonstrably worse than the effects of videos with nature sounds. These results are consistent with findings reported by two studies showing that visual scenes without sounds generate more fear and stress in participants than same scenes with sounds (Annerstedt et al., 2013; Wooller et al., 2016).

In spite of this growing body of work, the relationships between visual and acoustic stimuli are not fully understood. Given the importance that visual stimuli have played in conveying information to humans over evolutionary time (Kaplan & Kaplan, 1989) these findings are still somewhat counterintuitive and they invite future researchers to examine the underlying mechanisms that have produced findings from various studies demonstrating that acoustic stimuli have stronger effects on mood states than visual stimuli.

4.2.4. Different impacts on local and nonlocal participants' mood states

In comparing the results of the two experiments, we found the impacts of acoustic-visual environments on mood states, in general, were more positive for Illinois participants than for Hong Kong participants. The visual stimuli made significant impacts on Illinois participants' mood changes, but not for participants from Hong Kong. What might explain this finding?

We know from previous studies that residing in a particular region influences a person's evaluation of acoustic or visual landscapes within that region (e.g., Ren, Kang, Zhu, & Wang, 2018; Wahyuni & Furuya, 2017; Zhang & Kang, 2006). Moreover, individuals can attribute different meanings to the same scene depending on their relationship and familiarity with it (Holton, 2015; Kianicka, Buchecker, Hunziker, & Muller-Boker, 2006). All Illinois participants were Illinois residents, none of the Hong Kong participants had lived in or even visited the United States, let alone Illinois. Therefore, we suggest that participants' familiarity and attachment with the environmental stimuli might explain these differences (Mehrabian & Russell, 1974).

You might recall how we collected the experimental stimuli. The acoustic environments were likely equally familiar to the participants from Illinois and Hong Kong because the characteristics of the sound stimuli used in this study largely excluded cultural and regional differences. The visual stimuli, however, consisted of visual images captured only in Chicago, Illinois. It is almost certain that the Illinois participants were considerably more familiar with these visual stimuli than their Hong Kong counterparts. Previous findings suggest that familiarity with a landscape can have significant effects on mental health and well-being (Rose, 2012). When viewing unfamiliar scenes, participants engage in more visual probing (Elsadek, Sun, Sugiyama, & Fujii, 2019), spend more time, and exert more effort in extracting information from the visual stimuli (Duchowski, 2007; Elsadek et al., 2019). The effort associated with this activity might cause more fatigue (Miyao, Hacisalihzade, Allen, & Stark, 1989) which may trigger the negative moods associated with fatigue, such as stress, confusion, and irritability (Kaplan, 1987). We suspect that in this study, it was likely the nonlocal participants from Hong Kong experienced more mental demands in gathering and processing information from the scenes than did the local participants from Illinois, which further aroused a greater level of negative mood states than their Illinois counterparts.

In addition, people's familiarity with a place can predict their attachment to that place, which might further influence their mood states (Ratcliffe & Korpela, 2016). The participants from Illinois may have experienced a sense of place attachment while watching the videos, which was stimulated by their familiarity with the settings presented in the videos (Ujang & Zakariya, 2015). Because local people often have significantly stronger place attachment than nonlocals (Ganzevoort & van den Born, 2019), the Illinois participants may have had a stronger sense of place attachment to the videos and gained a great level of positive mood states than the Hong Kong participants. This interpretation is consistent with previous work demonstrating that viewing landscapes can improve people's moods when those people have a strong place attachment to the landscape (Scannell & Gifford, 2017). It is also consistent with work showing that place attachment can promote emotional well-being, fulfilment, and happiness (Ujang & Zakariya, 2015), and buffer mental stress (Mikulincer, Hirschberger, Nachmias, & Gillath, 2001).

4.2.5. The restorative effect of natural acoustic-visual environments

We found that the *Nature Sound & Urban Park* condition was the only treatment that produced a positive effect for both the Illinois and Hong Kong participants. This finding suggests the positive effects of natural acoustic-visual environments on mood states may not be subject to the local vs. nonlocal influence we observed with the other environments. The positive effects of the *Nature Sound & Urban Park* treatment on mood-change can be observed from the pairwise comparison between each pair of 12 acoustic-visual treatments in Table 6. The restorative effect of natural acoustic-visual condition is supported by a large number of studies. Experiments conducted in a wide variety of Western or Eastern countries have found that exposure to natural acoustic, or natural visual, environments can promote various measures of people's mental health (e.g., Alvarsson, Wiens, & Nilsson, 2010; Chang et al., 2021; Jiang et al., 2016; Jo, Song, & Miyazaki, 2019; Mavoa, Davern, Breed, & Hahs, 2019; Wang et al., 2016). The positive impact of natural acoustic and visual settings is further reinforced by a small number of studies conducted in Eastern or Western countries that produced similar results (e.g., Deng et al., 2020; Jahncke et al., 2015; Uebel, Marselle, Dean, Rhodes, & Bonn, 2021; Zhao et al., 2018). Thus, there is a growing body of evidence suggesting there might be a universal restorative effect that grows from exposure to natural acoustic-visual environments.

4.3. Applications

The findings presented above suggest that to create mood restorative environments within high-density cities, we should consider the quality of both the acoustic and visual conditions that people experience in urban spaces. Many previous research and design projects, however, have emphasized the effects of only visual environments on humans' mood states while neglecting the role that acoustic environments might play. Clearly, the planning and design of acoustic environments deserve greater attention from researchers, professionals, government officers, and the general public.

Environmental planning and design professionals often highlight the contrast between green and non-green visual features in designing and managing urban spaces. The findings presented here suggest that a part of the influence of green features might be ascribed to nature sounds within such places, such as birdsongs, the rustling of leaves in the breeze, and the sounds of waterfalls or other moving water. Thus, designers should preserve or provide green spaces in cities that produce nature sounds that can be easily perceived by residents and visitors (Pijanowski et al., 2011).

Our findings also speak to the irreplaceable values of large green and naturalistic spaces, such as large urban parks and urban forests, in high-density cities. Such green spaces not only provide visually natural settings, they also provide natural habitats and thus typically higher levels of biodiversity that other urban spaces. The natural richness of such large urban places likely has positive impacts on the mental health and wellbeing of people who visit these parks (Methorst, Bonn, Marselle, Böhning-Gaese, & Rehdanz, 2021).

Large green urban spaces can provide effective buffers from the unending anthropogenic sounds associated with high density cities. Large green spaces not only provide a variety of natural sounds, they also filter out some proportion of the anthropogenic sounds generated in the immediate vicinity (Hedblom, Knez, Ode Sang, & Gunnarsson, 2017). Small or moderate sized green spaces such as neighborhood parks and pocket gardens, although have a great deal to offer, are more vulnerable to invasion of anthropogenic sounds because small amounts of vegetation are not efficient sound buffers. Small, isolated green spaces also cannot provide diverse wildlife habitats to generate a variety lush nature sounds (Wilson, McGinnis, Latkova, Tierney, & Yoshino, 2016). Thus, government officers, planners, and designers should not be satisfied with how much total green space that exists within a city, but rather should work to ensure that some large naturalistic spaces are also available to residents and visitors.

It will likely be too costly to create highly immersive green spaces with adequate visual and acoustic features in many locations in high-density cities. One alternative that some have promoted concerns the use of electronic technologies to create virtual settings that promote wellbeing (Frishammar, Richtner, Brattstrom, Magnusson, & Bjork, 2019). Noise-canceling earphones or headsets, for instance, or wearable augmented reality devices, portable sound boxes, and immersive 360-degree interactive projectors might be useful for creating personal restorative experiences of nature even in barren and noisy environments. The social and ethical implications of such developments surely require careful study.

The stimuli tested in this study did not include pure natural, or pure anthropogenic sounds because we recognize that mixed sounds are an essential characteristic of high-density cities. We found that mixed acoustic stimuli – those that included natural and anthropogenic sound – positively or negatively impacted mood states, depending on whether natural sounds are the major sounds or not. These findings demonstrate that creating natural sounds in urban spaces in high-density cities is beneficial even when a range of anthropogenic sounds are also present. The important point is not to remove all anthropogenic sounds, but to find ways to make natural sounds predominant as much as possible.

Finally, this study compared the effects of environmental stimuli on local and nonlocal participants' mood states. Our findings suggest that impacts of urban spaces on local and nonlocal people's mood states should be jointly considered when we create public spaces in high-density cities. Nonlocals more likely lack a strong sense of place attachment and familiarity with these urban spaces, which might lead to negative moods, especially in the absence of natural acoustic and visual stimuli. The findings about suggest that one way to create urban settings that both local and nonlocal people find beneficial is to pair natural sounds with green visual features. Doing so is likely to promote positive mood states for both locals and nonlocals.

4.4. Limitations and future research

A single experimental study cannot examine a wide variety of possible combinations of acoustic and visual environments in high-density cities. We recognize several limitations of this study and suggest that future studies might be conducted to enrich our understanding of the research topic. We suggest four possibilities below.

First, in this study, we used two-dimensional videos of urban scenes as surrogates of real urban scenes. Although previous studies have consistently shown that such videos are valid surrogates of real scenes (e.g., Amati & Sita, 2018; Preis et al., 2015; Valtchanov, Barton, & Ellard, 2010), two-dimensional videos might be less immersive than being present in the actual settings. More interactive and immersive visual devices, such as three-dimensional (3D) TV, 3D personal viewer, and 3D cave projection, might be adopted in future studies. Visually immersive tools such as these will likely enhance the experience that people have of urban scenes (Browning, Saeidi-Rizi, McAnirlin, Yoon, & Pei, 2020; Hedblom et al., 2019). Sounds can also be presented in more immersive formats. Surround and binaural recordings, for instance, can be used to improve the realism of environments under study in laboratory conditions.

Second, although we suggest that the different effects of stimuli on local and nonlocal participants can be attributed to different levels of familiarity or place attachment to the stimuli used in this study (Hernandez, Hidalgo, Salazar-Laplace, & Hess, 2007; Kim & Kaplan, 2004; Korpela, Hartig, Kaiser, & Fuhrer, 2001), we did not quantify each participant's perceived familiarity or place attachment. In future research, participants' familiarity and place attachment to the stimuli presented should be measured, and the relationships proposed herein should be explored in greater depth.

Third, this study did not quantify the level of coherence or legibility associated with the combine acoustic and visual stimuli we presented. Thus, we do not know the extent to which participants found the combined stimuli plausible or realistic. Future studies should attend to this limitation by making measurements of people's reactions to the various combinations of acoustic and visual stimuli with particular attention to the levels of coherence and legibility that the stimuli jointly possess. Future studies might also examine the extent to which adding sounds of people talking and visually interacting with one another (e.g., people walking or chatting in some settings) impact the outcomes under study.

Finally, this study used typical sounds with little geographical or cultural uniqueness as acoustic stimuli. Acoustically unique stimuli, however, might influence participants' mood states. We suggest that geographical and cultural uniqueness of acoustic stimuli be presented in future studies to improve our understanding of this topic.

5. Conclusion

This study investigated independent and interactive effects of acoustic and visual environments on multidimensional mood states that people experience in the context of high-density cities. The findings show that acoustic and visual environments had significant independent and interactive effects on mood states, and that acoustic stimuli had stronger effects on mood states than did the visual stimuli. Although effects of acoustic-visual environments on mood states were generally stronger for local participants than for nonlocal participants, the universally positive effects of the combination of natural acoustic and visual environments were confirmed. We hope these findings provide support for creating healthier high-density cities through planning and design interventions of acoustic-visual environments.

Declaration of competing interest

None.

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