DOI: 10.61782/fa.2023.0133

EFFECTS OF AUDIO-VISUAL INTERACTION ON URBAN COURTYARD PERCEPTION

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ABSTRACT

This study aims to examine the effects of natural sounds, such as water sound and birdsong, on the perception of urban courtyards with and without the presence of sounds. A virtual reality (VR) environment was created by using three-dimensional (3D) models of small and large courtyards with different height-to-width ratios (i.e. 0.3 and 1) and different scenarios, such as empty courtyards and courtyards with natural features. A laboratory experiment was conducted in VR environments with normal-hearing participants. The experiments consisted of three sessions: 1) audio-only 2) audio-visual, and 3) visual-only. Participants rated their subjective responses to stimuli in terms of perceived pleasantness, perceived enclosure, and perceived spaciousness. Additionally, the participant's physiological responses were monitored in terms of facial electromyography (fEMG) and heart rate (HR) throughout the experiment. Findings showed that the perception of enclosure was reduced in audio-visual sessions for both small and large courtyards while natural features were added. The fEMG activity in the zygomaticus major (ZM) increased, whereas fEMG activity in the corrugator supercilii (CS) decreased by adding natural features.

Keywords: *urban courtyards; height-to-width ratio; audio-visual interaction; virtual reality, natural sounds*

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1. INTRODUCTION

Urban courtyards, street canyons, and all architectural spaces surrounded by walls or other artificial and natural elements like trees are specified as enclosures [1]. Street canyons have been examined regarding the environmental and acoustical features (e.g., natural light, air quality, thermal comfort, absorption, and diffusion of the street boundaries) [2-5]. Additionally, street canyons and courtyards with different types of boundaries and variable boundary heights have been investigated in terms of the recognition of enclosure with evolutionary and theoretical explanations [6-8].

Designing urban environments and incorporating vegetation can significantly influence how humans perceive their surroundings. Previous studies have shown that sound environments, such as traffic noise in street canyons with different height-to-width ratios (H/Ws), have a significant impact on the perceptions of enclosures [6]. Another study examined the effect of different landscape designs, such as vegetation, wood decking, and garden furniture on the soundscape [12]. Natural sounds like water and bird songs have been found to positively affect the perception of enclosure and improve the quality of urban soundscapes in terms of noise masking [9-11]. However, no research has been conducted on the effects of natural sounds on perception of urban courtyards.

The perception of enclosure with different settings such as H/W and design of the urban environments can be evaluated by using virtual reality (VR) technology, which offers simulations with realistic perceptions [6, 13]. In addition, physiological measurements such as facial electromyography (fEMG) and heart rate (HR) have been widely used in acoustic research areas as they are useful in analyzing people's reactions to different stimuli in urban environments [17-19].

This study aims to investigate the influence of natural sounds (i.e. water sound and birdsong) on the perception of enclosure in urban courtyards with varying H/Ws. A laboratory experiment was conducted in virtual reality (VR) environments with normal-hearing participants. Participants were asked to rate their subjective responses to stimuli in terms of the perception of enclosure, spaciousness, and pleasantness. Urban courtyards with different designs were presented with and without the presence of sounds. Additionally, the participant's physiological responses were monitored during the experiment in terms of fEMG and HR to evaluate sensations and emotional reactions. This study could provide information on issues concerning design and audio-visual interactions, particularly for enclosures in urban courtyards with different sizes, surrounding heights, and design elements.

2. METHODOLOGY

2.1 Participants

The participants were recruited after receiving ethical approval from the Ethics Committee of the University of Liverpool and the Ethics Committee of the National Institute of Advanced Industrial Science and Technology (AIST), Japan. Thirty-three participants aged between 20 and 40 took part in the experiment. The target number of participants was chosen to achieve a statistical power of 80% ($\alpha < 0.05$, two-tailed). None of the participants reported any hearing or visual disabilities.

2.2 Stimuli

Two different sized courtyards were modelled: small (750 m^2) and large (3000 m^2). The heights of the buildings were changed at two steps (7.5 m and 25 m); consequently, the H/Ws were 0.3 and 1 for each courtyard. Different scenarios were designed to investigate the effects of natural features on perception of courtyards. Natural features were trees, trees and vegetation (i.e. flowers and grass) and water features. Therefore, a total of five courtyards were modelled: 1) empty courtyards, 2) courtyards with trees, 3) courtyards with trees and vegetation, 4) courtyards with water features, and 5) courtyards with water features and vegetation.

For visual stimuli, 20 three-dimensional (3D) courtyards with different size, H/W, and scenarios were created using Sketch-up. Additional visual edits to the lighting were made in Unity to make the VR models more realistic. Furthermore, trees, grass, flowers and water fall were added to the VR models. Examples of the 3D models used in this study can be seen in Figure 1.

The audio stimuli were road traffic noise, birdsong and waterfall sound. The road traffic noise was recorded near a motorway in the suburb of Liverpool where there are no buildings nearby [17]. Birdsong was the recording of the song of Robin [18], while water sounds was the recording of sound from fountain with 37 jets and no extension, with a water flow rate of 20l/min in an anechoic chamber [19]. By using these three different sounds, a total of 52 sound stimuli were made after convolving the recordings with impulse responses extracted from Odeon software. Road traffic noise was set as a reference and different sounds were then added according to the scenarios. The sound pressure levels (SPL) of the empty courtyards were fixed at 50 dB at the lowest H/W level (i.e. H/W = 0.3) and frequency characteristics of the road traffic noise was adjusted by considering the barrier attenuations. The SPLs of the birdsong and water features were 3 dB lower than the traffic sounds at the lowest H/W level.

2.3 Procedure and design

It was hypothesised that adding natural sounds such as bird songs and water sounds might affect the perception of the enclosure and pleasantness. It was also hypothesised that H/W might affect the perception of the enclosure in urban courtyards with and without natural features. Lastly, it was assumed that there would be audio-visual interaction. Therefore, similar to some previous studies on audio-visual interactions [14,20], the experiment consisted of three sessions: 1) a visual-only condition, 2) a combined audio-visual condition and 3) an audio-only condition.

In visual-only and audio-visual sessions, participants rated their perception of the enclosure, perception of spaciousness and perception of pleasantness. In the audio-only session, participants were asked to rate their perception of pleasantness. For assessments of perceptions, an 11-point numerical scale used with different adjectives. For perceived enclosure, the adjectives representing '0' and '10' were extremely closed and extremely open. Similarly, perceived spaciousness was rated from 0 (not spacious at all) to 10 (extremely spacious), while the perceived pleasantness was assessed on an 11-point numerical scale from 0 (not pleasant at all) to 10 (extremely pleasant).

Figure 1. 3D models for the empty courtyard, courtyard with tree, courtyard with tree and vegetation, courtyard with water feature and courtyard with water features and vegetation

Physiological responses including two facial electromyography data (fEMG) and heart rate (HR) were recorded during the experiment. The Polymate Pro MP6100 physiological data acquisition system was used to acquire physiological signals. The fEMG signals were measured using five electrodes placed over facial muscles, associated with two different emotion expressions which are zygomatic muscle (for positive emotions) and corrugator supercilia (for negative emotions). The participant's skin was gently rubbed with a skin preparation gel in the areas where the sensors were placed to improve the quality of the fEMG signals. A photoplethysmography (PPG) sensor was also attached to the left index finger for measuring HR. The participants were asked to avoid large body movements throughout the experiment. The experimental setup and the participant who is ready to start the experiment can be seen in Figure 2.

The experiment took place in a listening booth with low background noise at the laboratory of the Biomedical Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), Japan. The participants were provided with a consent form and information sheet upon their arrival, they participated in the test after giving their consent. Each participant was exposed to a total of 60 stimuli, including 20 visual stimuli, 20 combinations of simultaneous sound and visual stimuli, and 20 sound stimuli. In each session, there was 20 seconds baseline before the stimuli start, after baseline, there was the sound and/or visual stimuli were presented for 20 seconds, and the participants were given 20 seconds to rate the questions on a head-mounted display (HMD, Oculus Rift). In each session, stimuli were randomly presented to avoid the order effects. Before the real experiment started, participants attended a training session for around three minutes to familiarize themselves with the virtual interface on the HMD and controllers. Training sessions included one visual-only scene, one audio-visual scene, and one audio-only scene. The participants had a break after completing half of the experiment.

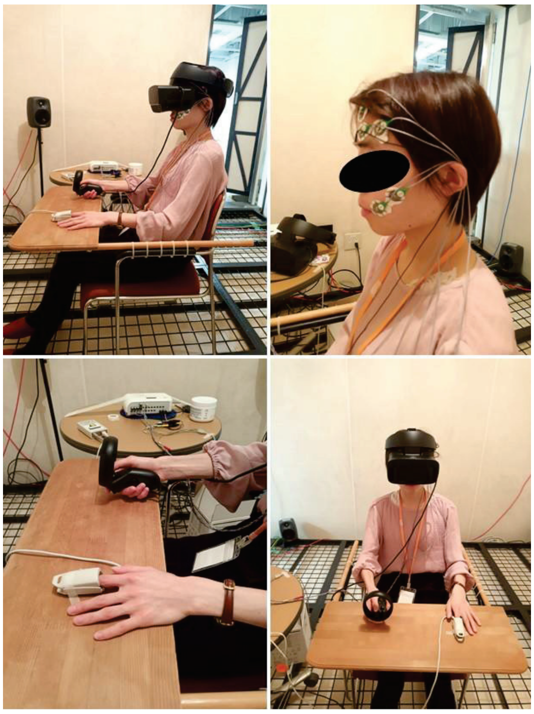

Figure 2. Experimental setup and a participant before starting the experiment

3. RESULTS

3.1 Effects of H/W on perceived enclosure

Figure 3 shows the mean ratings of perceived enclosure in audio-visual sessions for small and large courtyards, as a function of H/W across different scenarios. It is observed that the ratings for the perceived enclosure in audio-visual sessions increased with the H/W for all scenarios and courtyard sizes. Empty courtyards (E) showed the highest ratings for perceived enclosure for both small and large courtyards, whereas courtyards with trees (T) showed the lowest ratings. Moreover, large courtyards showed higher ratings for perceived enclosure compared to small courtyards.

A two-way repeated measures ANOVA (analysis of variance) was conducted to investigate the effects of H/W and natural features on perceived enclosure. The results indicated a significant main effect of the H/W on the subjective ratings for both small ([$F(1, 32) = 102.222$, $p < 0.01$)]) and large courtyards ([$F(2, 18) = 20.516$, $p<0.01$)]. In addition, the effects of different scenarios (i.e. incorporating natural features) on subjective ratings were significant for both small ([$F(4, 128) = 4.890$, $p < 0.01$)]) and large courtyards ([$F(4, 128) = 5.824$, $p < 0.01$)]).

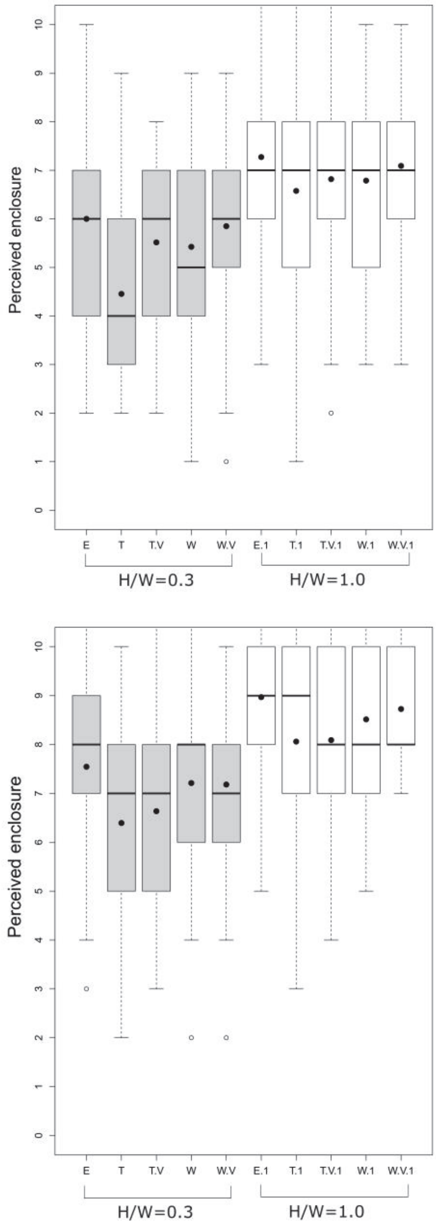

Figure 3. Mean ratings of perceived enclosure for different scenarios in audio-visual sessions as a function of H/W: small (top) and large (bottom) courtyards

3.2 Effects of natural features on perceived pleasantness and spaciousness

Figures 4 and 5 show the mean ratings of perception of pleasantness in audio-visual sessions at different H/Ws across scenarios for small and large courtyards. It was found that adding natural features to the empty courtyard increased the ratings. Two-way repeated measures of ANOVA were used to estimate the significance of the differences in the perception of pleasantness across the different H/Ws and scenarios. The impacts of H/W were significant for both small ([$F(1, 32) = 46.006$, $p < 0.01$)]) and large courtyards ([$F(1, 32) = 30.251$, $p < 0.01$)]). The effects of different scenarios on the perception of pleasantness were also statistically significant both for small ([$F(4, 128) = 28.475$, $p < 0.01$)]) and large courtyards ([$F(4, 128) = 19.897$, $p < 0.01$)]). Furthermore, the interaction between H/W and different scenarios was statistically significant for both small and large courtyards ($p<0.01$).

η^2 was calculated as the mean variability score for the perception of pleasantness to determine and quantify the distinctiveness of the subjective responses. A higher η^2 indicated a strong difference between the H/W levels and different scenarios, whereas a low η^2 indicated reduced subjective distinctiveness regarding the perception of pleasantness.

The differences in the perception of pleasantness in audio-visual sessions are more significant for the effect of H/W than the effect of changing scenarios for small and large courtyards (small courtyards: η^2=0.58 for the effect of H/W and η^2=0.47 for the effect of scenarios; large courtyards: η^2=0.48 for the effect of H/W and η^2=0.38 for the effect of scenarios).

The paired Wilcoxon signed-rank test was then conducted to see if the ratings from the scenarios with natural features are different from those from the empty courtyard with traffic noise only (reference). The results showed that the courtyards with natural features were significantly different from the reference for all scenarios.

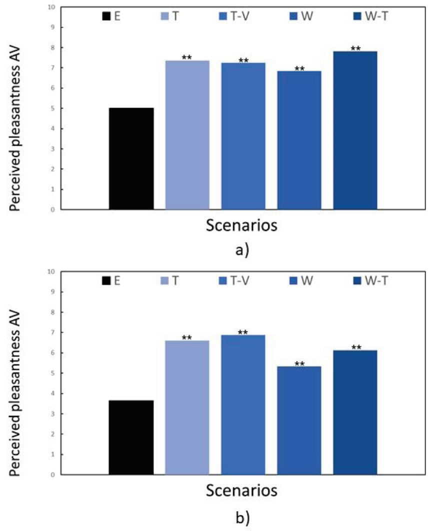

Figure 4. Mean ratings of perceived pleasantness in audio-visual sessions across scenarios for small courtyards: a) H/W=0.3 and b) H/W=1. Asterisks indicate significant differences obtained from the Wilcoxon test (*p<0.05 and **p<0.01).

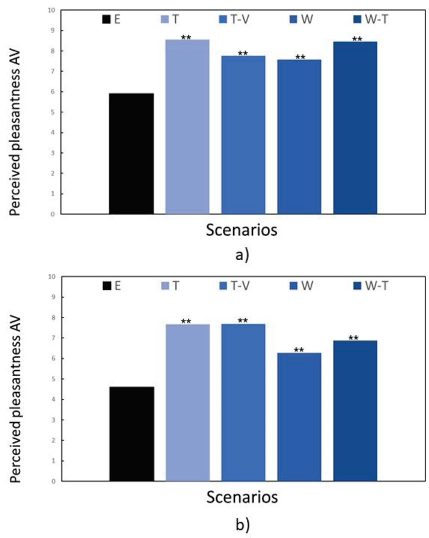

Figure 5 Mean ratings of perceived pleasantness in audio-visual sessions across scenarios for large courtyards: a) H/W=0.3 and b) H/W=1. Asterisks indicate significant differences obtained from the Wilcoxon test (*p<0.05 and **p<0.01).

Figures 6 and 7 show the mean ratings of perception of spaciousness in audio-visual sessions at different H/Ws across scenarios for small and large courtyards. It was found that the changes in ratings after adding natural features were more significant in the large courtyards than in the small courtyards. Two-way repeated measures of ANOVA were used to estimate the significance of the differences in the perception of pleasantness across the different H/Ws and scenarios. The impacts of H/W were significant for both small courtyards ([$F(1, 32) = 17.071$, $p < 0.01$)]) and large courtyards ([$F(1, 32) = 16.272$, $p < 0.01$)]). The effects of different scenarios on the perception of spaciousness were statistically significant for small courtyards ([$F(4, 128) = 4.217$, $p < 0.01$)]) while they were not significant for large courtyards ([$F(4, 128) = 1.426$, $p > 0.01$)]). The interaction between H/W and different scenarios was not statistically significant for both small and large courtyards ($p>0.01$).

The differences in the perception of spaciousness in audio-visual sessions are more significant due to the effect of H/W than the effect of changing scenarios for both small and large courtyards (small courtyards: $\eta^2=0.34$ for the effect of H/W and $\eta^2=0.11$ for the effect of scenarios; large courtyards: $\eta^2=0.33$ for the effect of H/W and $\eta^2=0.04$ for the effect of scenarios).

The paired Wilcoxon signed-rank test results showed that adding tress and vegetation (T+V) and water features and tress (W+T) made significant differences in small courtyards for both H/Ws. For large courtyards, the courtyards with natural features showed significant differences for all scenarios for both H/Ws.

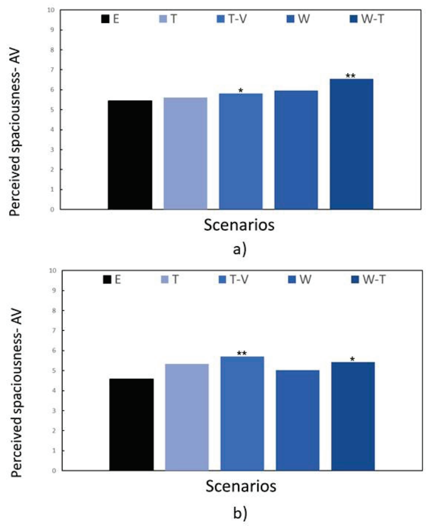

Figure 6. Mean ratings of perceived spaciousness in audio-visual sessions across scenarios for small courtyards: a) H/W=0.3 and b) H/W=1. Asterisks indicate significant differences obtained from the Wilcoxon test (*p<0.05 and **p<0.01).

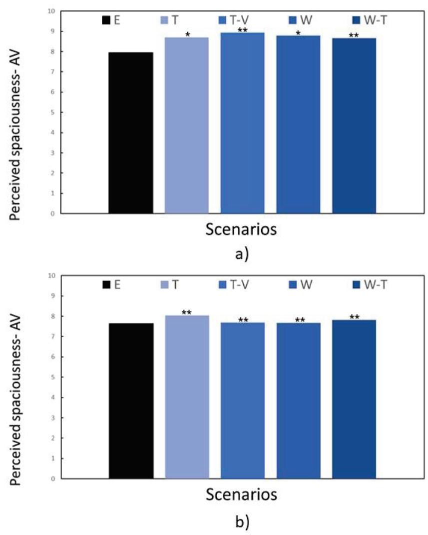

Figure 7. Mean ratings of perceived spaciousness in audio-visual sessions across scenarios for large courtyards: a) H/W=0.3 and b) H/W=1. Asterisks indicate significant differences obtained from the Wilcoxon test (*p<0.05 and **p<0.01).

3.3 Physiological responses in audio-visual sessions

Figure 8 shows the mean changes (%) in fEMG of the zygomaticus major (ZM) and corrugator supercilii (CS) muscle groups for large courtyards in audio-visual sessions. As plotted in the figure, fEMG ZM decreased for the empty courtyards for both H/Ws, whereas fEMG CS increased for all empty courtyards. According to the results of fEMG ZM, the courtyards with trees and vegetation led to the biggest increase, followed by courtyards with water features and vegetation. These results indicate that adding greenery and natural sounds has a positive impact on people's emotions towards the courtyards. On the other hand, the mean changes of fEMG CS for courtyards with natural features were smaller than those for empty courtyards with traffic noise only. This implies that people's negative emotions were reduced by adding natural features.

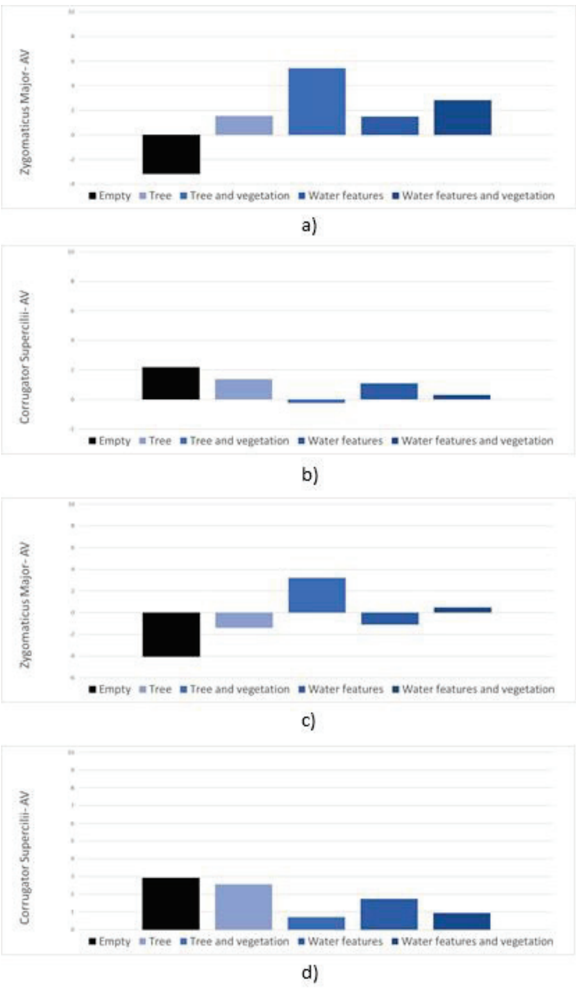

Figure 8. Mean changes of fEMG for large courtyards: a) ZM at HW=0.3, b) CS at HW=0.3, c) ZM at HW=1, and d) CS at HW=1

4. SUMMARY

The influences of natural features on the subjective and physiological responses to courtyards with varying height-to-width ratios (H/W) were investigated. A laboratory experiment was conducted in virtual reality (VR) environments with normal-hearing participants. Participants rated their subjective responses to stimuli in terms of the perception of enclosure, spaciousness and pleasantness. Additionally, the participant's physiological responses were monitored during the experiment in terms of facial electromyography (fEMG). The preliminary results showed that H/W and natural features significantly influenced the perception of the courtyards in most cases in audio-visual sessions. The perception of enclosure had the highest ratings for the empty courtyards in audio-visual sessions for both small and large courtyards, while the scenarios with vegetation had the lowest ratings. The fEMG results for the audio-visual sessions showed that adding natural features increased fEMG activity in the zygomaticus major (ZM) compared to the empty courtyard, indicating a positive emotional response. Additionally, the mean changes of fEMG activity in the corrugator supercilii (CS) for the courtyards with natural features were smaller than those for the empty courtyards, suggesting a reduction in negative emotions. In the future, heart rate results will be analysed, and further statistical analysis on physiological responses will be conducted.

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