PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Restorative soundscapes and stress recovery in children

Shan SHU[1]; Hui MA[2]

[1, 2] Tianjin University, China

ABSTRACT

Emerging studies have shown that restorative soundscapes have the potential to facilitate adults' stress recovery. Little is known, though, about whether restorative soundscapes could reduce children's stress. Therefore, the present study tested and compared the effects of several potential restorative soundscapes on children's stress using a physiological measure: electrodermal activity (EDA). During the experiment, 53 children aged 8-12 were exposed to different soundscapes (recovery period) after a stressful arithmetic task (stressor period), while children's EDA variation was monitored throughout the whole period. The results showed that children's EDA levels decreased significantly after all the soundscape exposure. However, only the fountain soundscape showed significant a better restorative effect compared with ambient noise. In addition, EDA decreased faster at the beginning and tended to increase slightly at the end of the recovery period. Moreover, significant interaction effects were found between soundscape and gender as well as time and gender. Those results suggest that soundscapes do facilitate stress recovery on children to some extent after a psychological stressor. However, different soundscapes showed varied restorative effects on boys and girls. Therefore, future soundscape design in urban parks should take children gender difference into consideration.

Keywords: Restorative effects, Children, EDA

1. INTRODUCTION

Numerous studies have documented the restorative effects of interacting with natural environments(1). As an essential part of physical environments, some pleasant soundscapes were also suggested to contribute significantly to the restorative effects of the environment (2). Those restorative benefits of soundscapes could be framed in terms of two prevailing theories of restorative environments: attentional restoration theory (ART) and stress recovery theory (SRT). ART is commonly referenced to identify and restore a cognitive mechanism (3), while SRT focuses primarily on the effects of environmental stimuli on psychophysiological responses, suggesting that interacting with nature could evoke positive responses indicative of stress reduction (4).

Based on the SRT theory, many studies over the past decades have provided evidence for this by demonstrating a restoration in stress-relieving measures, including psychological and physiological indices, after exposure to natural environments (4–7). In addition to the visual stimuli of natural settings, which was predominantly reported in previous studies, psychophysiological benefits from soundscape exposure were also frequently suggested in some evidence-based research recently. Many of those research focused on the comparison of natural sounds and noise (8,9) or with sound and without sound (10,11), while some explored the restorative effects of one specific sound, such as music (12,13) and birdsong (14). Additionally, a physiological study investigated the restorative effects of different soundscapes but it failed to a reveal significant difference between soundscapes (15). Similar results were indicated in another study exploring the physiological responses to 18 sound-clips(16). Therefore, there is still a lacking of research on which soundscape could facilitate stress reduction for people and to what extent such a soundscape could provide restorativeness. Moreover, different studies applied various measure method to assess stress recovery after soundscape exposure, which led to mixed results. For example, Alvarsson (8) found no significant difference between nature sound and environmental noise on the recovery of high frequency heart rate variability (HF HRV) while a significant increase in HF HRV was indicated after exposure to nature sound in

[1] shan.shu@outlook.com
[2] mahui@tju.edu.com

Cassandra's study (9). These diverging results were also found in other physiological measurements, such as heart rate (16) and skin conductance level (14). Thus, there is still some uncertainty regarding which psychophysiological indicators may be effectively affected by soundscape exposure. Although soundscapes have been widely evidenced to cause positive experience, their health effects have not been demonstrated definitively because of methodological and conceptual limitations in prior research.

Despite a number of studies dealt with the effects of sounds on adults' health, none have dealt with soundscapes for children. Given the widely reported academic stress in primary schools of China, which impose increasing risk on children's psychophysiological health, it may be quite urgent task to explore restorative stimuli that could facilitate stress reduction for children (17). In contrast with annoyed ambient noise, which has been widely proven to have adverse effects on children's health in previous studies (18), pleasant soundscapes exhibited restorative potentials as perceived by children (19). Moreover, restorative soundscapes such as water sound was examined to facilitate attentional restoration for children after a stressful task. Thus, it seems reasonable to expect a positive effect on children's physiological health after exposure to a restorative soundscape. In addition, considering children's rapidly physical growth, they appear to be more vulnerable to surrounding environments compared with adults (20), which might leads to different effects of restorative soundscapes on children and adults' health.

Therefore, the aim of this study was to identify the effects of various restorative soundscapes on children's physiological stress. Given the urban parks serve as a major playing environment for children to relax and rest, this study was carried out in a simulated urban park situation. During the experiment, EDA was recorded as measures of physiological stress. It was hypothesized that 1) exposure to urban park soundscapes could facilitate significant stress recovery and 2) the perceived restorative soundscapes showed more restorative effects on children's stress recovery than silence and ambient noise in urban parks.

2. METHOD

2.1 Participants

A total of 53 children ranging in age from 8 to 12 years participated in this study (29 boys and 24 girls, mean age=10 years, SD=1.13). Participants were recruited via social media and snowball sampling in Tianjin, China. All of the children in the study were screened for the normal hearing with an audiometric examination, and they also reported normal corrected vision. None of them was taking prescription medication.

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Academic Committee of School of Architecture, Tianjin University. All the children and their parents were informed about the study protocol, and they voluntarily participated in the study. Before the experiment, children gave oral consent, and parents gave written informed consent to the researchers.

2.2 Experimental Stimuli

Urban parks are important and popular places for children to play and relax after school. Therefore, the context of soundscapes was set as an urban park. A photo of a typical urban park in China was presented on a screen to simulate a park setting. The picture was shown on a large 46-inch screen, which was placed in front of the participants as a distance of approximately 100cm.

Figure 1 – The landscape view of an urban park

Regarding the acoustic stimuli, five potential restorative sounds, i.e. music (MS), stream sound (SS), fountain sound (FS), bell ring (BR), and birdsong (BS) and silence (SL, widely reported to be beneficial to health) were used as experimental stimuli, while ambient noise (AN) was used as controlled stimuli. The five experimental stimuli were indicated to have restorative potential on children according to our previous study, and the detailed information of the five potential restorative sounds could be referenced to that study (21). Additionally, the ambient noise was recorded in a typical urban park in Tianjin, including human voice, water sound, music and some other unclear noise. It is important to note that, to simulate the real-life settings of urban parks, the above five sounds were used as dominant sound signals, and separately combined with the urban park noise as a background to generate five true soundscapes. Specifically, the ambient noise in urban parks was set as 50dBA according to the general measurement results in previous studies, and a signal to noise (S/N) of 5dB was reported by children to be the most restorative in a preliminary test. Therefore, the A-weighted equivalent sound pressure level of five sounds was set as 55 dBA accordingly. The recording, editing and calibrating on the soundscape stimuli were processed by Adobe Audition software. During the experiment, binaural signals of the soundscapes were delivered by computer through headphones (AKG K702).

2.3 Measures

In the current study, electrodermal activity (EDA) expressed in micro-Siemens (μS) was used as the measure of children's physiological stress, because it was widely used and suggested as a sensitive sympathetic indicator. During the experiment, two electrodes were attached to the hypothenar eminence of the index and middle finger of the participant's non-dominant hand. The EDA was measured as the conductance between two electrodes with a Biopac EDA100C amplifier. The measurement data were continuously recorded on a laptop computer with a Biopac System MP160 at 1000Hz and then analyzed using the same software package with which the data were collected (AcqKnowledge 5.0, Biopac).

It is known that there is a delay in the onset of stimulus-evoked physiological activity. Therefore, the last minute (seconds 60-120s) of the stressful task was used as the stressor period for comparison with the averaged EDA value during the recovery period. In addition, to further explore the EDA recovery variation, the 3-min recovery period was divided into six successive 30 second periods. Moreover, since every individual has a unique EDA baseline, all the measured data during the recovery period were further calculated as a percentage change (%) from the stressor period to accommodate individual difference.

2.4 Procedure

The experiments were performed in a semi-anechoic chamber in Tianjin University. Participants were accompanied by their parents, who waited in a room outside the chamber during the experiment. Participants took part in the experiment individually, supervised by a researcher.

Participants came to the laboratory and were seated in a comfortable chair where the procedure was explained. To ensure precise measurements, all the electrodes were initially attached to the participant's body to make sure that the gel on each electrode was fully absorbed into the skin. Before the formal experiment, a 3-min quiet baseline level was measured to ensure no group differences across soundscapes. In addition, due to the limited experiment time and available sample size, each participant attended four experiment sessions which were randomly selected from the total seven soundscapes. Each session consisted of two parts: 1) a 2-min period of oral calculation testing (stressor period), which was assessed to be an effective way to induce stress (22), and 2) a 3-min period of relaxation with exposure to one of the four soundscapes (recovery period), during which participants were simply instructed to listen to the soundscapes and remain as still as possible. EDA was measured continuously to record its variations. Then the same session was repeated for the three other soundscapes. The order of soundscape presentation was randomized and counterbalanced by sex. Finally, the participants were asked to provide their demographic information, including age in years and gender. Figure 2 shows a graphical representation of the study protocol. Total time for the experiment was approximately 30 minutes.

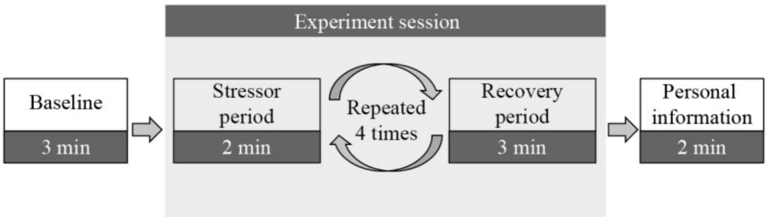

Figure 2 – The graphical representation of the study procedure

2.5 Data Analysis

In this study, all the analysis were done within the SPSS 25.0 software. First of all, the individual difference across soundscape groups was checked using a nonparametric Kruskal–Willis test (scale variables) and chi-square test (nominal variables). Then the Wilcoxon signed rank test was conducted to exam the effectiveness of stress-inducing task. Both of the above steps were the prerequisite before the following analysis. Due to the hierarchical and repeated-measure nature of the experiment (leading to autocorrelation), linear mixed models with varying complexities were fit to the data (23). Therefore, a 7 (soundscape) ×6 (time period) mixed-model with restricted maximum likelihood estimation was conducted to explore for main and interaction effects of soundscape and time on the EDA change. We also tested for the effects of gender, soundscape by time interaction, soundscape by gender interaction, and time by gender interaction, while the age and baseline measurements were included in the analysis as covariates. The effect of gender was included as its effects seems evident from previous studies on noise and health of both adults and children. In all analysis, alpha value less than 0.05 was used as the criterion to determine significant differences.

3. Result

In this study, 53 children were randomly assigned to four of the seven soundscape groups. Table 1 compared the demographics and baseline characteristics of the children in different soundscape groups. The results showed there was no significant difference in the demographics and baseline characteristics between the seven soundscape groups.

Table 1 – Comparison of sample characteristics between the soundscape groups (n=53)

Characteristics	SL n=33	MS n=33	SS n=30	FS n=31	BR n=32	BS n=30	AN n=29	*p*
Gender, n (%)								
Boy	18 (54.5)	17 (51.5)	16 (53.3)	15 (48.4)	16 (53.3)	17 (56.7)	16 (55.2)	.996
Girl	15 (45.5)	16 (48.5)	14 (46.7)	16 (51.6)	14 (46.7)	13 (43.3)	13 (44.8)	
Age, M (SD)	10.36 (1.22)	10.30 (1.21)	10.60 (1.00)	10.52 (1.12)	10.38 (1.29)	10.40 (1.04)	10.41 (1.15)	.962

Baseline EDA (μS), M (SD)	8.73 (5.51)	8.83 (5.27)	7.42 (5.20)	6.66 (4.71)	6.68 (4.42)	8.08 (5.35)	7.80 (4.65)	.556

Regarding the effect of stress-reducing task, the results showed that children's EDA measures increased substantially from the baseline period (M= 7.70, SD=5.02) to the stressor period (M= 13.57, SD=6.30), which proved that the oral calculation could effectively increase children's stress level in terms of EDA.

Table 2 shows the descriptive statistics, mean values with standard deviations (SD) and median values with Interquartile range (IQR), of EDA measurements during stressor period and recovery period for each soundscape. Non-parametric Wilcoxon signed rank tests showed that children's levels of EDA decreased significantly during the recovery period compared with the stressor period, no matter what soundscape was exposed to. This result supported our first hypothesis that all urban park soundscapes could induce stress reduction after an acute stressful task.

Table 2 – Descriptive statistics of EDA data during stressor and recovery period for each soundscape.

Soundscape	EDA-stressor period		EDA-recovery period		*p*
	Mean(SD)	Median(IQR)	Mean(SD)	Median(IQR)	
SL	14.58 (6.28)	13.78 (8.20)	12.70 (6.47)	11.99 (9.86)	.012
MS	13.40 (6.20)	12.67 (9.82)	10.35 (5.76)	9.54 (6.90)	.000
SS	12.17 (5.36)	12.01 (7.78)	9.56 (5.20)	8.28 (8.53)	.002
FS	14.24 (7.22)	12.45 (10.14)	9.83 (6.20)	8.38 (8.01)	.000
BR	12.89 (5.81)	12.54 (9.84)	9.48 (5.38)	8.66 (9.17)	.000
BS	13.80 (6.34)	12.49 (9.26)	10.67 (6.41)	9.34 (8.59)	.000
AN	14.11 (7.09)	13.63 (8.40)	10.57 (6.51)	9.50 (9.33)	.000

After controlling for various effects (age and baseline level), the linear mixed model showed a main effect of soundscape (F=2.24, *p*=0.040) and time (F=50.88, *p*=0.000) on the EDA change, but no significant interaction between soundscape and time (F=0.80, *p*=0.768) was found. Specifically, children showed significantly lower EDA during fountain soundscape exposure, compared with ambient noise exposure. However, there was no significant difference between other soundscapes and ambient noise. In addition, children's EDA levels decreased substantially at the beginning (before 60 seconds) and became relatively stable afterwards, then showed a slight trend of increase at the end of the recovery period. Nevertheless, none of the soundscapes could decrease children's EDA to the averaged baseline level during the entire recovery period, as shown in Figure 3.

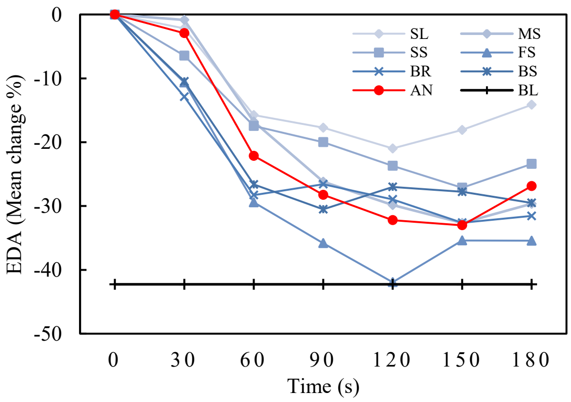

Figure 3 – Children's EDA change during exposure to seven soundscapes.

The linear mixed model also showed a significant interaction effect between soundscape and gender on EDA changes (F=2.22. *p*=0.041). As shown in Figure 4, for boys, ambient noise in urban parks could effectively decrease their EDA levels and showed significantly more restorative effects than silence, and it even induced marginally more stress reduction than other perceived restorative soundscapes. Meanwhile, for girls, only fountain sound showed significantly more restorative effects on children's stress, while no difference was found among other soundscapes.

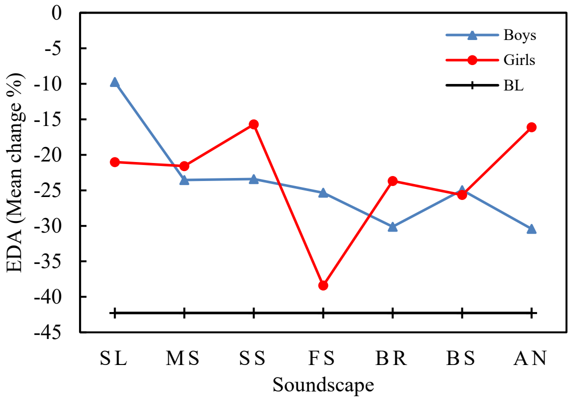

Figure 4 – Interaction effect of soundscape and gender on EDA.

Additionally, a significant interaction effect was also found between time and gender (F=3.12. *p*=0.009). As shown in Figure 5, during the first 60 seconds of the recovery period, girls' stress levels decreased much more than boys and then the girls' stress reduction became slower than boys. However, boys' stress levels appeared to slightly increase at the end of the recovery period while girls' stress levels continuously decreased.

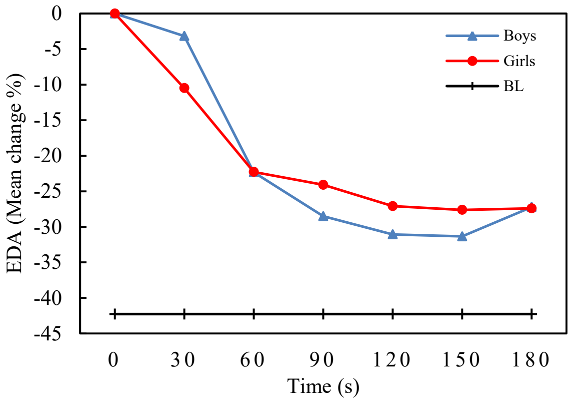

Figure 5 – Interaction effect of time and gender on EDA

4. DISCUSSION

In this study, experiments were conducted to examine the actual effects of potential restorative soundscapes in a (simulated) urban park on children's stress recovery, based on the physiological measures of EDA. In line with Hypothesis 1, the results demonstrated that acute exposure to all the soundscapes could effectively help children recover from a state of induced stress, including the ambient noise. Furthermore, a combination with fountain sound with an S/N of 5dB could facilitate even more stress recovery, at least for girls. It might due to the small fluctuation strength of fountain sound, which made it much easier for children to restore calm and relax. Another possible explanation is that fountain sound could facilitate great masking effect on ambient noise due to its spectral frequency characteristics, which is also in line with previous studies (24). However, it is interesting to note that no other soundscapes showed better restorative effects on stress levels than ambient noise in urban parks. This finding failed to support Hypothesis 2. Moreover, exposure to silence, i.e. simply reducing the noise level, induced much smaller stress reduction for boys, as compared with ambient noise. Those results indicated that the ambient noise of urban parks is a qualified restorative soundscape itself for young children, especially for boys. A possible reason is that children are quite familiar with the noise, therefore it is not easy to induce large physiological variations. In contrast, the ambient noise in urban parks could enable children to relax and rest to some extent. This result supported the previous study which suggested familiarity of the environments was positively related to restorativeness (15,25).

However, the study was limited to children between the ages of 8-12 years under settings of urban parks. This could be a threat to the generalizability of the findings to other settings or samples. It is suggested that conducting similar studies in other settings and in different age groups would test the applicability of the findings. In addition, the results indicated that different soundscapes showed varied restorative effects between boys and girls, who also showed different stress reduction tendency at the end of the recovery period. However, it is less clear whether this tendency will last for a longer time. Therefore, a longer recovery period should be considered in future studies.

5. CONCLUSIONS

In a simulated situation of an urban park, laboratory experiments were carried out to examine the restorative effects of soundscapes on children's physiological stress. Based on children's change of EDA responses, it was found that the perceived restorative soundscapes in urban parks, including the ambient noise, could provide physiological stress recovery for children to some extent after induced stress. Moreover, the gender difference is an important concern to the restorative effects of different soundscapes on stress reduction.

ACKNOWLEDGEMENTS

This research was funded by the National Natural Science Foundation of China (grant number 51478303 and 51678401). The authors are also grateful to the children for their participation in this study.

REFERENCES

1. Kaplan S. The restorative benefits of nature: Toward an integrative framework. J Environ Psychol. 1995;15(3):169–82.
2. Aletta F, Oberman T, Kang J. Associations between Positive Health-Related Effects and Soundscapes Perceptual Constructs: A Systematic Review. Int J Environ Res Public Health. 2018;15(11):2392.
3. Kaplan R, Kaplan S. The experience of nature : a psychological perspective. Cambridge University Press; 1989. 340 p.
4. Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M. Stress recovery during exposure to natural and urban environments. J Environ Psychol. 1991;11(3):201–30.
5. Berto R. The Role of Nature in Coping with Psycho-Physiological Stress: A Literature Review on Restorativeness. Behav Sci (Basel). 2014;4(4):394–409.
6. Beil K, Hanes D. The influence of urban natural and built environments on physiological and psychological measures of stress- A pilot study. Int J Environ Res Public Health. 2013;10(4):1250–67.
7. Tyrväinen L, Ojala A, Korpela K, Lanki T, Tsunetsugu Y, Kagawa T. The influence of urban green environments on stress relief measures: A field experiment. J Environ Psychol. 2014;38:1–9.
8. Alvarsson JJ, Wiens S, Nilsson ME. Stress Recovery during Exposure to Nature Sound and Environmental Noise. Int J Environ Res Public Health. 2010;7(3):1036–46.
9. Gould Van Praag CD, Garfinkel SN, Sparasci O, Mees A, Philippides AO, Ware M, et al. Mind-wandering and alterations to default mode network connectivity when listening to naturalistic versus artificial sounds. Sci Rep. 2017;7.
10. Annerstedt M, Jönsson P, Wallergård M, Johansson G, Karlson B, Grahn P, et al. Inducing physiological stress recovery with sounds of nature in a virtual reality forest — Results from a pilot study. Physiol Behav. 2013;118:240–50.
11. Jasper M, Heravi-Karimooi M, Zayeri F, Rejeh N, Vaismoradi M, Saadatmand V, et al. Effect of nature-based sounds' intervention on agitation, anxiety, and stress in patients under mechanical ventilator support: A randomised controlled trial. Int J Nurs Stud. 2012;50(7):895–904.
12. Sandstrom GM, Russo FA. Music Hath Charms: The Effects of Valence and Arousal on Recovery Following an Acute Stressor. Music Med. 2010;2(3):137–43.
13. Khalfa S, Dalla Bella S, Roy M, Peretz I, Lupien SJ. Effects of Relaxing Music on Salivary Cortisol Level after Psychological Stress. In: Annals of the New York Academy of Sciences. Wiley/Blackwell (10.1111); 2003. p. 374–6.
14. Hedblom M, Gunnarsson B, Schaefer M, Knez I, Thorsson P, Lundström JN. Sounds of Nature in the

City: No Evidence of Bird Song Improving Stress Recovery. Int J Environ Res Public Health. 2019;16(8):1390.
15. Medvedev O, Shepherd D, Hautus MJ. The restorative potential of soundscapes: A physiological investigation. Appl Acoust. 2015;96:20–6.
16. Hume K, Ahtamad M. Physiological responses to and subjective estimates of soundscape elements. Appl Acoust. 2013;74(2):275–81.
17. Hesketh T, Zhen Y, Lu L, Dong ZX, Jun YX, Xing ZW. Stress and psychosomatic symptoms in Chinese school children: cross-sectional survey. Arch Dis Child. 2010;95(2):136–40.
18. Evans GW, Lercher P, Meis M, Ising H, Kofler WW. Community noise exposure and stress in children. J Acoust Soc Am. 2001;109(3):1023–7.
19. Shu S, Ma H. The restorative environmental sounds perceived by children. J Environ Psychol. 2018;60(92):72–80.
20. Evans GW. Child Development and the Physical Environment. Annu Rev Psychol. 2006 Jan;57(1):423–51.
21. Shu S, Ma H. Restorative Effects of Classroom Soundscapes on Children's Cognitive Performance. Int J Environ Res Public Health. 2019;16(2):293.
22. Ma H, Shu S. An Experimental Study: The Restorative Effect of Soundscape Elements in a Simulated Open-Plan Office. Acta Acust united with Acust. 2018;104(1):106–15.
23. Krueger C, Tian L. A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points. Biol Res Nurs. 2004;6(2):151–7.
24. Rådsten Ekman M, Lundén P, Nilsson ME. Similarity and pleasantness assessments of water-fountain sounds recorded in urban public spaces. J Acoust Soc Am. 2015;138(5):3043–52.
25. Purcell T, Peron E, Berto R. Why Do Preferences Differ Between Scene Types? Environ Behav. 2001;33(1):93–106.