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The influences of vegetation and water features on the perception of urban streets

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ABSTRACT

This study aims to examine the influence of natural sound (i.e. water sound and birdsong) on the perception of the enclosure in urban street canyons with varying height-to-width ratios (H/W). A 27- meter wide street was selected as a typical urban street and three levels of H/W ratios (0.5, 2, and 4) were modelled by changing the height of buildings on both sides of the street. Vegetation and water features were added to the street as visual components, while synthesized car pass-by sounds, water sounds, and bird songs were introduced as sound stimuli. A laboratory experiment was conducted in a virtual reality (VR) environment with normal hearing participants. The experiments consisted of three sessions: 1) an audio-only condition, 2) a combined audio-visual condition, and 3) a visual-only condition. Participants were asked to rate their subjective responses to stimuli in terms of the perceived pleasantness and perceived source width for the audio-only condition, the perceived enclosure, perceived spaciousness, perceived pleasantness, and perceived source width for the audio-visual combined condition, the perceived enclosure, perceived spaciousness, perceived pleasantness for the visual-only condition. Additionally, the participant's physiological responses were monitored during the experiment in terms of facial electromyography and heart rate.

Keywords: Enclosure; Street canyon; Height-to-Width ratio; Audio-visual interaction; Virtual Reality, Water Sound, Birdsong.

1. INTRODUCTION

Enclosure specifies the street canyons, courtyards and other architectural spaces surrounded by walls or natural elements like trees [1]. Urban street canyons have been examined in terms of environmental features like thermal comfort, natural light and the quality of air [2, 3, 4, 5]. Also, street canyons have been investigated regarding the acoustical features (i.e., absorption and diffusion of the street boundaries).

Environmental and design aspects of the urban environments affect the perception of humans. The findings of a previous study revealed that the sound environments of street canyons with different height-to-width ratios significantly affect the perceptions of enclosures [6]. According to several studies, natural sound sources like water and bird songs could have a positive effect on the perception of urban environments in terms of soundscape [7, 8]. Also, using water features improves the quality of the acoustic environment with their feature of noise masking; thus, it has been widely used to improve the quality of urban soundscapes [7, 9].

Virtual reality (VR) technology for simulations offers a high degree of perceptual realism in the evaluation of the perception of the enclosure in different settings [10]. Furthermore, physiological measurements such as facial electromyography (EMG) are useful to understand people’s reactions to different stimuli in urban environments so these have been introduced in the acoustic research areas [11, 12, 13].

Hence, in this study, the influence of natural sound (i.e. water sound and birdsong) on the perception of the enclosure in urban street canyons with varying height-to-width ratios (H/W) are investigated. This study could provide information on issues concerning audio-visual interactions, particularly for enclosures in urban streets with different designs. A laboratory experiment was conducted in a virtual reality (VR) environment with normal hearing participants. Participants were asked to rate their subjective responses to stimuli in terms of the perception of enclosure, spaciousness, pleasantness and source width. Additionally, the participant's physiological responses were monitored during the experiment in terms of facial electromyography and heart rate.

2. METHODOLOGY

2.1 Participants

The participants were recruited after receiving ethical approval from the Central Ethics Committee of the University of Liverpool (approval reference: 11249). Although our target number of participants is 40 participants, 10 participants (5 males and 5 females) aged between 26 and 38 (M = 30.1, SD = 3.8) have participated 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 Street Canyons

The model employed a 500-m length of the street with continuous buildings along the sides at constant heights. Street canyons of 27 m in width were chosen to represent wide urban streets. The heights of the buildings were changed at three steps (13.5 m, 54 m, and 108 m); consequently, the H/W was 0.5, 2 and 4.

2.3 Stimuli

The visual stimuli for the visual-only sessions consisted of 21 three-dimensional (3D) street canyons with different H/W levels and scenarios. The 3D models of the streets and buildings were created using 3DsMax, while natural features were added using Adobe Photoshop. For all H/W ratios, natural features were added to the default setting which is the street canyons only with traffic. They were 1) waterfalls, 2) fountains, 3) trees, 4) trees and waterfalls, 5) trees and fountains, and 6) flowers.

The audio-visual sessions consisted of 30 3D street canyon models with different H/W levels and scenarios. In addition to the scenarios used in the visual-only session, three more scenarios including birdsong were used: 1) trees and birdsong, 2) trees, waterfall, and birdsong, and 3) trees, fountain, and birdsong. The 3D models of the buildings were made using Sketchup and then were imported to Unity to create the VR models. Additional visual edits to the roads and lighting were made in Unity to make the virtual reality (VR) models more realistic. Moving vehicles were generated by using Unity and Oculus Rift. The vehicles were then combined with the convolved sound sources. Thirty cars were used in the VR models for all streets. Examples of the 3D models used in this study can be seen in Figure 1.

The audio stimuli for the audio-only sessions consisted of 18 sounds. Road traffic noise was set as a reference and different sounds were then added according to the scenarios. Added sounds are 1) waterfall, 2) fountain, 3) birdsong, 4) waterfall and birdsong, and 5) fountain and birdsong. For the road traffic noise, a synthesised car pass-by sound [14] at a driving speed of 50 km/h was convolved with the impulse responses from the computer simulation (ODEON). First, a 30-second-long car pass-by sound was cut into 301 pieces (0.09 second/piece) [6]. The impulse responses were generated from the acoustic simulations from ODEON software with one fixed receiver and 301 sound sources along the street. A total of 602 impulses responses ((301 sources × two positions) × one receiver)) were extracted for each street. Next, the 301 segments of the car pass-by sound were convolved with impulse responses. The Hamming window of two-block length was implemented to generate the smoothest and most realistic convolved car pass-by sound. For the scenarios with birdsong, bird sound was added to the trees in the VR models [15]. The birdsong used in this study was the song of Robin. For the scenarios with water features, water sounds recorded in an anechoic chamber were used [16]. The sound pressure levels of the road traffic noise were fixed at 60 dB at the lowest H/W level (i.e. H/W = 0.5).

2.4 Procedure and design

Similar to some previous studies on audio-visual interactions [11,17], this experiment was designed to include different sessions with and without the presence of sound stimuli. The experiment consisted of three sessions: 1) Session 1: a visual-only condition; 2) Session 2: a combined audio-visual condition and 3) Session 3: an audio-only condition.

Figure 1 – Streets with a building height of 13.5 m for only traffic, traffic with trees, traffic with waterfall and trees, traffic with trees and fountain, traffic with flowers, and traffic with waterfall.

In the experiment, it was hypothesised that adding natural sounds like water sounds and bird songs might have an impact on the perception of the enclosure. Another hypothesis was that H/W might affect the perception of the enclosure in urban street canyons with natural features. In the audio-visual sessions, participants rated their perception of the enclosure, perception of spaciousness, perception of pleasantness and perception of source width. In visual-only sessions, participants rated their perception of the enclosure, perception of spaciousness and perception of pleasantness. In the audio-only sessions, participants rated their perception of pleasantness and perception of source width.

The participants rated perceived enclosure on an 11-point numerical scale ranging from 0 (extremely closed) to 10 (extremely open). The participants also rated the stimuli on an 11-point numerical scale of perceived spaciousness from 0 (not spacious at all) to 10 (extremely spacious), whereas the perceived pleasantness was assessed on an 11-point numerical scale from 0 (not pleasant at all) to 10 (extremely pleasant). For the rating of the perceived source width, an 11-point numerical scale (with 0 representing 'not wide at all' and 10 representing 'extremely wide'), which was previously used in a previous study [6], was adopted.

Two physiological responses including two facial electromyography data (fEMG) and heart rate (HR) were recorded during the experiment. The Biopac MP150 physiological data acquisition system and AcqKnowledge 4.4 (BIOPAC Systems) were 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 (to measure positive emotions) and corrugator supercilia (to measure 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. Before starting the experiment, the impedance level of the skin was examined to confirm that it was low enough for the signals collection (<5 kΩ) [18]. A photoplethysmography (PPG) sensor was attached to the right index finger for measuring heart rate (HR). The participants were asked to avoid large body movements. The experimental setup and a participant who is ready to start the experiment can be seen in Figure 2.

The experiment is taking place in a listening booth with low background noise at the Acoustics Research Unit, University of Liverpool. 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 69 stimuli, including 21 visual stimuli, 30 combinations of simultaneous sound and visual stimuli, and 18 sound stimuli. In each session, there was 10 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 15 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 familiarise 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.

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

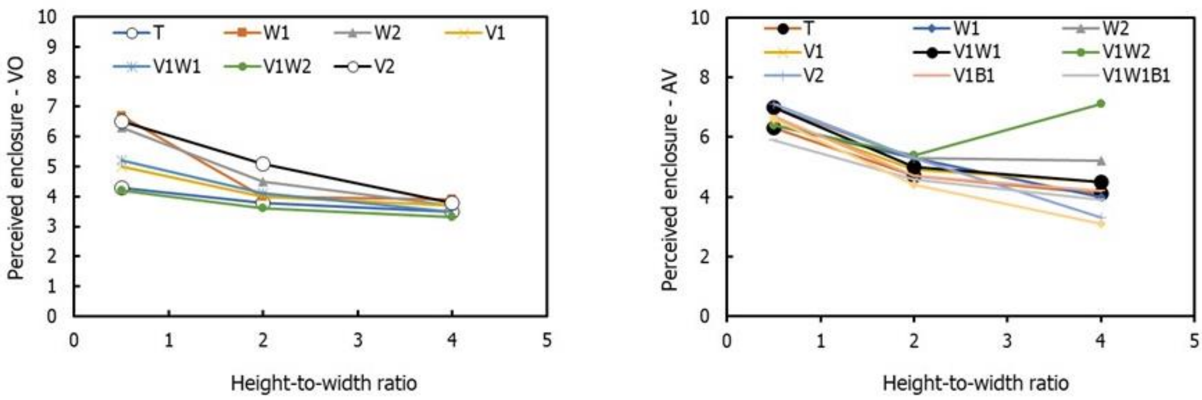
3. RESULTS

Even though this study investigated several perceptions, only the perception of enclosure for the visual only and audio-visual sessions will be presented in this section as a preliminary result. As it is an ongoing study, current results are from just 10 participants. After the completion of data collection with 40 participants, the statistical analysis for all the subjective variables also physiological data will be further analysed.

3.1 Effects of H/W and different Scenarios on perception of enclosure

Figure 3 shows the mean ratings of perceived enclosure across scenarios as a function of H/W: a) visual-only session and b) audio-visual combined session. It can be seen that ratings for the perceived enclosure in visual-only sessions decreased with the increase in H/W for all scenarios with and without natural features. Although perceived enclosure decreased with the increase in H/W, the highest perception of the enclosure was seen in the scenario with traffic and flowers (V2). On the other hand, the lowest rating was seen in the scenario with traffic, trees and fountains (V1W2). In the audio-visual session, the lowest perception of the enclosure was seen in scenario V2 (traffic and trees).

A two-way repeated measures ANOVA (analysis of variance) was conducted to investigate the effects of H/W and natural features on the perception of enclosure. It was found that there is a significant main effect of the H/W on the subjective ratings for both visual only session ([$F(2, 18) = 18.978$, $p<0.01$)]) and audio-visual session ([$F(2, 18) = 20.516$, $p<0.01$)]. It was also revealed that the effects of different scenarios (i.e. adding natural features) on the subjective ratings are significant in visual-only sessions ([$F(6, 54) = 3.872$, $p < 0.05$)]), whereas it was not significant in audio-visual sessions ([$F(9, 81) = 1.250$, $p > 0.01$)]).



a) b)

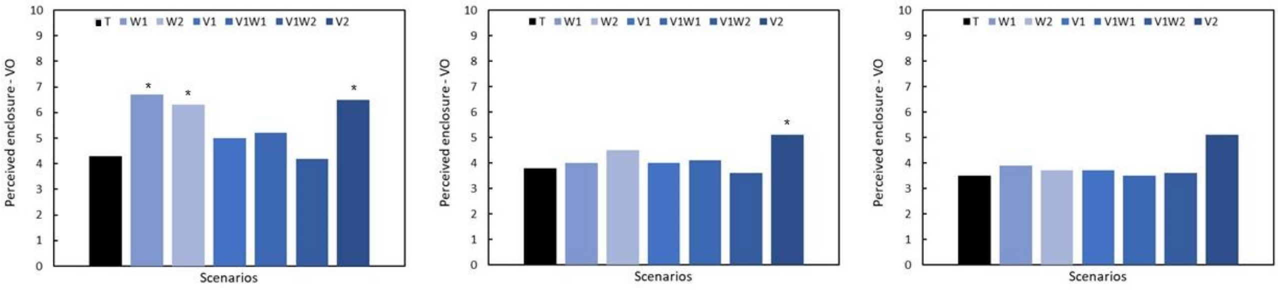
Figure 3 – Mean ratings of perceived enclosure for different scenarios as a function of H/W: a) visual only session and b) audio-visual combined session

3.2 Effects of different scenarios on perception of enclosure

Figure 4 shows the mean ratings of perception of enclosure in visual-only sessions at different H/Ws across scenarios. The black bars indicate the ratings for the default setting without any natural features. It was found that the ratings changed according to the visual images. Two-way repeated measures of ANOVA were used to estimate the significance of the differences in the perception of enclosure across the different H/Ws and scenarios. The effects of different scenarios on the perception of the enclosure were statistically significant ([$F(6, 54) = 3.872$, $p<0.05$)]) and the impacts of H/W were also significant ([$F(2, 18) = 18.978$, $p < 0.01$)]). Also, the interaction between H/W and different scenarios was statistically significant ($p<0.01$).

$\eta 2$ was calculated as a mean variability score for the perception of enclosure to determine and quantify the distinctiveness of the subjective responses. A higher $\eta 2$ indicated a strong difference between the H/W levels and different scenarios, whereas a low $\eta 2$ indicated reduced subjective distinctiveness regarding the perceived enclosure. The differences in the perceived enclosure in visual-only sessions are more significant for the effect of H/W than the effect of changing scenarios (η2 for the effect of H/W: 0.67 and η2 for the effect of scenarios).

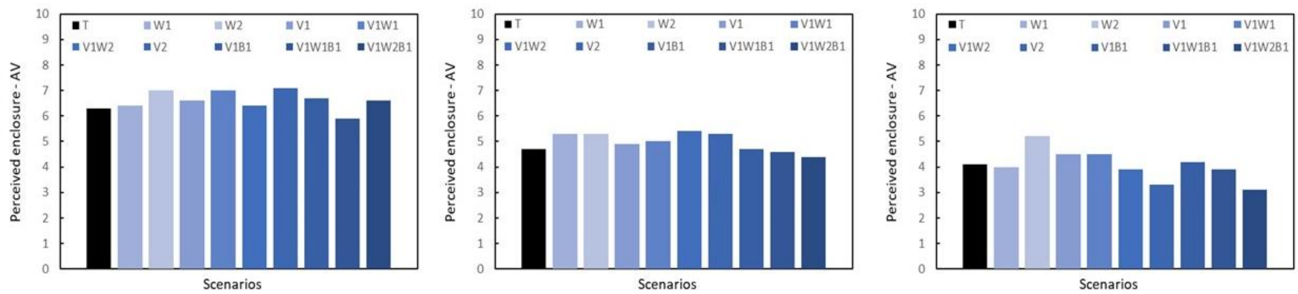
The paired Wilcoxon signed-rank test was then conducted to see if the ratings from the scenarios with natural features are different from those from the traffic only (reference). The results showed that the differences there were three significant differences at the lowest H/W and one difference at H/W=2; however, there was no difference at H/W=4.



a) b) c)

Figure 4 – Mean ratings of perceived enclosure across scenarios in visual-only session: a) H/W=0.5, b) H/W=2, and c) H/W=4. Asterisks indicate significant differences obtained from the Wilcoxon test (*p<0.05 and **p<0.01).

Figure 5 shows the mean ratings of perception of enclosure in audio-visual sessions at different H/Ws across scenarios. Compared to the visual-only session, the variations of the ratings across the scenarios were relatively small. In addition, the ratings of the streets with natural features were not statistically different from those of the reference (i.e. traffic only). Two-way repeated measures of ANOVA revealed that the scenarios across the different H/W did not make a significant change in the ratings ([F(9, 81) = 1.250, p>0.01)]) but the effect of H/W was significant ([F(2, 18) = 20.516, p < 0.01)]). It was found that the interaction between H/W and scenarios was significant (p<0.01). Similar to the visual-only session, the effect of H/W on the perception of enclosure was greater than the scenarios in the audio-visual session (η2 for the effect of H/W: 0.69 and η2 for the effect of scenarios: 0.12).



a) b) c)

Figure 5 – Mean ratings of perceived enclosure across scenarios in audio-visual session: a) H/W=0.5, b) H/W=2, and c) H/W=4.

SUMMARY

The influence of natural sound (i.e. water sound and birdsong) on the perception of the enclosure in urban street canyons with varying height-to-width ratios (H/W) were investigated. A laboratory experiment was conducted in a virtual reality (VR) environment with normal hearing participants. Participants were asked to rate their subjective responses to stimuli in terms of the perception of enclosure, spaciousness, pleasantness and source width. Additionally, the participant's physiological responses were monitored during the experiment in terms of facial electromyography and heart rate. The height-to-width ratio (H/W) were 0.5, 2 and 4 for street widths 27 m. The preliminary results showed that the impacts of H/W and different scenarios on the perception of the enclosure were significant for most cases in visual-only sessions; however, it was not the case in audio-visual sessions. This project is still ongoing so further analyses will be conducted with 40 participants along with physiological responses.

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