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Effects of Audio–Visual Interaction on Physio-Psychological Recovery of Older Adults in Residential Public Space

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Abstract: It is now well established that everyday interaction with nature has a restorative potential on the elderly population's health and well-being. However, empirical evidence on the restorative effects of neighborhood greenspace is still lacking, and scant attention has been given to the cross-effect of the visual–audio experience. The present study examined the restorative effects of audio–visual interactions on older adults in typical residential public spaces in Chinese cities. A pretest–post-test design was used to measure changes in participants' physiological responses, mood states, and mental restoration. Participants (mean age = 68.88 years) were asked to experience six simulated audio–visual conditions (3 scenes × 2 sounds) of residential public space. The results showed that: (1) A green scene combined with nature sounds showed the most restorative effect on the elderly participants' psycho-physiological health. (2) Viewing green scenes facilitated the most psycho-physiological recovery for the elderly, followed by viewing the activity scene. (3) Compared to the traffic noise, adding nature sounds could promote many more benefits in HR recovery, positive mood promotion, and perceived restorative effects, and the advantage of nature sounds over traffic noise was mainly demonstrated in the green scene. (4) Visual scenes demonstrated a greater impact on the elderly participants' psycho-physiological recovery than the sounds. Our findings suggested the necessity of providing residential nature and activity spaces, encompassing both sound and vision, to promote healthy aging in Chinese residential contexts.

Keywords: older adults; restorative environment; residential public space; physio-psychological recovery

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1. Introduction

The world is facing the severe challenge of an aging population. The population of people aged 60 years and older will rise to 2.1 billion by 2050, with 80% of the aging population living in developing countries [1]. In China, the proportion of citizens who are aged 60 or above is expected to increase beyond 30% by 2035. Furthermore, projected fertility rates and expected population age structures show that, in the decades to come, most older people in China will live in urban areas [2]. Meanwhile, urban aging populations have been widely shown to face serious physical and mental health problems, which pose greater challenges for themselves, their family, and the whole society [3]. The question of how to foster healthy aging has, therefore, attracted global attention. It is essential to consider the elderly population's well-being, including physiological and psychological health, in urban environmental design. In view of this, urban greenspace, which provides ideal nature-based open public spaces for recreational activities, is a critical environmental resource that benefits the health and well-being of elderly residents [4]. An increasing body of research has shown that urban residential greenspace can reduce stress-related depression symptoms [5,6], promote recovery of ischemic heart disease [7], reduce dementia risk [8], foster physical activities [9], and increase longevity of urban elderly dwellers [10].

The health benefits of greenspace have been proposed by diverse possible mechanisms, and one of the leading hypotheses is the theory of restoration, indicating the process of renewing, recovering, or re-establishing diminished physical, psychological, and social resources or capabilities in ongoing efforts to meet adaptive demands [11]. Research on the restorative environments has been guided by two main theoretical frameworks: Stress Recovery Theory (SRT) and Attention Restoration Theory (ART). SRT claims that restoration is derived from the release of stress and the reduction of negative moods through being exposed to restorative environments [12]. ART explains how natural environments capture involuntary attention and allow restoration of cognitive capacities [13]. Based on these theories, an increasing amount of research evidence has shown the restorative benefits of greenspace on older adults. One of the pilot studies was conducted by Berto, who recruited 50 older adults and asked them to rate the restorative value of 10 pictures of environments, ranging from natural to built, using the Perceived Restorativeness Scale [14]. Likewise, more research has been performed to examine the restorative benefits of nature on older adults based on their self-reported restorativeness [15–18].

Despite growing studies on the relationship between greenspace exposure and health, empirical evidence for restorative effects remains quite ambiguous. For instance, a field experiment performed in an elderly care institution in China showed that a five-minute VR forest experience can bring immediate psychological improvements, but was unable to significantly decrease blood pressure [19]. Similarly, a study was conducted with 34 middle-aged elderly adults, showing them VR experiences of natural and urban settings. The results showed significant restorative effects in mood levels rather than physiological responses [20]. On the contrary, a lab experiment used bamboo and urban images as stimuli to offer indirect contact with nature and found it enhanced both psychological and physiological conditions in the elderly [21]. Field experiments also showed a significant restorative effect of green walking on the psycho-physiological health of the elderly [22,23]. Taken together, the restorative effects of greenspace on the elderly population's psycho-physiological health have not been conclusively backed up by the existing empirical research. More evidence-based studies are still needed to confirm whether psychological and physiological restoration could be induced by greenspace exposure in older adults.

In addition, most existing studies linking greenspace and restoration focused on the comparison between natural and urban scenarios [20], and suggested the restorative benefits of urban natural environments [16]. However, the restorative designation of small greenspaces in urban residential contexts has yet to be fully examined. With rapid urbanization in China, elderly city dwellers generally live in high-density residential areas and have less opportunity to visit large nature parks due to their limited physical mobility, along with other barriers (e.g., low income). They usually spend a lot of time in peripheral small residential public spaces to rest, socialize, or exercise. An accessible natural environment within walking distance from home is more likely to be used daily. Given this, planning and design considerations for residential public spaces for the elderly require more attention because the location advantage makes it livable and accessible for its high-density aged population. Overall, there is a need to create residential greenspaces that could foster restorative experiences for older adults.

Moreover, extant studies are limited by solely validating and quantifying the restorative benefits of urban greenspace, and the mechanism of possible influential factors on the generation of restorativeness is still unclear. In recent years, much research recognized that restorativeness emerges from a diverse, complex, and integrated process of multi-sensory information about the environment, especially the visual and auditory sources [24]. To date, considerable research has focused on the restorative effects of visual elements, showing that more visible greenery is related to better restorativeness [25]. It is noteworthy that sight is not the only sense that affects the restorative response of humans, which can be partially or even largely attributed to the acoustic environment. The restorative effects of nature soundscapes have been validated from multiple perspectives. Generally, natural sounds (e.g., birdsong and water sounds) were found to be positively associated with psychological and physiological benefits, while urban sounds (e.g., traffic noise) were negatively associated with those benefits [26,27]. It is also important to bear in mind that visual landscapes and sounds never exist and work alone, and the interaction of audio–visual experiences is omnipresent in urban and nature environments [28]. Many studies have shown that sounds influence the evaluation of visual stimuli, and vice versa [29]. Moreover, their coherence has been exemplified to be associated with restorative benefits by some previous studies. For example, a study highlighted that landscapes containing natural water and high plant cover matched with birdsong can produce a higher restorative potential [30]. Another study indicated that naturally related visual and auditory stimuli can promote better restorative benefits than single visual stimuli [31]. Notwithstanding the restorative benefits reported elsewhere, the integration effect of visual and auditory stimuli on the elderly population's restoration has remained largely unexplored. This leads to a lack of clear theoretical guidance on how audio–visual design could be integrated into the restorative environment design practice for the elderly.

This study aimed to find reliable evidence to inform public space design of audio–visual combinations to improve the restorative quality of residential public space for older residents. To this end, a pre–post-test experimental design was employed to measure elderly participants' physio-psychological recovery and mental restoration after the reproduction of common audio–visual scenarios of residential public spaces in a laboratory setting. Specifically, this study aimed to address the following two main questions:

(1) Can residential public space foster psychological and physiological restoration for older adults?
(2) Which visual and acoustic factors could facilitate better restorative effects on older adults in residential public spaces?

2. Materials and Methods

2.1. Participants

A total of 62 older adults (42 males and 20 females) participated in the experiment. They were recruited via social networking platforms (e.g., WeChat) and snowball sampling in Qingdao, China. People who were at least 60 years old and living in an urban setting were eligible to participate. We opted to select mainly young older adults (aged from 60 to 80, with an average age of 68.88 $\pm$ 5.19) in good health, in order to avoid that cardiovascular diseases, cognition disorders, or specific visual and hearing problems might affect their psycho-physiological experience and a reliable evaluation of the environments. All participants were instructed to avoid consumption of alcohol and caffeine for at least 24 h before the experiment.

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Academic Committee of the College of Architecture and Urban Planning at Qingdao University of Technology. Before the experiment, the participants were informed about the study protocol and gave written informed consent to the researchers. All the elderly participants voluntarily participated in the study, and they were free to quit the experiment if they felt uncomfortable during the process.

2.2. Research Design

A pre–post-test experimental design was applied to investigate the restorative effects of audio–visual combinations on the psycho-physiological health of older adults in residential public spaces. Three typical visual scenes of residential public space (square scene, activity scene, and green scene) were separately combined with two sound types (traffic noise and nature sounds) to form six different audio–visual combinations: (1) square scene + traffic noise, (2) square scene + nature sound, (3) activity scene + traffic noise, (4) activity scene + nature sound, (5) green scene + traffic noise, and (6) green scene + nature sound (Figure 1). In addition, in order to control the experiment within an hour to avoid fatigue and impatience effects on health indices, as well as due to the limited available sample size, each participant experienced three or four audio–visual stimuli, which were randomly selected from the total six stimuli and presented in random order.

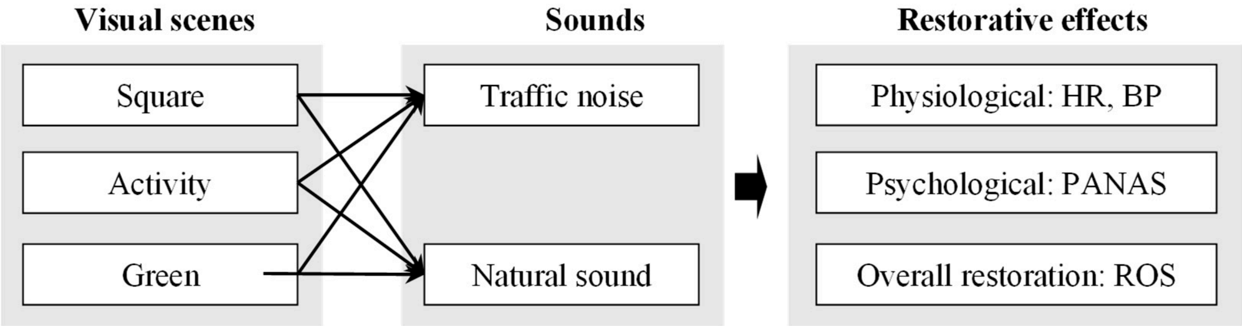


Figure 1. Diagram of the study design.

2.3. Environmental Setting

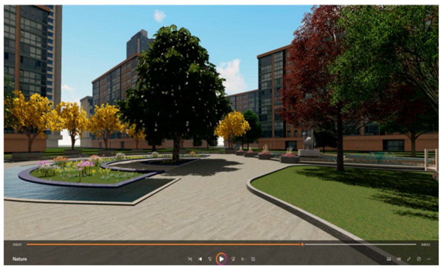
2.3.1. Visual Scenes

In this study, a typical high-density residential district in China was modeled in SketchUp 2018 to represent the outdoor contexts in residential areas. The central square, a 5000 m^2 public space surrounded by high-rise residential buildings, was selected as the original prototype of the experimental setting. It was used as the "square" without any additional restorative visual landscape.

To test participants' responses in public spaces with different visual characteristics, we categorized visual elements into two types, "activity scene" and "green scene", mainly because we considered two types of visual elements that have shown restorative potential: well-designed man-made features and natural green elements. Specifically, the activity scene incorporated fitness facilities, pavilions, and seats, which are expected to promote the intentions of physical exercise and social interaction and further foster the restorative experience. The green scene incorporated large areas of lawn, various tree species, as well as waterscapes (fountain and ponds). It was designed to foster mental health for older adults. It is important to note that the presence of people was excluded in all environments since it was indicated to have different impacts on the restorative experience of different scenarios [15,32]. We also maintained the same size and a similar layout for the three scenes to maximize the comparability. Except for the restorative design interventions, all three scenes were identical in terms of all other elements.

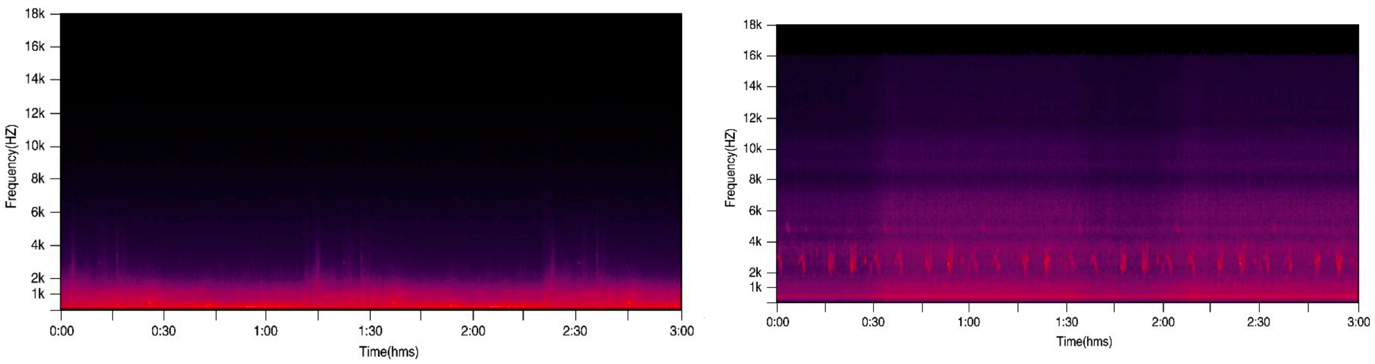
Regarding the visual scenes, SketchUp software was first used to establish the three-dimensional geometric model, and Lumion 10.0 software was then used to render the videos for screen representation. Video is a valid display medium that older adults are familiar with and it could provide an immersive experience of the scene without dizziness or fear issues that could possibly affect the elderly participants' psycho-physiological fluctuations [33]. Specifically, the video was recorded to simulate walking around the public space, and the walking routes were identical in the three visual scenes for comparability. The visual point of the video was at a height of 1.6 m to simulate the view of participants when they were walking around. The duration of each video was set at 6 min, which was thought to be enough to foster restorative benefits in a laboratory simulation [34]. The videos were rendered at a 4 K resolution at 30 frames per second (fps) and presented on a 27-inch LCD monitor with a 3840 × 2160 pixel resolution and a 60 Hz refresh rate. The aerial views and screenshots of each visual scene are shown in Table 1.

Table 1. Aerial views and screenshots of the visual scenes and corresponding detailed descriptions.

Visual Features	Aerial View	Screenshots of the Video
Square scene Large square surrounded by lawns		
Activity scene Adding walking trails, fitness equipment, and amenities, seats, and pavilions		
Natural scene Adding more grasslands, colorful flowers, various plant species, and waterscapes		

2.3.2. Sounds

In this study, two types of sounds were considered: traffic noise and natural sounds. Since road traffic is one of the major sources of noise pollution in urban residential areas, it was designated as the non-restorative sound. On the contrary, nature sounds were widely acknowledged to have restorative effects in previous studies; thus, it was designated as the restorative sound. The traffic noise was downloaded from open sources on the Internet, and predominantly contained low-frequency components below 2.0 kHz, as shown in Figure 2a. The nature sounds were recorded in a typical urban park in Qingdao using a Sony PCM-100 digital recorder equipped with two stereo microphones, and featured birdsong and flowing water sounds. Figure 2b shows that the nature sounds were dominated by mid- to high-frequency components from 500 Hz to 8 kHz. In terms of temporal characteristics, the traffic noise was constant with low temporal variability, whereas the nature sounds were intermittent with high temporal variability. All the acoustic stimuli were stored in uncompressed wave digital format and converted into the same sample rate and size of 44.1 kHz, 16 bit. In addition, the sound pressure levels were all normalized to 55 dBA for two reasons: (1) the upper limit of the environmental sound level in residential areas is 55 dBA according to the sound quality standard in China, and (2) people can hear the acoustic stimuli clearly but do not feel annoyed at this sound level, as indicated by previous studies [27]. The calibration was conducted using a AWA6270+ sound level meter coupled to a Beyerdynamic DT 900 Pro headphone, which was driven by a soundcard (YAMAHA Steinberg UR242, Steinberg Media Technologies GmbH, Hamburg, Germany). Besides, the duration of the acoustic stimuli was set at 6 min to match with the visual stimuli. All the editing and calibration of the acoustic stimuli were performed using the Adobe Audition software (version 2022). The acoustic stimuli were played back to the participants via the same Beyerdynamic DT 900 Pro headphones.



(**a**) (**b**)

Figure 2. Spectrogram of the acoustic stimuli: (**a**) traffic noise and (**b**) nature sounds, including birdsong and water sounds.

2.4. Measures

2.4.1. Physiological Measurements

To measure older adults' physiological recovery, two simple measures were applied: mean arterial pressure (MAP) and heart rate (HR). These indices are commonly suggested as sensitive indicators for stress recovery in restorative environment research, and they are widely used to assess cardiovascular effects in older adults [23]. Notably, the MAP was calculated based on systolic blood pressure (SBP) and diastolic blood pressure (DBP), as: $((DBP \times 2) + SBP)/3$. During the experiment, SBP, DBP, and HR were measured using a portable cuff-based electronic sphygmomanometer (HEM-7137, Omron, Tokyo, Japan). Measurements were performed in a relaxed sitting position with the instrument placed on the right arm at the heart level. Any tight-fitting or thick clothing was removed from the arm before measurement. Two measurements were conducted with a 20 s interval. In the analysis, the average of the two measurements was used. Since every individual has a unique MAP and HR baseline, all the measured data after the audio–visual exposure were further calculated as a percentage change (%) from the stress period to accommodate individual differences.

2.4.2. Psychological Measurements

The Positive and Negative Affect Scale (PANAS) was employed to measure the emotional outcomes in this study [35]. The original PANAS consists of 20 items and is widely used to evaluate changes in positive and negative emotions [36,37]. We finally extracted 6 items from the original PANAS since they are easily understood by the older adults and highly matched to the experience in public space, as indicated in a preliminary experiment. Therefore, the shortened version of the scale consisted of six items divided into two subscales: the positive mood state was calculated from three items (i.e., interested, excited, or attentive), and the negative mood state was calculated from three items (i.e., nervous, upset, or irritable). The order of these items was randomized to avoid an order effect. Participants were asked to indicate the extent to which they felt a series of different emotions "at the present moment" on a 5-point Likert scale (1 = not at all; 5 = extremely).

2.4.3. Mental Restoration

In this study, participants' overall mental restoration was measured using the Restoration Outcome Scale (ROS) [38]. The ROS scale consisted of six items, three of which reflect relaxation and calmness ("I feel restored and relaxed", "I feel calm", and "I have enthusiasm and energy for my everyday routines"), one reflects attention restoration ("I feel focused and alert"), and two reflect clearing one's thoughts ("I can forget everyday worries" and "My thoughts are clear"). Each item was assessed on a 5-point scale (1 = not at all; 5 = extremely). The scale has been widely used in previous studies and confirmed with high reliability and validity [39].

2.5. Procedure

The experiments were conducted in a quiet laboratory from October to December 2022. The background noise in the laboratory was measured as below 35 dB(A) with no distinguished background noise, and the indoor temperature was kept between 18 and 22 °C. Each participant took part in the experiment individually, supervised by a staff member.

After arrival at the laboratory, participants were guided to sit in a comfortable chair and the experimental procedure was explained. The first physiological measure was conducted after sitting quietly for 3 min without any intervention, as the baseline level, which was used to ensure no differences across audio–visual groups. For each audio–visual stimulus, there were two periods: (1) A 3 min stressor period, during which participants were asked to accurately perform continuous oral subtraction from a number with a step of 7 (or 13), as soon as possible. The arithmetic task could effectively induce stress and fatigue, as indicated in previous studies [27,40]. (2) A 6 min recovery period with exposure to one audio–visual condition. Physiological measurements (MAP and HR) and psychological questionnaires (PANAS) were completed immediately at the end of each period. Thereafter, the participants were asked to fill out the restoration scale (ROS) based on their experience of the video. The same process was repeated for the next stimulus, as shown in Figure 3.

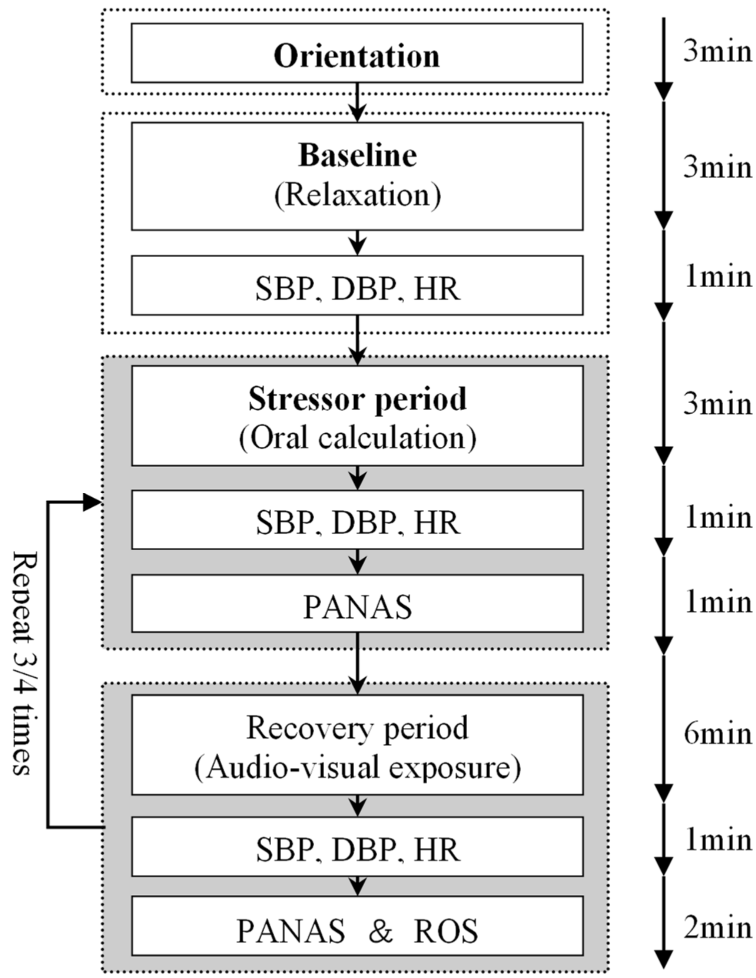


Figure 3. Diagram of the experimental procedure.

2.6. Statistical Analysis

All the data analyses were performed using SPSS software (version 26). Non-parametric tests were chosen for the raw data analysis due to the non-normality, as examined by a

Kolmogorov–Smirnov test. First, the individual differences across audio–visual conditions were checked using a non-parametric Kruskal–Willis test (scale variables) and chi-square test (nominal variables). Then, the Wilcoxon signed-rank test was conducted to examine the effectiveness of the stress induction. Both of the above steps were the prerequisites to allow testing psycho-physiological recovery differences. Additionally, to verify the restorative effects of the audio–visual conditions on the physio-psychological data, pretest values and post-test values were compared for each audio–visual condition using the Wilcoxon signed-rank test.

To determine whether the audio–visual conditions were different in psycho-physiolo gical recovery, the recovery (i.e., increase or decrease) of the measures was considered, which was calculated as the relative difference: (post-test value − pretest value)/pretest value × 100%. Due to the normality of the recovery values, analysis of variance (ANOVA) tests were performed, with visual stimuli (square, activity, and green) and acoustic stimuli (traffic noise and nature sounds) considered as the between-subjects factors. In all ANOVA tests, the least significant difference (LSD) post-hoc tests were conducted for pairwise comparisons. Additionally, partial eta-squared values ($\eta^2{}_p$) were determined to measure the effect size. In all analyses, a p-value less than 0.05 was used as the criterion to determine significant differences.

3. Results

3.1. Descriptive Data

In this study, 62 older adults were randomly assigned to 3 (or 4) of the 6 audio–visual conditions. Table 2 shows the demographics and baseline characteristics of the elderly participants in different conditions. No significant difference was found in any of the psycho-physiological measures among the six audio–visual groups.

Table 2. Comparison of sample characteristics among the audio–visual conditions (N = 62).

	Square		Activity Park		Green Park		
	Traffic (N = 37)	**Nature (N = 33)**	**Traffic (N = 33)**	**Nature (N = 33)**	**Traffic (N = 31)**	**Nature (N = 39)**	***p***
Gender (N; % Male)	22; 59.5%	26; 78.8%	25; 75.8%	21; 63.6%	24; 77.4%	24; 61.5%	0.284
Age (years)	68.16 ± 4.54	68.30 ± 5.15	68.79 ± 5.33	69.76 ± 6.02	68.68 ± 5.24	69.56 ± 5.02	0.792
Baseline value							
MAP (mm Hg)	92.09 ± 8.07	98.16 ± 12.77	99.01 ± 12.62	95.74 ± 12.85	98.08 ± 12.92	93.68 ± 8.65	0.074
HR (bpm)	75.30 ± 7.91	73.58 ± 10.07	74.30 ± 10.81	74.03 ± 8.21	74.58 ± 10.22	75.59 ± 7.71	0.879
PA (0–15)	9.22 ± 1.46	10.00 ± 2.10	10.12 ± 2.22	9.88 ± 1.91	10.26 ± 2.14	9.54 ± 1.64	0.527
NA (0–15)	3.46 ± 0.77	3.36 ± 0.60	3.27 ± 0.57	3.36 ± 0.74	3.29 ± 0.53	3.49 ± 0.76	0.748

MAP = mean arterial pressure, HR = heart rate, PA = positive affect, and NA = negative affect.

Regarding the effect of the stress induction, significant changes from baseline to the pretest were detected for MAP (mean = 3.49%, 95% CI = 2.90–4.08, increase), HR (mean = 1.60%, 95% CI = 1.18–2.03, increase), PA (mean = 25.65%, 95% CI = 19.75–31.55, decrease), and NA (mean = 25.05%, 95% CI = 21.94–28.16, increase). The results proved that the oral calculation could effectively induce elderly participants' stress levels in terms of psychological and physiological measures.

Table 3 shows the descriptive statistics, mean values with standard deviations (SD), of the psycho-physiological measures during the pretest and post-test for each audio–visual condition. The Wilcoxon signed-rank test showed that participants' MAP, HR, and PA strongly recovered after exposure to both the activity scenes and green scenes. Although a tendency of recovery was also indicated in the square scenario, the changes were rarely significant. Notably, older adults' negative mood significantly decreased in the post-test compared to the pretest in all conditions, no matter what audio–visual stimuli the participants were exposed to (Figure 4).

Table 3. Descriptive statistics of psycho-physiological measurements in the pretest and post-test for each visual and sound combination.

Visual	Square		Activity		Green	
Sound	Traffic	Nature	Traffic	Nature	Traffic	Nature
MAP (mm Hg)						
Pretest	95.55 ± 8.31	101.20 ± 11.16	103.71 ± 13.04	97.92 ± 12.76	100.78 ± 14.94	97.62 ± 8.87
Post-test	95.10 ± 7.04	99.78 ± 10.22	101.38 ± 10.91	95.35 ± 10.21	96.81 ± 13.13	93.20 ± 8.73
p	0.081	0.017 *	0.000 **	0.000 **	0.000 **	0.000 **
HR (bpm)						
Pretest	77.86 ± 8.35	75.79 ± 10.56	75.55 ± 11.28	75.48 ± 8.83	75.97 ± 11.13	78.38 ± 8.10
Post-test	77.46 ± 8.19	74.61 ± 10.97	74.64 ± 10.66	74.33 ± 8.73	74.87 ± 10.39	75.62 ± 7.81
p	0.158	0.077	0.058	0.027 *	0.009 **	0.000 **
PA						
Pretest	8.00 ± 1.68	8.91 ± 2.48	8.73 ± 2.45	8.70 ± 2.04	8.71 ± 2.38	8.44 ± 1.87
Post-test	6.92 ± 2.95	9.36 ± 2.69	10.39 ± 2.51	11.48 ± 2.49	11.00 ± 2.88	13.23 ± 1.87
p	0.057	0.116	0.000 **	0.000 **	0.000 **	0.000 **
NA						
Pretest	5.19 ± 1.35	4.06 ± 1.17	4.36 ± 1.22	4.67 ± 1.19	4.13 ± 1.18	5.33 ± 1.44
Post-test	3.92 ± 0.76	3.15 ± 0.44	3.09 ± 0.38	3.12 ± 0.70	3.03 ± 0.18	3.21 ± 0.89
p	0.000 **	0.000 **	0.000 **	0.000 **	0.000 **	0.000 **
ROS	2.48 ± 0.77	3.45 ± 0.94	3.69 ± 0.79	3.62 ± 0.82	3.87 ± 0.89	4.23 ± 0.71

* $p < 0.05$; ** $p < 0.01$ (2-tailed). MAP = mean arterial pressure, HR = heart rate, PA = positive affect, NA = negative affect, and ROS = Restorative Outcome Scale.

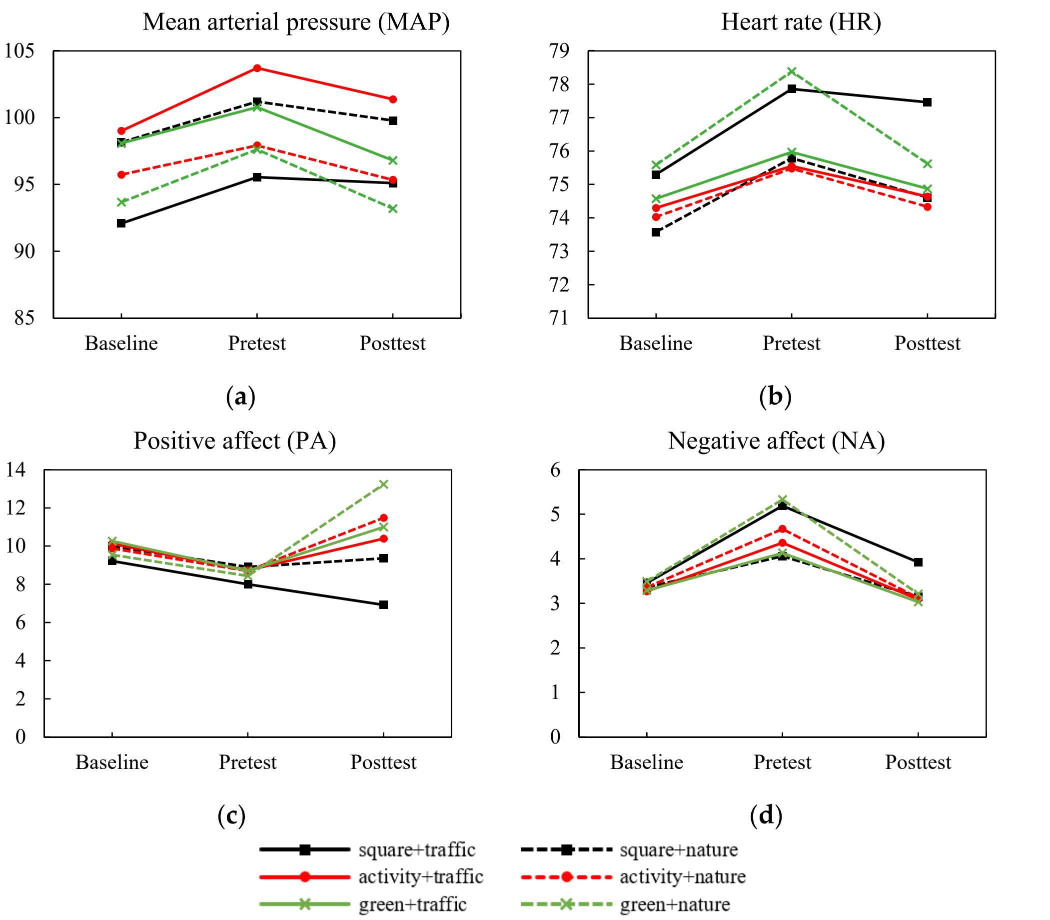


Figure 4. Average physiological and psychological outcomes at baseline, pretest (after stressor), and post-test (after recovery) among different audio–visual conditions: (**a**) mean arterial pressure, MAP; (**b**) heart rate, HR; (**c**) positive affect, PA; (**d**) negative affect, NA.

3.2. Differences between Audio–Visual Conditions in the Recovery

Table 4 provides an overview of the tested differences in recovery values between visual scenes, sounds, and audio–visual combinations, with the effect sizes indicated by (η^2_p). Overall, visual scenes showed a significant influence on the recovery of all psycho-physiological measures, while acoustic conditions only showed a significant influence on the recovery of HR, PM, and overall POS. Meanwhile, interactions between audio and visual stimuli were only detected in the POS. Detailed multiple comparison results for the recovery outcomes between different visual and audio conditions are presented in the following.

Table 4. Summary of ANOVA results for psycho-physiological recovery.

	Visual			Audio			Audio * Visual		
	F	p	η^2_p	F	p	η^2_p	F	p	η^2_p
ΔMAP	16.39	0.000 **	0.141	2.27	0.134	0.011	0.12	0.888	0.001
ΔHR	4.16	0.017 *	0.040	8.53	0.004 **	0.041	1.66	0.194	0.016
ΔPA	32.81	0.000 **	0.247	17.54	0.000 **	0.081	2.37	0.096	0.023
ΔNA	3.55	0.031 *	0.034	2.31	0.130	0.011	2.70	0.070	0.026
ROS	30.81	0.000 **	0.236	13.63	0.000 **	0.064	6.91	0.001 **	0.065

* $p < 0.05$; ** $p < 0.01$ (2-tailed). Δ = Recovery values; η^2_p = partial eta-squared (effect size). MAP = mean arterial pressure, HR = heart rate, PA = positive affect, NA = negative affect, and ROS = Restorative Outcome Scale.

3.2.1. Physiological Recovery

The ANOVA results on MAP change values showed a main effect of visual scenes ($p < 0.001$, $\eta^2_p = 0.141$), but no significant effect of acoustic stimuli ($p > 0.05$, $\eta^2_p = 0.011$). Additionally, no significant interaction between visual and acoustic stimuli was found ($p > 0.05$, $\eta^2_p = 0.001$). As shown in Figure 5a, the green scene facilitated a higher MAP decrease compared to the activity and square scenes despite the acoustic conditions. Nevertheless, slight differences in MAP recovery between sounds were indicated in all the scenes, i.e., the nature sound tended to decrease MAP more than the traffic noise, although not on a statistically significant level ($p > 0.05$).

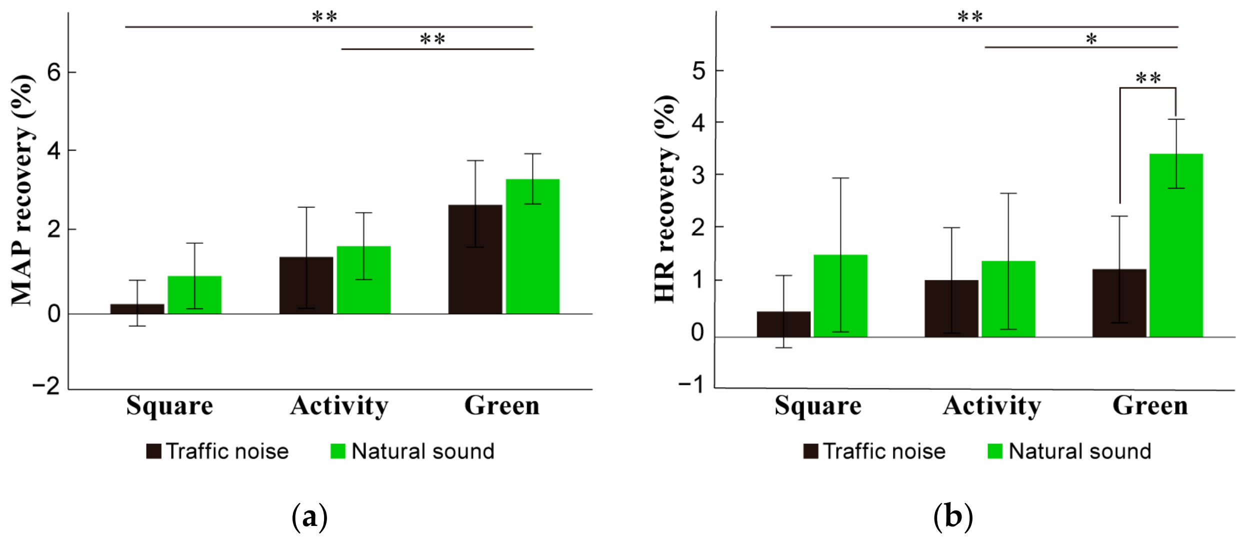


Figure 5. Comparison of physiological recovery in different audio–visual conditions: (**a**) MAP recovery and (**b**) HR recovery. * $p < 0.05$; ** $p < 0.01$ (2-tailed).

Regarding HR recovery, ANOVA results showed main effects of both the visual condition ($p < 0.05$, $\eta^2_p = 0.040$) and the acoustic condition ($p < 0.01$, $\eta^2_p = 0.041$). The effect size showed that visual scenes and sounds had a similar influence on the elderly participants' HR recovery. However, no significant acoustic and visual interaction was detected ($p > 0.05$, $\eta^2_p = 0.016$). Further multiple comparisons showed that the green scene facilitated a higher HR reduction than the activity and square scenes. As for the acoustic stimuli, nature sounds facilitated a higher HR reduction than traffic noise, and the advantage of the nature sounds was much more evident in the green scene ($p < 0.001$), as shown in Figure 5b.

3.2.2. Psychological Recovery

The ANOVA tests on positive mood promotion showed significant effects of both the visual scene ($p < 0.001$, $\eta^2_p = 0.247$) and sound ($p < 0.05$, $\eta^2_p = 0.034$), but no audio–visual interaction was detected ($p > 0.05$, $\eta^2_p = 0.023$). In particular, the effect size of the visual scene was quite large, while the effect size of the acoustic condition was moderate, indicating a higher impact of visual scenes than sounds on the positive mood promotion. As shown in Figure 6a, the green scene showed the best restorative effect on positive mood, followed by the activity scene, while the square scene exposure showed a detrimental effect. As for the acoustic condition, nature sounds showed more restorative effects compared to the traffic noise in all visual scenes. However, the difference between sounds was not significant in the activity scene.

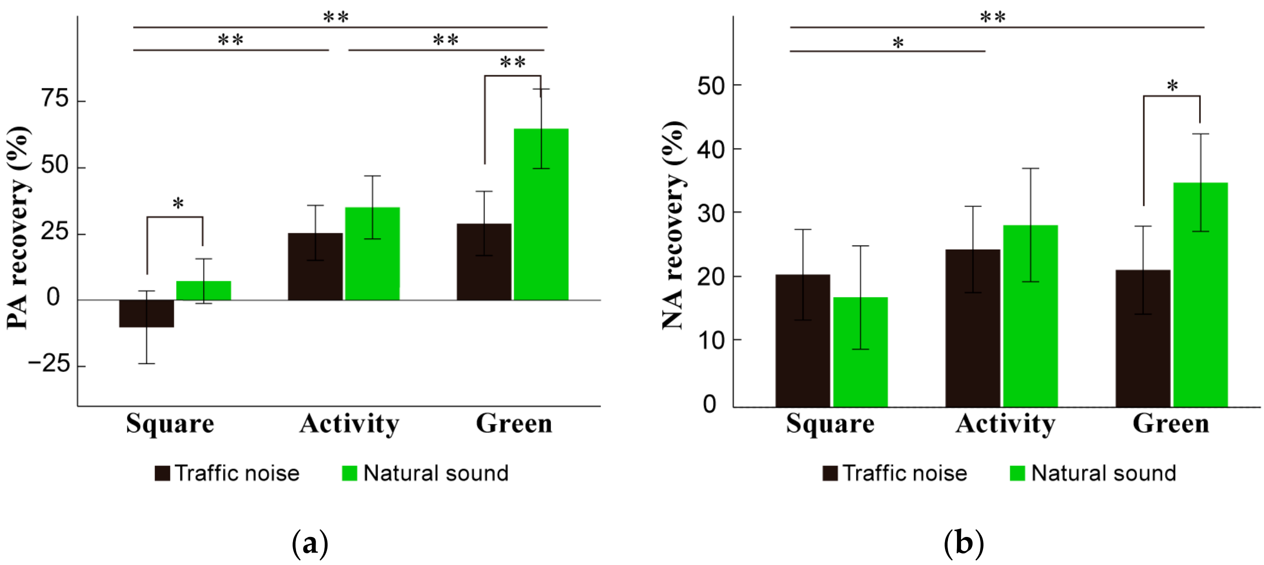


Figure 6. Comparison of psychological recovery in different audio–visual conditions: (**a**) positive mood recovery and (**b**) negative mood recovery. * $p < 0.05$; ** $p < 0.01$ (2-tailed).

The ANOVA tests on negative mood recovery showed only a main effect of the visual scene ($p < 0.001$, $\eta^2_p = 0.081$). Compared to the square scene, both the activity and green scenes generated a higher NA decrease. However, no significant effect of the acoustic condition ($p > 0.05$, $\eta^2_p = 0.011$) was identified in terms of NA recovery, nor was an audio–visual interaction revealed ($p > 0.05$, $\eta^2_p = 0.070$). Nevertheless, nature sounds showed a better restorative effect on negative mood than traffic noise in the green scene ($p < 0.01$), although no significant differences between sounds were detected in the square and activity scenes ($p > 0.05$), as shown in Figure 6b.

3.3. Overall Perceived Restorativeness

The overall restorativeness was assessed using the Restorative Outcome Scale (ROS), and the results showed main effects of the visual scene ($p < 0.001$, $\eta^2_p = 0.236$), acoustic condition ($p < 0.001$, $\eta^2_p = 0.064$), as well as audio–visual interactions ($p < 0.001$, $\eta^2_p = 0.065$). Notably, the effect size of the visual scene was much larger than that of the sounds. The green scene was perceived as the most restorative scene, followed by the activity scene. As for the audio–visual interaction, Figure 7 shows a comparison of the acoustic performance on the perceived restorativeness under each visual scene. A significant difference between sounds was detected in the square scene, and nature sounds were rated to be more restorative than traffic sounds ($p < 0.001$). However, no significant difference between acoustic stimuli was found in either the activity ($p > 0.05$) or green scenes ($p > 0.05$).

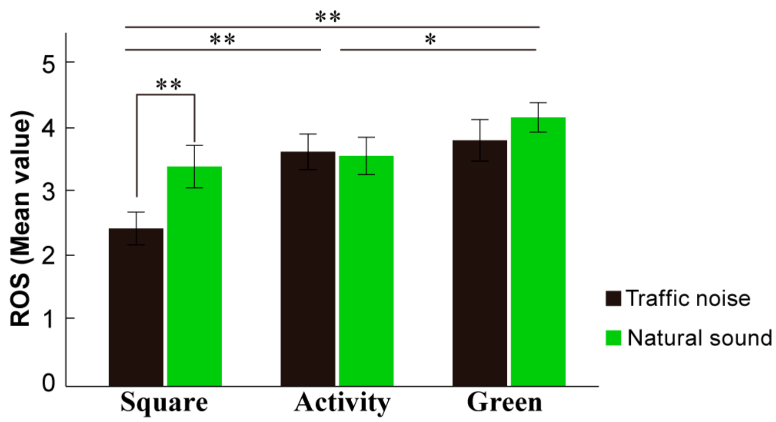


Figure 7. Perceived restorativeness of different audio–visual conditions. * $p < 0.05$; ** $p < 0.01$ (2-tailed).

Spearman's correlation analysis showed that older adults' overall perceived restorativeness had a strong positive correlation with MAP ($r = 0.261$, $p < 0.001$) and PA ($r = 0.311$, $p < 0.001$), as well as HR ($r = 0.175$, $p < 0.05$). However, there was no strong relationship between perceived restorativeness and NA ($r = -0.039$, $p > 0.05$). Moreover, the psychological recovery indicators were also significantly correlated with the physiological recovery indicators, except MAP and NA ($r = 0.127$, $p > 0.05$) (Table 5).

Table 5. Spearman's relationships between psycho-physiological recovery and perceived restorativeness.

	MAP	HR	PA	NA
MAP				
HR	0.210 *			
PA	0.284 **	0.186 **		
NA	0.224 *	0.242 **	0.370 **	
ROS	0.243 **	0.175 *	0.311 **	−0.039

* $p < 0.05$; ** $p < 0.01$ (2-tailed). MAP = mean arterial pressure, HR = heart rate, PA = positive affect, NA = negative affect, and ROS = Restorative Outcome Scale.

4. Discussion

In this study, a laboratory experiment was conducted to examine the effects of audio–visual scenarios on psycho-physiological recovery of older adults in high-density residential public space. Here, we first assess how our findings address our key research questions. We then discuss the implications for planning and design. Finally, we consider the limitations of our study and directions for future research.

4.1. Benefits of Residential Public Space on Older Adults' Restoration

The first aim of this study was to confirm whether older adults could recover from a state of stress and fatigue after exposure to a scenario of residential public space. The results of the physiological measures were largely in line with our expectations, indicating that a brief exposure period to the green scenario in residential environments could induce significant positive changes in blood pressure and heart rate in older adults. This finding was also consistent with previous studies suggesting that built-up urban environments with greenery views have positive effects on physiological stress [36]. In addition, we could observe from Figure 4 that the mean values of physiological indicators of post-recovery stress levels went back to, or even lower than, their baseline measures for those elderly participants in the activity and green scenes, indicating complete recovery. Overall, however, the present findings in relation to MAP and HR are consistent with SRT, which suggests that natural landscapes produce immediate affective responses, and that natural views are effective for recovery from stress [41].

Additionally, it is important to note that there was a tendency for significant MAP and HR recovery in the activity scene, indicating that adding activity-based elements could effectively promote the physiological restoration of the residential public space. The restorative effects induced by the activity scene on the blood pressure and heart rate seemed to confirm the outcomes of a previous study, suggesting that well-designed residential environments incorporating fitness facilities and furniture could be perceived by older people as a potential physical activity possibility and, consequently, generate a restorative experience [42].

Results from the positive mood evaluations were similar to the physiological outcomes in that both the green and activity scenes could significantly promote the elderly participants' positive mood, but not the square scene. All the results confirmed that green-based and activity-based public spaces in residential areas could provide restorative effects for older adults. However, it is interesting to note that the negative mood significantly recovered after all experimental conditions, no matter what audio–visual stimuli the participants were exposed to. One possible reason is that the elderly participants in our study generally displayed a low level of negative mood, even after the stress induction, as shown in Table 3. Older people with high levels of negative mood (e.g., anxiety and depression) should be further studied in future research.

4.2. Different Restorative Effects among Audio–Visual Conditions

The results from the overall restorative perceptions answered the second research question, indicating that the green scene was perceived as more restorative than other scenes in residential public space. Along the same line, older adults experienced a larger restorative benefit from nature sounds compared to traffic noise. The subjective evaluation outcome was also strongly backed up by physio-psychological evidence, including blood pressure, heart rate, and positive mood.

As for the visual scene, we found that the activity scene was perceived as much more restorative than the square scene by the elderly participants. This result is consistent with a previous study, which suggested that older people preferred colorful parks to squares [43]. However, the actual restorative advantage of the activity scene over the square scene was only identified in terms of the mood recovery, rather than the physiological recovery. It is possible that the activity scene was generally characterized as positive valence but high arousal (e.g., exciting) in the view of older adults. Therefore, although exposure to the activity scene could effectively promote psychological recovery, the physiological measures were still on a rather high level.

Regarding the effects of acoustic stimuli, the restorative advantage of nature sounds over traffic noise was mainly demonstrated in the HR and PA recovery, indicating that natural sounds, including birdsong and water sounds, can effectively reduce autonomic nervous system activation and promote positive mood after acute stress. This conclusion is reinforced by many previous studies, which identified significantly greater HR recovery when participants were exposed to natural sounds rather than urban noise [44,45]. However, the effect sizes of the sounds were generally small ($\eta^2{}_p < 0.01$), indicating that the effect of sounds on the elderly participants' restorative experience was less strong than the visual scenes. This was different from a prior study, which found that elderly participants assigned more importance to the acoustic characteristics of scenarios than the visual elements [43]. A possible reason is that traffic noise is ubiquitous in high-rise residential areas, and the elderly are quite accustomed to the presence of traffic noise in such residential contexts. Therefore, instead of regarding the traffic sounds as environmental noise, participants rather took them as normal environmental sounds in urban residential contexts, which was quite familiar and relaxing for the elderly, although it was subjectively evaluated to be much less restorative than the natural sounds. Consistent with this interpretation, Alvarsson et al. also noted that the differences between nature sounds (50 dBA) and low traffic noise (50 dBA) did not reach significance in the recovery of SCL [26]. In addition, it is also possible that visual stimuli (composed of trees, plants, water, sky, pavilion, etc.) are more complex than auditory stimuli (only implying a category, i.e., traffic noise, birdsong, and water sounds). Thus, participants may have simply spent more time on visual than acoustic information.

Despite this, it is interesting to note that significantly more recovery was identified in the exposure to nature sounds compared to traffic noise in the green scene. However, the advantage of nature sounds was not pronounced in the activity scene. This might be explained in terms of the congruence between the sound and the visual context [46]. In the activity scene, participants felt confused about the experience when they heard a loud birdsong and water sounds, which indicated trees or a water body were somewhere nearby but they were unable to see them in the video. Alternatively, the nature sounds matched the green scenes with green plants and waterscapes. Human sounds, such as talking, laughing, and children playing, were more common in such an activity context, as reported by some participants after the experiments. This finding supported prior research, which reported that the audio–visual coherence indeed plays an important role in restorative perceptions [47].

4.3. Implications for Planning and Design

The findings of this study could have implications for enhancing visual and acoustic design in urban residential areas. First, from the view of psycho-physiological restoration for older adults, green parks should be a priority in the planning of residential public spaces, and where this is not possible, activity parks might represent a viable alternative since they could effectively promote older adults' mood states [43]. However, the existence of a green park or activity park itself may not necessarily be a factor guaranteeing a positive effect on the quality of life. Residents' well-being and soundscape should be taken into account in pre-design as well as re-design of urban parks [48], such as involving the user's experience in co-design processes [49], improving sound environment quality through spatial planning and landscape management [50]. Particularly, congruence between visual scenes and acoustic design should be taken into account. In the case of green parks, nature-based sounds play an important role in enhancing the restorative experience. Thus, residential design should increase and enrich plants to attract birds and insects to live. Meanwhile, moving waterscapes should be considered in the residential landscape design to create water sounds, and they could be artificial (e.g., fountains) or natural (e.g., streams) [51]. Moreover, to improve restorative quality in residential public spaces, acoustic strategies should include not only the addition of nature sounds but also the control of traffic noise. In this study, traffic noise with a sound level of 55 dBA had detrimental effects on older adults' positive mood. Therefore, traffic noise in residential public spaces should be strictly limited by planning methods, such as increasing buffer distances or vegetation barriers [52].

4.4. Limitations and Future Research

This study was innovative in examining the restorative effect of residential public spaces on the elderly participants' health. Herein, a differentiation was made in audio versus visual effects, and in physio-psychological and self-reported outcomes. Potential limitations of this study are related to the participants and the experiment setting. As for the participants, only elderly persons in a good state of health and abilities were sampled in the current study. Previous research has shown that healthier older people are more likely to perform physical activities [9]. People with disabilities might be in greater need than their able counterparts for the health benefits from green environments. Besides, their unique embodied biographies (e.g., gender, educational level, pre-retirement occupation, income, and cultural background) were not assessed, which could strongly influence elderly individuals' relationships with potentially restorative environments [5]. It is, therefore, important to consider these factors in future studies to promote the generalization of the results to the entire older population. As for the experiment setting, only a few typical audio–visual stimuli were presented due to the limitation of experiment time. Future studies should consider other environmental factors that might influence human–environment interactions, including common sounds in residential areas (human voices, mechanical noise, etc.) and other visual elements (presence of people, cultural landscape, etc.). Additionally, only limited psycho-physiological measures and short-term effects were explored in this study. To obtain a more complete picture of the restorative effects of residential parks on individuals, more objective measures, such as performing cognitive tasks and long-term effects, should be considered in future studies. Despite these limitations, the results from this study provided more evidence for the actual restorative effects of residential environments as well as extended the understanding of restorative environments to older adults.

5. Conclusions

In a simulated situation of residential public space, six (three visual $\times$ two audio) scenarios were presented to the elderly participants to examine the restorative effects of audio–visual public space on the elderly population's psycho-physiological health. Based on the elderly participants' MAP and HR responses, as well as emotional ratings and perceived restorativeness, the following conclusions could be drawn:

(1) Viewing green scenes in residential public spaces facilitated the most psycho-physiolo gical recovery for the elderly, followed by viewing the activity scenes, while the square scene only showed restorative benefits on the elderly participants' negative mood.
(2) Compared to the traffic noise, adding nature sounds in residential public spaces could promote many more benefits in HR recovery, positive mood promotion, and perceived restorativeness.
(3) The advantage of nature sounds over traffic noise was mainly demonstrated in the green scene, indicating the importance of the audio–visual congruence in residential design.
(4) Visual elements demonstrated a greater impact on the elderly participants' psycho-physiological recovery than the acoustic elements in residential contexts.

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