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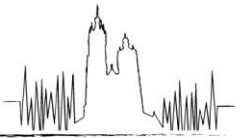
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Semantic assessment of water features used over road traffic noise

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Summary

Semantic differential analysis has been carried out for a wide range of small to medium sized water features which can be installed in gardens or parks. The main goal of the study was to identify the principal components affecting water sounds' perception in the context of peacefulness and relaxation where road traffic noise is audible. The work also looked at correlations with audio-only preferences, as well as correlations between physical and perceptual properties of the water sounds. Laboratory listening tests were carried out for ten water sounds by using semantic differential analysis based on a five-point verbal scale that consisted of nine antonymous adjectives. Results showed that water sounds' characterisation is mainly defined by three principal components which are related to both emotional and physical attributes of sounds: 'emotional assessment', 'sound quality' and 'envelopment and temporal variation'. A statistically significant correlation was found between 'emotional assessment' and preferences, as well as between 'sound quality' and preferences. Furthermore, it was not possible to find clear relationships between semantic components and individual acoustical/psychoacoustical parameters.

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1. Introduction

Water generated sounds have been widely considered as a potential mean for masking annoying urban noises [1-8] by taking advantages of their distracting effect as "wanted" sounds [1] as well as improving soundscape perception due to their inherent positive qualities [9]. Previous studies showed that water generated sounds cannot easily produce low frequency levels comparable to traffic noise [1,6]; natural streams and fountains with multiple upward jets tended 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 [6]; and the preferred level of water sounds should be similar or not less than 3 dB below the road traffic noise [6,10]. Several efforts have been made to investigate the acoustic use of water sounds used over road traffic noise but it is not yet clear which water features can be more

appropriate for improving relaxation in outdoor environments. Furthermore, the evaluation of soundscape quality is rather complicated due to its inherent connection with the subjective perception of individuals [9]. For that reason, there is a need to identify the principal dimensions of soundscape perception in view of understanding how to design an acoustic environment in relation to people's perceptual reactions [11,12]. In this context, the goal of the present study was to evaluate the qualitative characterisation of ten different waterscapes (waterfalls, streams, and fountains) used over road traffic noise in the context of relaxation and peacefulness, by using a semantic differential analysis. In addition, this work follows from previous research [6,13] based on the acoustical and perceptual assessment as well as the audio-visual interaction of water sounds used over road traffic noise.

2. Methodology

The waterscapes examined included small to medium sized water features that can be installed in outdoor settings (e.g. gardens and parks) as well

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as in indoor environments such as hotels' lobbies, restaurants and offices. The water sounds used in the tests were generated by water features constructed in the laboratory by Galbrun and Ali [6]. 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 [6]. In the study presented here, ten different water sounds have been selected from this pool of data 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 an edge made of 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) [6]. These features can be classified in three different categories such as waterfalls, fountains with upwards jets, and streams. In the present research, LJT has been considered as belonging to two categories (fountain and stream). LJT has been categorised as a stream due its shallow and irregular distribution of water, as suggested by Galbrun and Ali [6]. It is also worth mentioning that water was the main impact material chosen for the water features considered in the study with the exception of CA, FF and ST. The hard impact surfaces were excluded, as it was found that water tends to be the preferred impact material compared to hard materials such as concrete, stones and boulders [6]. All the sounds were measured by using a test structure built in the laboratory, with the exception of sound from the natural stream which was measured in the field [6]. Measurements were carried out at a distance of 0.5m from the centre section of the basin (impact area of falling water) and 1m above floor level [6]. In addition, acoustic and psychoacoustic parameters for both water sounds and water sounds with road traffic noise were also calculated [6]. Audio recordings of 20s were made for each water feature considered and carried out with a digital sound recorder (Zoom H4n) connected to Brüel and Kjaer Type 4190 ½ microphones attached to a dummy head [6]. 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) [6].

2.1 Participants

Forty-four people (23 females and 21 males of age distribution 24-44 years, average age 30.3 years) who reported normal hearing ability participated in all tests, which were typically carried out over two

sessions. All subjects were recruited among students and researchers working at Heriot-Watt University, as a representative sample matching with a wide age distribution and varied cultural groups. Tests were conducted in the anechoic chamber of the School of the Built Environment, Heriot-Watt University, in view of ensuring a low level of background noise (around 21 dBA during tests, including noise from the computer used).

2.2 Test procedure

Three different tests were carried out in the laboratory (Figure 1): an auditory test, a visual-only test and an audio-visual test. Two types of auditory tests were undertaken: firstly, audio-only preferences were examined using paired comparisons of water sounds and, secondly, qualitative sound characterisation was examined. In this paper, the portion of this work related to the semantic differential test is the only part presented. During the experiments, audio stimuli were presented from a computer through closed headphones (Beyerdynamics DT 150). Binaural signals consisted of water sounds that were played at 55 dBA (same level used for water sounds and road traffic noise), as it was shown that a difference of 0 dB between water sounds and traffic noise tends to be preferred [6,10]. The level used for the tests was 55 dBA, as it characterizes an outdoor environment that can significantly benefit from the use of water features, being not too quiet (no need for masking sounds) and not too noisy (masking sounds irrelevant for relaxation).

2.3 Semantic test

The semantic test was performed following the first part related to sound preferences and typically lasted 30 minutes per subject, including instructions. The ten water sounds were played individually (7 seconds of audio recording) through closed headphones. For each sound, subjects had to answer a questionnaire after listening to each

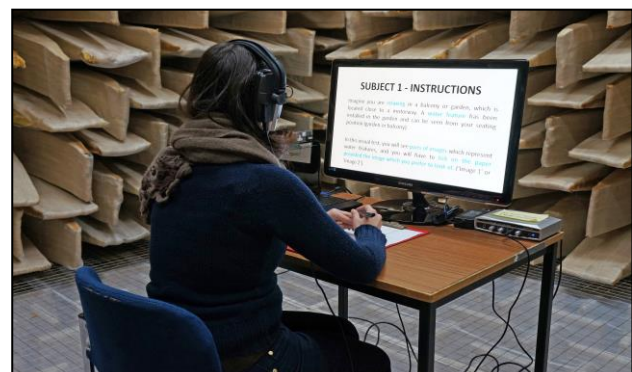
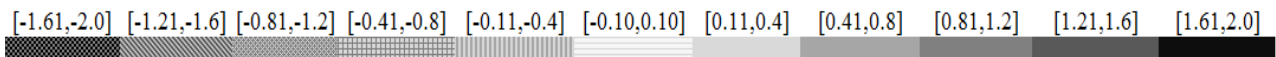


Figure 1. Laboratory setting used for tests.

Table I. Maps of the average scores for each semantic attribute based on a 5-point numerical scale (e.g. -2 = very stressful, -1 = stressful, 0 = neither stressful nor relaxing, 1 = relaxing, 2 = very relaxing), with sound codes listed in order of ranking preferences obtained from the audio-only test.



| Audio-only ranking | Sound code | Relaxation | Naturalness | Freshness | Familiarity | Perceived sharpness | Perceived roughness | Speed | Envelopment | Temporal variation |
|--------------------|------------|------------|-------------|-----------|-------------|---------------------|---------------------|-------|-------------|--------------------|
| 1 | ST | Dark | Dark | Dark | Dark | Light | Light | Light | Light | Light |
| 2 | FTW | Dark | Dark | Dark | Dark | Light | Light | Light | Light | Light |
| 3 | CA | Dark | Dark | Dark | Dark | Light | Light | Light | Light | Light |
| 4 | FF | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 5 | DF | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 6 | LJT | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 7 | SEW | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 8 | SHW | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 9 | NJT | Light | Light | Light | Light | Light | Light | Light | Light | Light |
| 10 | PEW | Light | Light | Light | Light | Light | Light | Light | Light | Light |

individual 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 the qualitative analysis. Based on a review of previous studies on semantic differential analysis of soundscapes [2,5,7,8,11,14-16] nine pairs of antonymous adjectives were identified for the qualitative analysis of individual water sounds. The qualitative descriptors of water sounds selected consisted of relaxation (relaxing-stressful), naturalness (natural-artificial), familiarity (familiar-unfamiliar), freshness (refreshing-weary), perceived sharpness (sharp-flat), perceived roughness (rough-smooth), speed (fast-low), envelopment (enveloping-directional) and temporal variation (unsteady-steady). Relaxation, familiarity and freshness were selected in view of understanding how components related to emotional attributes might influence water sounds' perception in the context of relaxation and peacefulness. In addition, naturalness was included in order to study how different water features made subjects think of natural or artificial sounds. Furthermore, perceived sharpness, perceived roughness, temporal variation and spatial quality were investigated in this analysis in order to understand how individual physical properties of sounds can drive subjective perception for different waterscapes used over road traffic noise. The latter choice was also made in view of allowing a comparison between results obtained in terms of perceptual properties of sound and the physical parameters measured for the corresponding water sounds tested. Each pair of antonymous adjectives was assigned a five point rating scale (e.g. very relaxing, relaxing, neither relaxing nor stressful, stressful, very stressful).

3. Results

Thirty-eight subjects (19 females and 19 males) passed the consistency test (judgement within a 95% confidence interval) 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". The average scores obtained for each attribute are given in Table I. Results pointed out that water sounds like ST, CA and FTW were defined by the words relaxation, freshness, naturalness and familiarity and tended to be preferred. Among all water features studied in this work, SHW, FTW and CA have larger sharpness, but CA and SHW were rated as having low perceived sharpness. The same trend was observed for sounds (ST and LJT) with larger roughness. However, a good agreement was found between the low perceived sharpness expressed for the natural stream (ST) and its actual value of sharpness. This suggests that people might not be able to correctly make judgements on sound quality parameters. Water sounds generated from LJT and NJT were defined as directional (i.e. not enveloping) sounds, and tended not to be preferred. Finally, it is interesting to note that the natural stream (ST) was not highly rated for the attribute envelopment: this sound was judged as not very enveloping. This result was not expected due to the strong spatial quality reflected in the left and right channels of the binaural recording of the natural stream (this sound was measured at the junction of two streams). This might be due to the fact that people rated envelopment as a quality for which no direction can be associated to the sounds (i.e., not

even a combination of right and left channels, as in the case of ST).

3.1 Principal components affecting water sounds' perception

A principal component analysis (PCA) was carried out in view of identifying whether it was possible to group semantic attributes under different components. Results showed that three main components are important in the characterisation of different waterscapes, as shown in Table II. The first component is related to the qualitative properties of water sounds. The second and third components are related to psychoacoustical and physical properties of sounds. Component 1, called 'emotional assessment', includes attributes such as relaxation, naturalness, freshness, and familiarity. Component 2, called 'sound quality', consists of perceived sharpness, perceived roughness and speed. Component 3, called 'envelopment and temporal variation', includes envelopment and temporal variation. Component 1 explains 32% of the total variance, followed by component 2 with 20% and component 3 with 14%. This result suggests that emotional attributes had a greater weight on waterscapes' characterisation than physical properties of sounds. This means that subjective perception of waterscapes depends mainly on the emotional components associated to each stimulus. However, it is also affected, but in a less significant way, by components related to sound quality.

3.2 Correlations between semantic attributes

The analysis of correlations (Spearman test) between average scores obtained for each semantic attribute showed that relaxation, naturalness, freshness, and familiarity are positively correlated with each other ($p < 0.01$). This suggests that these attributes provide a mutually positive contribution to each other. For example, water sounds' perception related to relaxation increased as water sounds were highly rated for naturalness, and vice-versa. It was also found that relaxation, naturalness, freshness and familiarity are negatively correlated with perceived sharpness and perceived roughness ($p < 0.05$). High values of perceived sharpness or perceived roughness were associated to water sounds poorly rated in the attributes of relaxation, naturalness, freshness and familiarity. In addition, the attribute speed (fast-slow) was found to be correlated with envelopment ($p < 0.01$). A significant correlation was also found between temporal variation and naturalness ($p < 0.05$), familiarity ($p < 0.01$) and envelopment ($p < 0.01$).

Table II. Principal components affecting waterscapes' perception.

| <i>Component</i> | <i>Attribute</i> |
|---|---|
| Component 1 'Emotional assessment' | Relaxation Naturalness Freshness Familiarity |
| Component 2 'Sound quality' | Perceived sharpness Perceived roughness Speed |
| Component 3 'Envelopment and temporal variation' | Envelopment Temporal variation |

3.3 Correlations between semantic components/attributes and audio-only preferences

The analysis of correlations between results obtained from the semantic components and subjective preferences from the audio-only test is shown in Table III. Component 1 (emotional assessment) is significantly correlated with audio-only preference scores and within it, relaxation, naturalness and freshness are significantly correlated with preferences. This component had a positive relationship with preference scores suggesting that 'emotional assessment' can strongly affect subjective perception by increasing preferences scores in the audio-only test. On the contrary, the correlation between component 2 (sound quality) and audio-only ratings was found to be negatively significant. Significant negative correlations with preferences were found in particular for perceived sharpness and perceived roughness. In addition, no correlation was found between component 3 and preference scores. The negative relationship found for component 2 can be considered as follows: low levels of perceived sharpness, perceived roughness and speed were associated to water sounds which tend to be preferred in the context of peacefulness and relaxation. On the contrary, the sharper or rougher the water sound was judged, such as NJT and PEW, the more negatively it was rated in the audio-only test, although it should be noted that NJT and PEW are not characterised acoustically by high sharpness and high roughness. The contradiction between psychoacoustical data and semantic characterisation of NJT and PEW sounds might be attributed to the difficulty of subjects in correctly judging water sounds in terms of sound quality. Overall, it can be concluded that most of the attributes related to 'emotional assessment' as well as perceived

Table III. Correlations (Spearman coefficient) between semantic components and subjective preferences obtained from the audio-only tests.

| Component | Correlation coefficient (ρ) |
|---------------------------|------------------------------------|
| 'Emotional assessment' | 0.81** |
| 'Sound quality' | -0.87** |
| 'Envelopment and temporal | -0.30 |

** Correlation significant at the 0.01 level ($p < 0.01$)

sharpness and perceived roughness, had an important role in waterscapes' perception.

3.4 Correlations between perceptual components and physical parameters of water sounds

An analysis of correlations (Spearman test) was made in order to identify the relationship between the qualitative assessment of different waterscapes used over road traffic noise and the physical properties of the corresponding sounds. Results showed that temporal variation in level ($L_{A10}-L_{A90}$) positively correlates ($p < 0.05$) with component 3, 'envelopment and temporal variation', for water sounds and road traffic noise (RTN), as shown in Table IV. Roughness was also found to be positively correlated ($p < 0.05$) with components 2 and 3. In addition, a significant correlation ($p < 0.05$) was obtained for pitch strength in relation to component 1. Overall, it can be observed that the significant correlations obtained do not provide clear explanations in finding a relationship between individual physical parameters and semantic components of water sounds. Furthermore, the analysis carried out between average scores obtained for each semantic attribute and acoustical/psychoacoustical parameters showed that sharpness and roughness are negatively correlated with the attributes speed and envelopment, whilst temporal variation in level ($L_{A10}-L_{A90}$) positively correlates with speed and envelopment. In addition, pitch strength is negatively correlated to familiarity. These results suggest that people are unable to correctly assess sharpness, roughness and temporal variation in level ($L_{A10}-L_{A90}$), as no correlations between physical parameters and their corresponding perceptual descriptors were found. Overall, there was no clear trend in finding a unique relationship between individual acoustical/psychoacoustical parameters and ratings obtained from the qualitative characterisation of water sounds in the presence of road traffic noise.

Table IV. Correlations (Spearman coefficient) between semantic components and acoustical/psychoacoustical parameters of water sounds over road traffic noise.

| | Component 1 | Component 2 | Component 3 |
|-------------------|-------------|-------------|-------------|
| $L_{A10}-L_{A90}$ | 0.70 | 0.45 | 0.75* |
| $L_{Ceq}-L_{Aeq}$ | 0.45 | 0.13 | -0.20 |
| Sharpness | -0.18 | -0.33 | -0.50 |
| Roughness | 0.17 | 0.67* | 0.71* |
| Pitch strength | -0.64* | 0.14 | 0.24 |

* Correlation significant at the 0.05 level ($p < 0.05$)

3.5 Discussion

Three principal components were identified as important in the characterisation of different waterscapes used over road traffic noise in the context of peacefulness and relaxation. Component 1, 'emotional assessment', was related to the subjective preferences produced by emotional attributes of sounds, and its attributes included relaxation, freshness, naturalness and familiarity. Components 2 and 3 were related to psychoacoustical and physical properties of sounds. Component 2, 'sound quality', consisted of perceived sharpness, perceived roughness and speed; whilst component 3 included envelopment and temporal variation. Results pointed out that water sounds defined by the words relaxation, freshness, naturalness and familiarity like ST, FTW and CA, tended to be preferred. This suggests that sound properties related to emotional attributes might be used for improving waterscapes' perception in the context of peacefulness. Results obtained for component 2 showed that people are not able to correctly make judgements on sound quality parameters: the perceived sharpness and perceived roughness did not always correspond to the actual values of sharpness and roughness calculated for the water sounds considered. The exception was represented by the good agreement between the low perceived sharpness expressed for the natural stream (ST) and its calculated value of sharpness. In addition, water sounds, such as NJT and LJT, defined by the adjective directional tended not to be preferred. Finally, it was interesting to note that people rated envelopment as a quality for which no direction can be associated to the sound (i.e. not even a combination of right and left channels, as in the case of ST). The analysis of correlations (Spearman test) showed a positive relationship between component 1 and preferences. On the contrary, component 2

correlated negatively with water features' auditory ratings. Significant negative correlations with preferences were found in particular for perceived sharpness and perceived roughness. This negative impact on water sounds' perception could however be interpreted as follows: the more the water sounds were defined by low perceived sharpness and low perceived roughness, the more they tended to be preferred in the audio-only condition. Overall, it can be concluded that most of the attributes related to 'emotional assessment', as well as perceived sharpness and perceived roughness can strongly affect waterscapes' perception. In addition, no clear trend could be found to identify a unique relationship between semantic components/attributes and acoustical/psychoacoustical parameters for the water sounds considered in this study. No correlations were found between sharpness, roughness and temporal variations and their corresponding perceptual descriptors, suggesting that people are unable to correctly assess these sound qualities for water sounds used over road traffic noise. On the contrary, the perception of speed and envelopment were strongly correlated with acoustic ($L_{A10}-L_{A90}$) and psychoacoustic (sharpness and roughness) parameters.

4. Conclusions

Following from previous research [6,13], the present study aimed at evaluating the qualitative characterisation of different waterscapes that can be used in gardens or parks for improving relaxation. Three perceptual components ('emotional assessment', 'sound quality' and 'envelopment and temporal variation') were identified as principal elements to be considered for the soundscape design of water features used over road traffic noise. In particular, properties related to the emotional attributes of sounds were found to be strongly influential on subjective perception. Furthermore, a relationship was also found between auditory preferences and attributes related to psychoacoustical and physical properties of sounds, but in a less significant way. In addition, the analysis of correlations between perceptual components and corresponding acoustical-psychoacoustical parameters could not identify a unique relationship between perceptual and physical parameters.

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