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Audio – visual interaction and perception of waterscapes used in outdoor environments

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ABSTRACT

This paper examines the audio – visual interaction and perception of a wide range of waterscapes where road traffic noise is audible. The waterscapes examined include small to medium sized water features that can be installed in outdoor settings (e.g. gardens and parks), in view of improving soundscape perception in terms of peacefulness and relaxation. The visual impact of the water features' displays has been examined using images of the displays placed over a single natural background, whilst auditory perception was based on the corresponding water sounds recorded in the laboratory. Audio only, visual only and audio – visual preference tests have been carried out under controlled conditions, in view of identifying the interaction between audio – visual factors. Qualitative analysis has also been performed using a semantic differential scale, in view of investigating how evocation and meaning might affect preferences.
Keywords: Soundscape, Environmental Noise, Water Features

1. INTRODUCTION

The application of water generated sounds is recognised as an efficient acoustic solution for enhancing the soundscape perception in outdoor environments [1]. Soundscape perception can be influenced by acoustical and non – acoustical factors such as visual settings [1]. This paper presents the audio – visual interaction and perception of different waterscapes through the use of auditory, visual and auditory/visual experiments carried out in the laboratory. In these experiments, a variety of small to medium sized water features was considered, including waterfalls, streams, cascades and fountains that can be usually found in gardens or parks. The analysis presented aims at examining how multi – sensory stimuli can influence water sounds perception in view of improving relaxation and peacefulness in outdoor spaces where road traffic noise is audible.

The paper starts by showing the relevant background to the research and continues by presenting the methodologies used for the laboratory tests. This is followed by the presentation of results and data analysis, and by conclusions summarising the main findings of the study.

2. BACKGROUND

The sound that moving water makes can be considered as a pleasant sensation, as well as a potential component for masking unwanted sounds [2]. Among natural and artificial sounds, the sound

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of water is often regarded as the preferred sound in an urban soundscape [3] as well as the best sound used for enhancing soundscape perception [4].

In soundscape research, several efforts have been made to investigate the perceptual assessment as well as the acoustical characterisation of water generated sounds used in outdoor spaces affected by road traffic noise, with the aim of improving soundscape perception [2,4–11].

Water generated sounds cannot easily produce low frequency levels comparable to traffic noise [7,11], but their use as maskers takes advantage of their distracting effect as "wanted" sounds (natural sounds) over "unwanted" sounds (e.g. road traffic noise) [7,11].

Moreover, previous studies have investigated the effects of water sounds on masking urban noises, but it is not yet clear which water features can be used as more suitable maskers. For that reason, examining the effects of design factors on acoustical and psychoacoustical properties of water sounds has been recently suggested as a need, in view of understanding which water feature can be more appropriate for improving relaxation in outdoor environments in presence of road traffic noise [11].

Laboratory experiments revealed that water sounds should be similar or not less than 3 dB below the road traffic noise [4,11]. In addition, natural streams and fountains with multiple upward jets were found to be preferred for improving relaxation, whilst waterfall sounds tended not to be liked and water was indicated as the preferred impact material in contrast to hard materials [11]. Galbrun and Ali [11] also suggested that the perceptual assessment of water sounds cannot be guided only by individual parameters such as acoustical and psychoacoustical properties. Furthermore, this study [11] suggested that it would be worth investigating the influence of the evocative effects and meanings of the water sounds, as well as the audio – visual interaction on subjective sound preferences.

The evaluation of soundscape quality is rather complicated due to its inherent connection with the subjective perception of individuals. For that reason, subjective impressions in terms of sound preference can be dominated by multi–modal sensorial patterns (aural only, visual only, aural – visual). Previous research has shown that the audio – visual interaction constitutes an important factor affecting sound perception in different settings such as natural landscapes and urban spaces [9,12–16].

Laboratory experiments based on evaluating the interaction between aural and visual stimuli for 32 combinations of different sounds and visual landscapes were carried out by Carles et al. [12]. The results showed that the sound, and not the visual component, dominated the pattern of preference due to the more varied nature of sounds, in comparison with the relatively homogeneous quality of the visual scenes shown [12]. Moreover, the degree of matching (congruence or coherence) between visual and auditory information has been suggested as a significant component in sound ratings [13,14].

In addition, listeners' judgements can be affected by co – occurring visual settings in the urban sound environment, as argued by Viollon et al. [14]. Results indicated that visual influence varied with the visual scenes and the type of sounds concerned [14].

Recently, Jeon et al. [9] carried out a study on the acoustical characterisation of water sounds for soundscape improvement in urban spaces, and found that preference scores were affected by the acoustical characteristic of water sounds and visual images of water features. By comparing the results from audio only and audio – visual sessions, results showed that visual images have a significant effect on the perception of urban noises when water sounds are introduced as a sound masker [9]. In most cases, preference scores increased as visual images were added simultaneously [9].

The existing body of research involved in the study of audio – visual interaction has focused on laboratory experiments where visual images were taken from existing landscapes or urban environments which had the potential to be matched with the sound stimuli. In this paper, the visual impact of different water features' displays is examined by using images in which the displays are placed over the same natural background, the displays matching exactly those used to generate the sounds in the laboratory.

3. METHODOLOGY

This section illustrates the audio and visual materials used to carry out the experiments, as well as the methods adopted for investigating the audio – visual interaction and perception of different waterscapes. All tests were carried out in view of improving soundscape perception in terms of relaxation and peacefulness in outdoor spaces where road traffic noise is audible. The road traffic noise used in the listening tests consisted of dense road traffic with low temporal variability, which was recorded at 200 m from the centre of a busy motorway (M8 Edinburgh – Glasgow, UK) [11].

3.1 Auditory stimuli

The water sounds used in the tests were generated by small to medium sized water features constructed in laboratory by Galbrun and Ali [11]. These structures can be classified in three different categories such as waterfalls, fountains with upwards jets and streams. A variety of water sounds were obtained by varying design parameters such as the waterfall's width, height of falling water, flow rate and impact material [11]. In this study, ten different water sounds have been selected to represent a wide range of water sounds: a waterfall with a plain edge (PEW), a waterfall with a sawtooth edge (SEW), a waterfall with small holes (SHW), a fountain with 37 upwards jets (FTW), a foam fountain (FF), a dome fountain (DF), a large jet (LJT), a narrow jet (NJT), a cascade with four steps (CA) and a natural stream (ST) (measured in the field). The design properties of each water feature are illustrated in Table 1.

Audio recordings of the water features used in the tests were taken from recordings carried out by Galbrun and Ali [11] with a digital sound recorder (Zoom H4n) connected to Brüel and Kjaer Type 4190 ½ microphones attached to a dummy head.

Table 1 – Properties of water features used in the experiment

Sound code	Water feature type	Impact material	Flow rate (l/min)	Height (m) – Width (m)
PEW	Plain Edge Waterfall	Water	120	1.0 – 1.0
SEW	Sawtooth Edge Waterfall	Water	30	0.5 – 1.0
SHW	Small Holes Waterfall	Water	30	0.5 – 1.0
FTW	Fountain (37 jests)	Water	30	-
FF	Foam Fountain	Stones & Boulders	30	-
DF	Dome fountain	Water	30	-
LJT	Large jet (25 mm nozzle)	Water	15	-
NJT	Narrow jet	Water	15	-
CA	Cascade (4 steps)	Stones (pebbles)	15	-
ST	Stream	Stones & Water	Low (not meas.)	-

3.2 Visual stimuli

Visual materials consisted of images in which different water features' displays were placed over the same natural background. In this experiment, ten visual stimuli were produced for the water features considered (Figure 1). All images were developed using *Adobe Photoshop CS3* photo editing software. A garden within the campus of Heriot – Watt University was identified as a suitable landscape representative of a garden or park with vegetation. The water features' displays reproduced in the images of Figure 1, are as similar as possible to the actual features of Table 1 which were tested in the laboratory (with the exception of the stream tested in the field).

3.3 Audio – visual tests

Three different tests were carried out (audio only, visual only and combined audio – visual conditions), with the aim of identifying the preferred water sounds, the visual impact of water features' displays, and the audio- visual interaction between preferences. These tests were undertaken within the context of relaxation and peacefulness in outdoor environments where road traffic is audible, for the ten different waterscapes of Table 1. Forty – four people (twenty – three females and twenty – one males) participated in all tests which were typically carried out over two sessions. All subjects involved in these tests reported normal hearing ability. During each test, subjects were instructed that they had to imagine to be relaxing in a garden or balcony where they could hear (for the auditory test) /see (for the visual test, and both senses for the audio – visual test) water features. Tests were carried in the anechoic chamber of the School of the Built Environment, Heriot – Watt University, as shown in Figure 2, in view of ensuring a low level of background noise (around 21 dBA during tests).

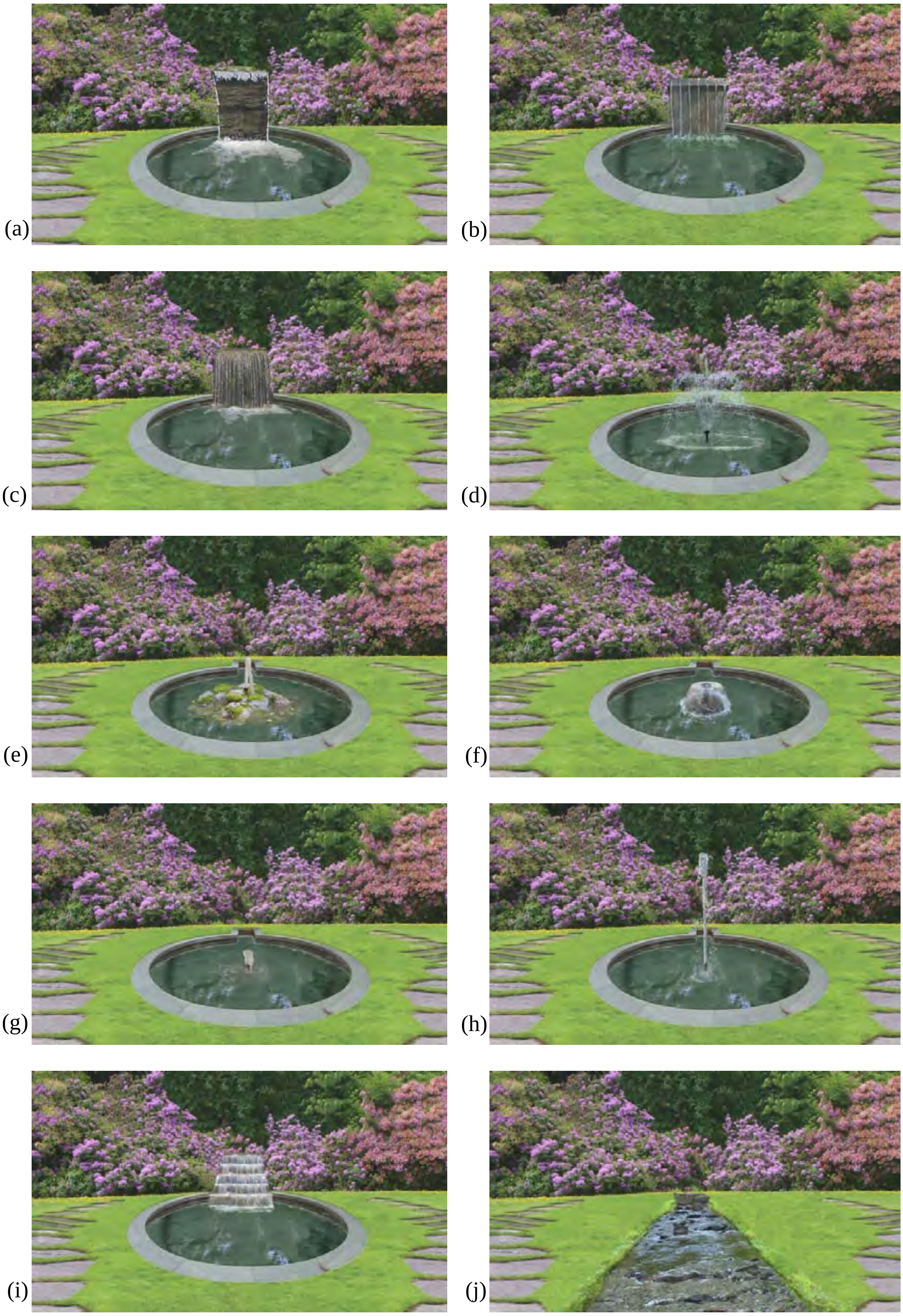

Figure 1 – Visual materials used in the experiments. (a) PEW, waterfall with a plain edge, (b) SEW, waterfall with a sawtooth edge, (c) SHW, waterfall with small holes, (d) FTW, fountain with 37 upward jets, (e) FF, foam fountain, (f) DF, dome fountain, (g) LJT, large jet, (h) NJT, narrow jet, (i) CA, cascade, (j) ST, natural stream.

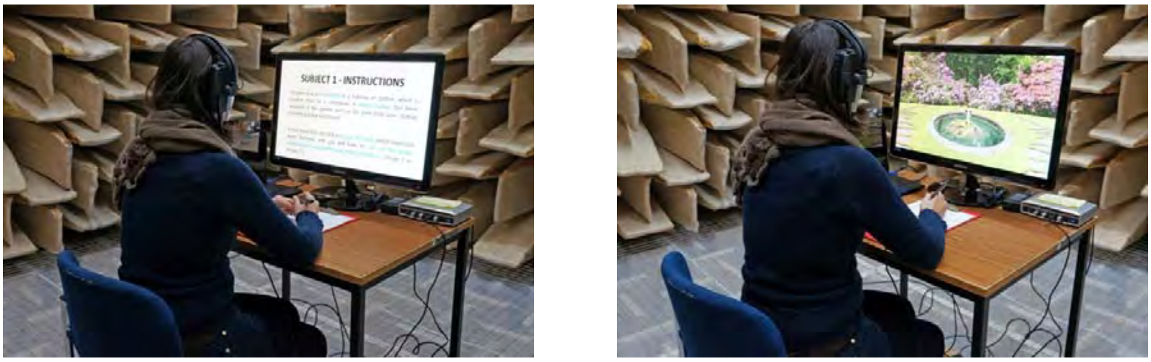

Figure 2 – Laboratory setting for audio –visual tests

During the experiments, audio and visual stimuli were presented from a computer through closed headphones (Beyerdynamics DT 150) and a widescreen LED monitor (Samsung S27A350H, 27 inch) respectively. The monitor was located on a desk close to the seating position of participants, in order to ensure a high sense of involvement in the visual scene. Binaural signals were played at 55 dBA (same level used for water sounds and road traffic noise, as this tends to be preferred [4,11]).

The paired comparison method was adopted to evaluate stimuli preferences for the three conditions tested. Each test included forty – five comparisons which consisted of seven seconds of stimulus 1, one second of silence, seven seconds of stimulus 2, and three seconds of silence before the next pair was played. Ten comparisons were repeated in the audio test, to identify the consistency of subjects. Comparisons were randomised in view of statistical validity, i.e. different orders of stimuli were obtained for each subject. However, the same sequence was used for each subject in the three conditions (audio, visual and combined audio – visual). After listening to each comparison, subjects were asked to select the stimulus that they preferred in terms of relaxation and peacefulness. After every ten paired comparisons, subjects could independently decide to take a break before continuing the test. Each test lasted typically thirty minutes.

Two types of auditory tests were undertaken: firstly, sound preferences were examined using paired comparisons and secondly, qualitative sound characterisation was examined. The latter aimed at investigating water sounds' qualitative properties, as well as evocation and meaning, by using a semantic differential method. This test was generally carried out following the first part related to sound preferences and typically lasted 20 minutes per subject, including instructions. The ten water sounds were played individually through the headphones, and for each sound, subjects had to answer a questionnaire. Subjects could listen to each sound as many times as they wanted. In order to assess water sounds' characterisation, questions based on a five – point verbal scale were used for qualitative analysis. Based on a review of previous studies on semantic differential analysis of soundscapes [8,17–19], eight pairs of antonymous adjectives (*relaxing – stressful*; *natural – artificial*; *familiar – unfamiliar*; *refreshing – weary*; *unsteady – steady*; *enveloping – directional*; *rough – smooth*; *sharp – flat*; *fast – slow*) were assigned to describe the subjective impression of water sounds and these were related to a five point rating scale (e.g. very relaxing, relaxing, neither relaxing nor stressful, stressful, very stressful). Furthermore, evocation was examined by asking an open ended question to participants ("*If the sound evokes anything to you, please explain what it makes you think of*"). In view of examining sounds' identification, subjects were also asked to indicate which type of water feature the sound made them think of (waterfall, fountain, natural stream, none of them), as well as to indicate if the water sound could be associated to a manmade sound (e.g. water falling into a drain/container or a tap) or rainfall.

4. RESULTS

Thirty – eight subjects (nineteen females and nineteen males) passed the consistency test and were retained for the analysis of results. The age distribution of subjects ranged from 24 to 47 years (mean 30.1 years and standard deviation 4.47 years). The cultural groups were composed of nineteen "White", four "Asian", fourteen "Middle Eastern" and one "African". Results have been expressed in terms of normalised preferences, based on a ± 2 scale (where -2 means "never preferred" and + 2 means "always preferred"). These were obtained for aural only, visual only and aural – visual tests, as shown in Figure 3.

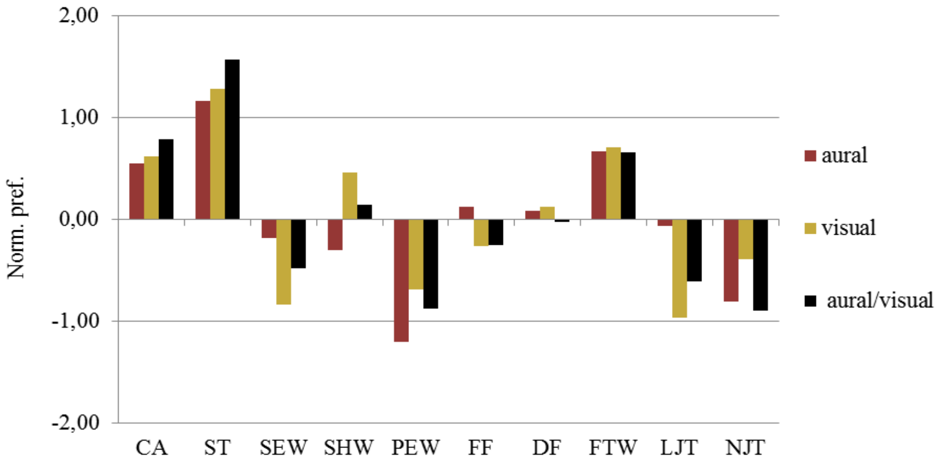

Figure 3 – Preferred water features for aural, visual and aural/visual conditions

Table 2 – Ranking of preferred water stimuli in aural, visual and aural/visual tests

	Aural test		Visual test		Aural – visual test	
	Sound code	Norm. pref.	Sound code	Norm. pref.	Sound code	Norm. pref.
1	ST	1,16	ST	1,27	ST	1,57
2	FTW	0,67	FTW	0,70	CA	0,78
3	CA	0,55	CA	0,62	FTW	0,65
4	FF	0,12	SHW	0,46	SHW	0,14
5	DF	0,08	DF	0,12	DF	-0,02
6	LJT	-0,07	FF	-0,27	FF	-0,26
7	SEW	-0,19	NJT	-0,40	SEW	-0,48
8	SHW	-0,30	PEW	-0,69	LJT	-0,61
9	NJT	-0,81	SEW	-0,84	PEW	-0,88
10	PEW	-1,20	LJT	-0,97	NJT	-0,90

4.1 Aural test

The results from the aural test (Figure 3) show that the preferred water sounds are the natural stream ST, the fountain made of 37 upward jets FTW, the cascade CA and the foam fountain FF. By contrast, the least preferred water sounds are the waterfall with a plain edge PEW, the single jet with a narrow nozzle NJT, the waterfall with small holes SHW and the waterfall with a sawtooth edge SEW. A statistical analysis of the results indicated that no significant differences in responses were found between different ages and genders (Mann – Whitney, $p > 0.05$). However, significant differences were found among different cultural groups for SHW, PEW, FF, DF, and LJT (Kruskal – Wallis test, $p < 0.05$). Different subjective ratings might be partly attributed to the evocation and meaning that water sounds can have for different cultures. For Asian and Middle Eastern subjects, listening to SHW and PEW sounds made them think of heavy rainfall, water on concrete, small waterfalls and cold weather; these sounds were more appreciated by subjects from countries where rain is more frequent and people are used to listen to it. This confirms also the findings of Jeon et al. [18] according to which cultural differences could lead to different subjective evaluations.

The results of the semantic differential analysis for the ten water sounds are shown in Figure 4. Semantic differential analysis showed that the water sounds preferred in the auditory tests (ST, CA and FTW) were classified as relaxing, refreshing, steady, familiar, enveloping, smooth and flat sounds. By contrast, sounds from waterfalls (SEW and PEW), as well as fountains with single upward jets (NJT and LJT), were considered stressful, artificial, weary, unsteady, unfamiliar, directional, rough and sharp sounds.

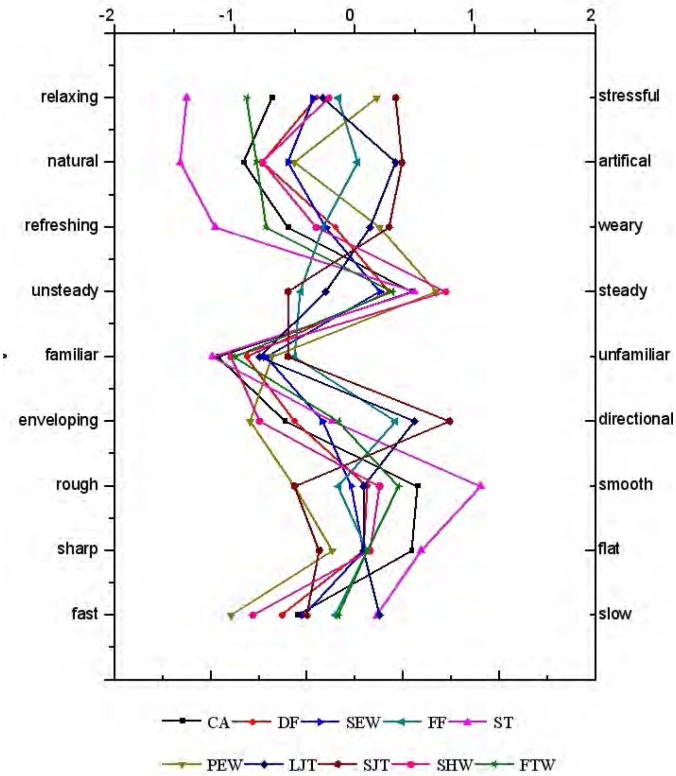

Figure 4 – Semantic characterisation for individual water sounds.

Additionally, when the subjects were asked to identify the water features corresponding to the sounds heard, it was shown that sounds from natural stream and fountain with upwards jets can normally be recognised. However, subjects presented difficulties in identifying sounds from waterfalls. Further analysis also showed that sounds generated from fountains with a single upward jet (NJT and LJT) and the foam fountain (FF) were evocative of manmade water features. Additionally, sounds from waterfalls with small holes and a plain edge (SHW and PEW) resembled rainfall.

4.2 Visual test

Results from the visual test identified the preferred water features' displays as shown in Figure 3. Visual elements were ranked positively for ST, FTW, CA and SHW. The least preferred displays were LJT, SEW, PEW and NJT. No statistically significant differences in responses were found between different ages and genders (Mann – Whitney test, $p > 0.05$), with the exception of FF for responses of different genders (Mann – Whitney test, $p < 0.05$, $p = 0.028$). No significant differences in ratings were found between different cultural groups (Kruskal – Wallis test, $p > 0.05$).

4.3 Aural – visual test

The audio – visual test indicated that ST, CA, FTW and SHW are the water features which made subjects feel more relaxed. The least preferred water features were NJT, PEW, LJT and SEW. No significant differences in responses were found between different ages and genders (Mann – Whitney test, $p > 0.05$) as well as different cultural groups (Kruskal – Wallis test, $p > 0.05$).

4.4 Aural – visual interaction

The relationship between different sensorial patterns and subjective perception has been examined, as different sensorial conditions may influence the perception of different waterscapes and result in different subjective ratings. The results obtained from a comparison between the different tests' conditions show that:

- ✓ *Aural vs. Visual*: significant differences in responses occur for SEW, SHW, PEW and LJT;
- ✓ *Aural vs. Aural – Visual*: significant differences occur just for ST;
- ✓ *Visual vs. Aural – Visual*: significant differences occur for SEW and NJT;
- ✓ *Aural vs. Visual vs. Aural – Visual*: significant differences occur for SEW and SHW.

These results suggest that the differences in preference scores between uni – modal and bi – modal sensorial conditions vary with different waterscapes. In the case of ST, CA, FTW and SHW, the visual settings significantly affect sound perception: preference scores increased as water features' displays were added to the corresponding sound stimuli. By contrast, visual stimuli negatively influenced perception in the cases of SEW and LJT: preference scores decreased with the presentation of the visual displays. The visual impact of water features' displays has a significant influence on waterscapes' perception.

In Figure 5, correlation maps are given for each waterscape which has been examined in this study. The figure shows that subjective sound ratings are not correlated with visual ratings. By contrast, responses from aural tests are significantly correlated to the combined aural – visual condition. Similarly, a significant correlation is found between visual and aural – visual results. Subjective perception in the combined aural – visual condition is found to be influenced by uni – modal sensorial patterns (aural only and visual only). The most significant correlation between bi – modal and visual condition is found for CA ($\rho = 0.527$, $p < 0.01$) and ST ($\rho = 0.469$, $p < 0.01$). In addition, a relationship between aural only and the bi – modal condition is found for NJT ($\rho = 0.628$, $p < 0.01$) and LJT ($\rho = 0.561$, $p < 0.01$). Results suggest that there is no unique dominant pattern of preferences between uni – modal conditions: both aural and visual settings significantly influence waterscapes' perception.

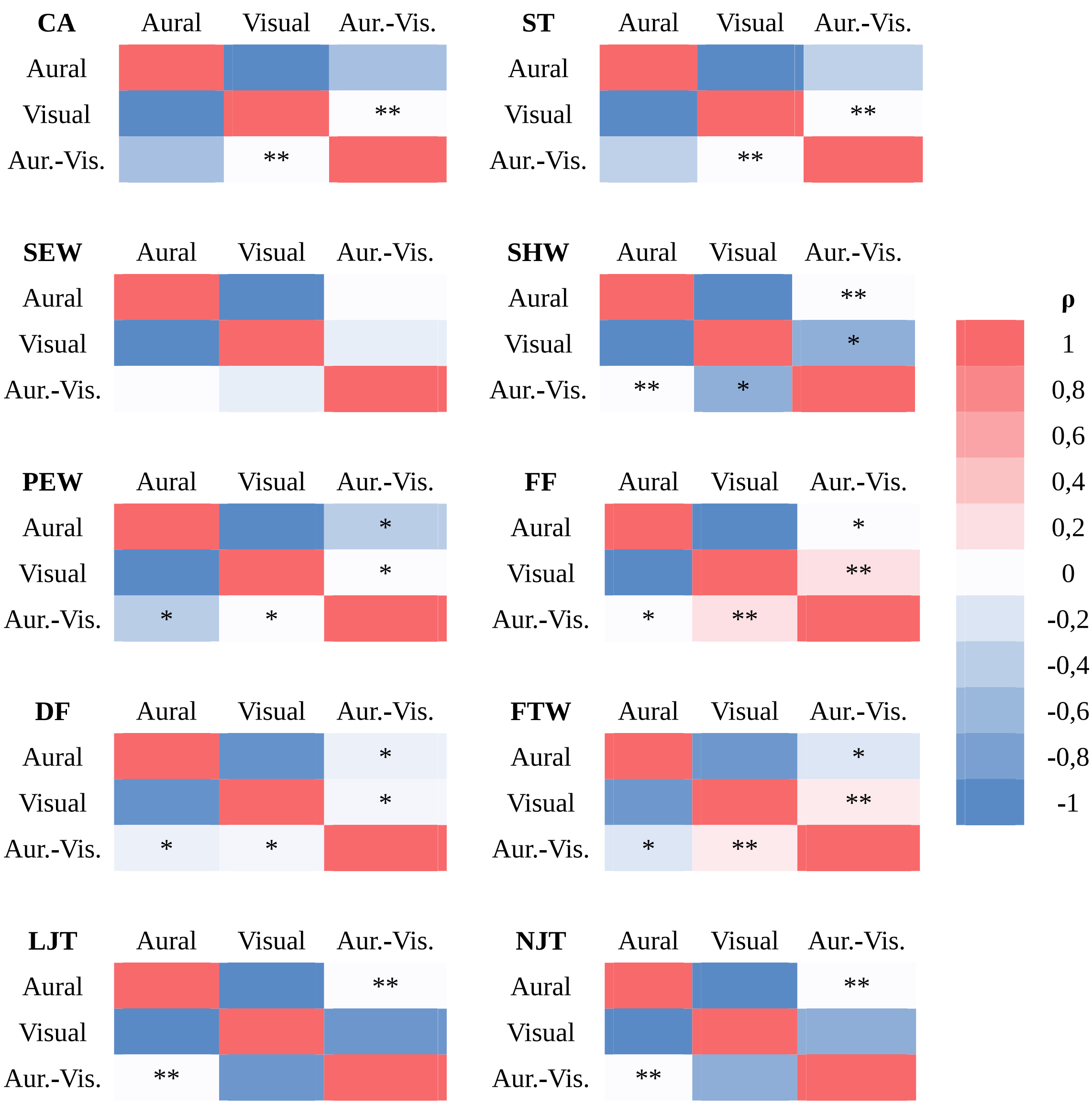

Figure 5 – Correlation maps for ten different waterscapes based on Spearman coefficient (ρ) where ** indicates a significant correlation at the 0.01 level and * indicates a significant correlation at the 0.05 level.

However, results obtained in terms of correlations and differences suggest that the findings presented are not always applicable to all water features: no single rule can be used to explain the influence of audio – visual interaction on waterscapes' perception.

5. CONCLUSIONS

This study examined the audio – visual interaction and perception of different waterscapes for outdoor environments. Laboratory experiments showed that natural streams and fountains with upward jets are the most suitable water features for improving relaxation and peacefulness, whilst waterfalls and fountains made with single jets are not appreciated. This confirms also the findings obtained by Galbrun and Ali [11] from auditory tests.

Auditory experiments showed also that differences in cultural groups can generate different perceptions of water sounds. A preliminary analysis of the semantic differential tests showed that evocation and meaning of water sounds are an important factor affecting water sound perception. However, further analysis of the results obtained is needed.

In addition, the results showed that differences in preference scores between different sensorial conditions varied with different water features. It can be noted that aural elements as well as visual settings played an important role in waterscapes' perception. In the case of the preferred water features, the co – occurring two senses (audition and vision) made subjective perception to be positively increased. Furthermore, the water features' types were found to be influential on subjective ratings of different waterscapes. All these findings point out the complexity of preferences and suggest that no single rule can be used to explain waterscapes' perception.

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