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THE ROLE OF WATER SOUNDS IN MULTI-SENSORY ENVIRONMENTS

ABSTRACT

Water sounds have always been, and are still nowadays, absolutely among the most appreciated natural sounds. Besides its multiple types of emission in terms of loudness, temporal variation and spectral sound distribution, water sounds are rarely interpreted as a negative element.

Furthermore, water sounds evoke positive sensations and expectations, and the informational masking of water sounds is effective in mitigating the adverse effects of noise. From a psychophysiological perspective, listening to water sounds can improve the perceived Restorativeness of a place, induce neural relaxation, or activate the parasympathetic nervous system responsible for stress relief.

This review analyses the role of water sound in multi-sensory environments through the investigation performed in several disciplines. In the first part, we briefly describe the typologies of sounds generated by water, then the effects that water sounds can have on humans, and in the end, are presented the preliminary results of a study on the emotions elicited by water noise conducted at Isola del Liri, a unique historical village in central Italy where inhabitants cohabit daily with a waterfall noise.

1. THE CHARACTER OF WATER SOUND

The water sound is produced by water movement, the flowing along a path, or the falling on a surface. It is mainly a white sound, characterized by equal energy across all frequencies and with no dominant tones. Water sound is associated with the movement of water along natural elements, such as rivers or waterfalls. Moreover, water sounds can also be produced by artificial elements which mimic natural ones, like water structures. Dewar [1] grouped water structures into three types: still water structures, moving water structures, and fountains. A classification of sounds produced by moving water structures and fountains was proposed by Rutherford [2] into: 1) jet and basin fountains made up of single or multiple nozzles, distinguished by the sounds produced by the hissing of the geysers and the splashing and bubbling of the water falling into the basin; 2) naturalized waterfalls, whose sound is characterized by the turbulence of the water splashing into a pool of waterfall or impacting on surfaces as it falls; and 3) Linear step or cascade structures generate a line source of sound by involving a series of formal or naturalized steps with vertical drops ranging from centimetres to metres.

The aforementioned water structures produce varying levels of sound. According to Brown and Rutherford [2], a fountain with three large geysers and four smaller geysers distributed over a basin of 18 x 7 meters with an overall flow rate of 20 l/s can generate sound levels ranging from 73 to 79 dB(A), a naturalized waterfall of 6 meters high and 11 meters wide with a flow rate of 125 l/s produces sound levels of 79 dB(A) at its base, and a continuous flow of water with low volume dropping down a series of 20 steps generate sound levels of 67 dB(A).

You et al. in [3] investigated the characteristics of some previously mentioned water structures finding that sounds from streams, falling water, and waterfalls are distinguished by continuous sound pressure levels, whereas water sounds from fountains have different temporal variability of the sound pressure levels. The fountains have been found to have the highest sound pressure level, while the stream has the lowest.

2. THE EFFECTS OF WATER ON HUMANS

Exposure to water sounds protects people against the impact of environmental stressors, improving the human perception of a place and mediating the adverse effects of stress by enhancing positive emotions and changes in physiological activity [4–10].

2.1. HUMAN PERCEPTION

Paton et al. in [11], aiming to determine the factors that affect human acoustic comfort, investigated 16 different water sounds:

1) natural: streams, small waterfalls (< 2 m), surf or soft waves (< 1 m), heavy rain during a winter storm and a weak rain in spring;
2) water jets: jets of medium size (~ 2 m), jets of long size (> 4 m), intermittent jets, multiple jets that do not collide and jets that collide;
3) waterfall of small (50 cm), medium (1.5 m) and high (> 4 m) height;
4) faucet/dripping, with regular, irregular, temporary, or multiple simultaneous drips.

According to the responses of a sample of 135 subjects, natural sounds are preferred over artificial sounds, and more specifically, water jets and waterfalls produce a marked acoustic aversion to humans.

On the other hand, Pérez-Martínez et al. [12] investigated the perception of dominant sounds in 19 sites in the Alhambra (Granada), which are primarily distinguished by the presence of water sounds in large part of its extension and in various forms (e.g., fountain, water flowing, and waterfalls). According to a survey conducted on a sample of 385 people, 58.7% of participants identified the water sound, while 38.2% of participants identified the water sound as dominant, mainly in 8 locations. Moreover, 83.6% of participants evaluated the water sound as pleasant, only 3.1% as unpleasant, and the remaining part (13.3%) as neutral.

As the water sound spectrum may be similar to the city noise spectrum, some components of urban noise can be masked by water sounds. In effect, when the city background noise is at least 8 to 10 dB(A) below the water sounds, it can be completely masked. Partial masking occurs when the differences become smaller [2]. De Coensel et al. [13] explored the potential of fountains as a partial masking means. They showed that introducing sound from water structures into the urban setting reduces the perceived loudness of the freeway and major road traffic noise.

Moreover, water structures characterized by sounds with low sharpness and large temporal variation, such as sea and water streams, are highly effective in terms of information masking of road traffic noise, improving the sound environment's overall pleasantness preferable to fountains and waterfalls [14,15].

2.2. PSYCHOPHYSICAL EFFECTS

The effects induced by evocative audio-visual water structure on the perceived restorativeness in an urban park were investigated by Masullo et al. [16]. An immersive audio-visual virtual reality experiment with different water structures was used.

More specifically, water structures with regular or wrapping shapes combined with four different water sounds (big and small sea waves; big and small river) and a basic scenario simulating the urban park as it was, were used. The degree of Restorativeness of each scenario was measured using the Perceived Restorativeness Scale. The results showed that all the scenarios were perceived as restorative compared to those without water structures. The river sound seemed to induce a greater perceived Restorativeness with respect to the sound of sea waves (Figure 1).

The overall mental state assessment and brain network changes of brain processes related to informational masking of road traffic noise were investigated using EEG measurements by Li et al. [17]. During the listening test, the road traffic noise was combined with fixed, switching and moving water sound sources. The EEG spectrum results showed that the introduction of water sound in a traffic noise environment increases the power of the alpha band with a consequent enhancement of neural relaxation confirmed by the alpha-beta ratios (Figure 2), an index representative of mental relaxation opposite to mental fatigue and mental stress.

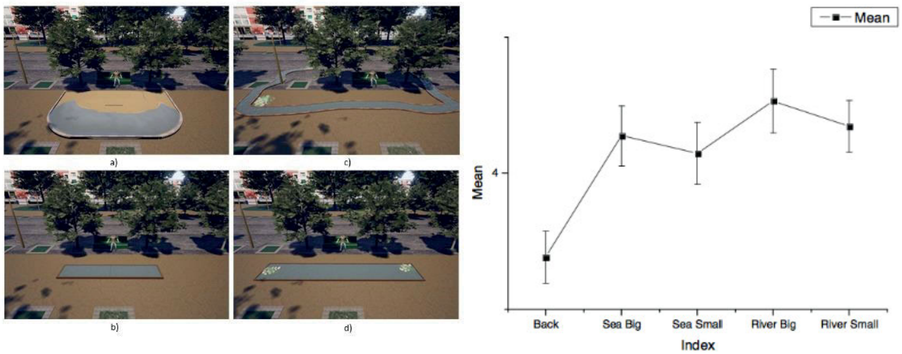

Figure 1. Left: The virtual reality scenarios: (a) big sea waves; (b) small sea waves; (c) big river; (d) small river. Right: Result of perceived Restorativeness extracted from Masullo, M., Maffei, L., Pascale, A. Effects of combination of water sounds and visual elements on the traffic noise mitigation in urban green parks. Proceedings of Internoise 2016, Hamburg, Germany, 21-24 August.

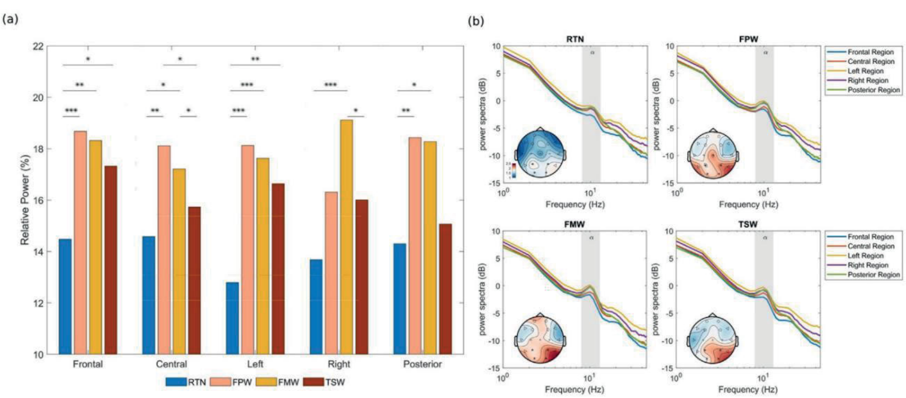

Figure 2. Left: The average relative power of alpha band across five regions between four conditions: RTN – road traffic noise; FPW — frontal position-fixed water sound; TSW - two-position switching water sound; FMW- four positioned — randomized moving water sound. Right: power spectrum of EEG across five regions between four conditions with topography of the alpha band is depicted. The asterisks indicate the significance level of the post hoc ANOVAs results: *p < 0.05, **p < 0.01, and ***p < 0.001 extracted from Li, J., Maffei, L., Pascale, A., Masullo, M. (2022). Neural Effects of the Spatialisation of Water-Sounds Sequences on Masking Traffic Noise: a Psychophysical Study. J. Acoust. Soc. Am. 152(1), 172-183.

Furthermore, Shu and Ma have investigated the physiological responses (Electrodermal Activity, EDA; Hearth Rate Variability, HRV) [18]. Their study tested the restorative effects of different soundscapes on children's stress in a simulated urban park setting. The study used a stream and a fountain sound as potential restorative water structure. The physiological responses were measured during and after a stressor task. When comparing the stressor and recovery periods, the findings revealed that children's levels of EDA and HRV (Beats Per Minutes) decreased significantly during both water sounds structures exposure. More specifically, the EDA decreased more during fountain sound exposure.

3. EMOTIONS AND WATERFALLS SOUND POWER

Isola del Liri is a small town in central Italy whose historic centre is characterized by the presence of waterfalls. The territory is rich in watercourses such as those of the river Liri, Melfa, Rapido and Fibreno, which led to the installation of numerous paper mills [19]. The town is characterized by two waterfalls named "Cascata Grande" and "Cascata del Valcatoio". The waterfall named "Cascata Grande" is the big one (Figure 3), and it is formed by the right arm of the Liri river, and it is about 27 meters high.

The waterfall area is surrounded by the Boncompagni - Viscogliosi Castle, Via Cascata, which is lined with restaurants, bars,

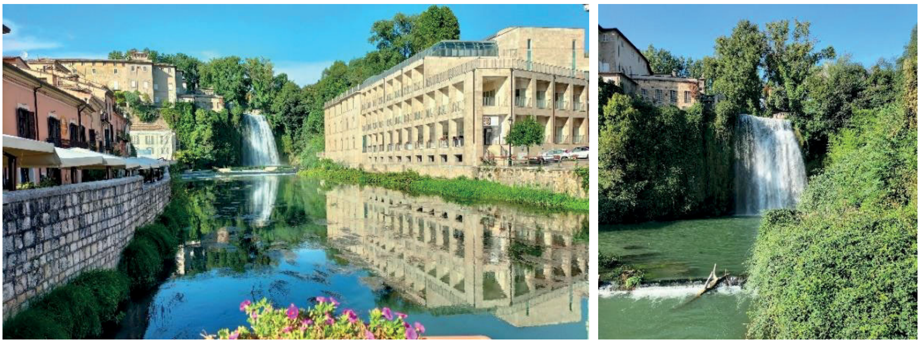

Figure 3. Isola del Liri. Cascata Grande Waterfall.

and pizzerias, the town hall, and the ex-felt factory Ippolito & Pisani, which houses a gallery and the panoramic terrace overlooking the waterfall. The sonic environment is defined by typical café and restaurant sounds, music, people's conversations, road traffic noise, and, most notably, the sound of the waterfall.

Spot binaural recordings were carried out on September 2022 while the waterfall flow rate was medium-low. A 4-channel recording/playback system SQobold and a binaural headset BHS II were used. For the acoustic measurements were selected three sites: the panoramic terrace overlooking the waterfall (ex-felt factory Ippolito & Pisani); via Cascata (closer to Boncompagni – Viscogliosi castle) and an area hidden from the view of the waterfall (Piazza San Lorenzo) (Figure 4).

The acoustic measurement results showed that the A-weighted sound equivalent level is 77.2 dB(A) in the proximity of the waterfall, and it decreases in the shadow area where the A-weighted sound equivalent level becomes 55 dB(A). In the intermediate area overlooking the waterfall, the noise level was measured at 67 dB(A).

Simultaneously, to investigate the effects of the waterfall sounds on the surrounding environment, a questionnaire was

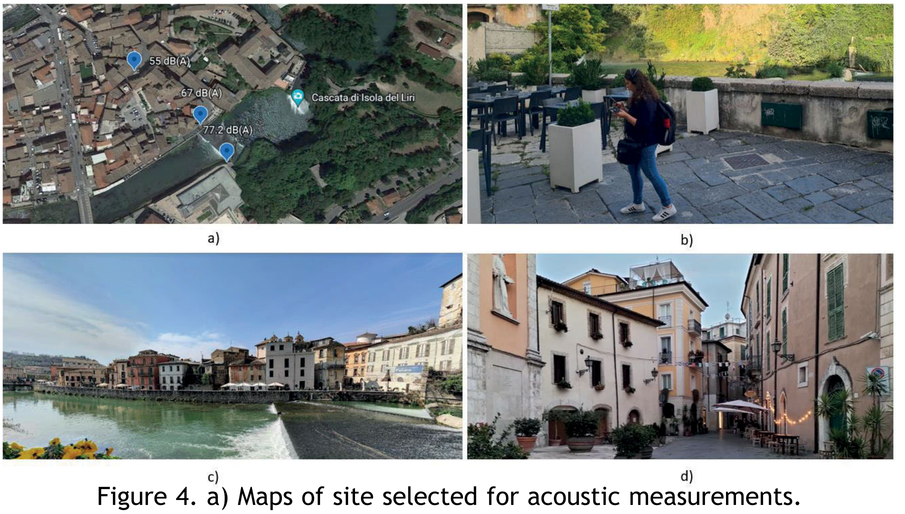

Figure 4. a) Maps of site selected for acoustic measurements.
b) Spot binaural recordings. c) area overlooking the waterfall.
d) shadow area from view
of the waterfall.

administered to local people who were present in the waterfall area. The questionnaire was divided into three sections: 1) General information on socio-demographic data; 2) Weinstein Noise Sensitivity Scale [20, 21]; and; 3) Emotional Salience [22]. More specifically, the last section of the questionnaire aimed to assess the sonic environment perception and the feelings provoked by the auditory stimuli. To this aim, two 6-items questionnaires on a 9-point Likert scale were used.

Ten people were involved in the survey (7 male and 3 female) ranging from 18 to 39 years. Half of them visit the waterfall area daily, while the rest stay in the area several times per year (3) or per week (2). The participants' noise sensitivity was measured using the italian version of the Weinstein Noise Sensitivity Scale.

The subjective questionnaire results revealed that the waterfall sound is perceived as Pleasant, Attractive, and Stimulating (Fig 5 left), while, on the other hand, it induces a state of Calm, causing people to feel Happy and to be Energetic (Fig 5 right).

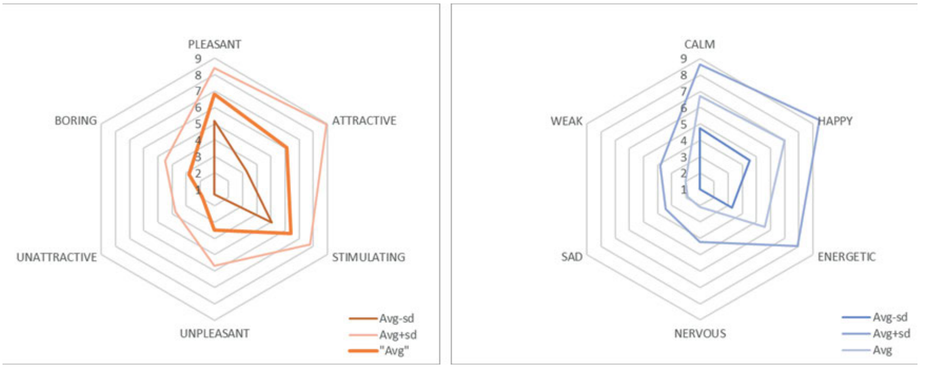

Figure 5. Results of the 6-items questionnaires. Left: sonic environment perception; Right: feelings provoked by the auditory stimuli.

4. CONCLUSIONS

In this paper, the role of water sound in multisensory environments has been described. The results that emerged from the studies of different disciplines showed that the use of water sounds has a positive effect on human well-being and environmental perception. Among the various water sounds investigated, the waterfall is less preferred when compared to other water sounds.

However, the investigation carried out in the small town of Isola del Liri where the presence of a huge and continuous waterfall is responsible, all day and night long, for sound levels in the range 55–77 dB(A), showed that the sound environment is evaluated positively by the people interviewed and induces positive emotions.

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