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AUDIO-VISUAL PREFERENCES OF WATER FEATURES USED IN OPEN-PLAN OFFICES

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Noise masking has proven to be effective in reducing the annoyance of irrelevant speech in open-plan offices, and water generated sounds have been suggested as potential masking sounds. Within that context, this paper examines the use of water generated sounds as a mean of masking irrelevant speech and improving the sound environment in open-plan offices. Two experiments were carried out. The first experiment aimed to identify the preferred sound pressure level of the water sounds in the presence of irrelevant speech. The second experiment examined the audio-only and audio-visual preferences of different waterscapes. Thirty-nine participants took part in the first experiment, in which two water sounds were played at five different sound pressure levels against a constant level of irrelevant speech (48 dBA). In the second experiment, 33 participants evaluated the audio-only and audio-visual preferences of six different water features. Paired comparisons were adopted in both experiments. The results showed that, within a working context, people prefer to listen to water sounds that are 3 dB lower than the level of irrelevant speech (i.e., 45 dBA). Preferences were found to be different between audio-only and audio-visual settings. In addition, different water sounds were found to be differently affected by the visual stimuli.
Keywords: water sounds, noise masking, soundscape.

1. Introduction

The economic advantages of open-plan offices over private ones are evident; however, these advantages do not come cheap. People working in open-plan offices have been reported to be dissatisfied with their work environment [1], fatigued [2], and less concentrated and subjectively impaired to carry out their tasks [2,3]. Dissatisfaction with the acoustic environment, i.e., background noise and lack of speech privacy, have repeatedly been highlighted as the main cause of these issues [4-6]. Among the noise sources, intelligible speech coming from co-workers has been identified as the most annoying type of noise and hence has the largest impact on the comfort level of people working in open-plan offices [3,7–11]. The performance level of cognitive tasks has also been reported to be negatively affected by intelligible speech [7].

Introducing a masking system to make speech less intelligible has been reported to be beneficial towards reducing the annoyance level caused by intelligible speech in open-plan offices [11,12]. The masking approach attempts at increasing the background noise level by introducing a neutral sound (a masking sound), which subsequently decrees the signal-to-noise ratio of the speech and makes it less intelligible [9,13,14]. Examples of masking sound used in previous research are pink noise [15, 16], white noise [17] and filtered pink noise whose sound pressure level decreases 5 dB per octave band [8,18,19].

Water sound, on the other hand, is a natural sound that has inherent positive qualities [20] and physical properties that make it a potential noise masker [21]. It is a broadband and continuous type of noise which can mask a wide range of unwanted sounds without containing much information itself to distract people's attention away. Water sounds have been successfully used over road traffic noise to create a more peaceful and relaxing sound environment [21], and there is scientific evidence suggesting that water sound could be a better speech masker than the conventional artificial masking noises [11].

There are some guidelines available in the literature regarding the appropriate level of masking sound, but these are restricted to artificial types of masking noise such as pink noise and white noise [22]. The sound pressure level and types of water sound to be used as a speech masker are yet to be examined. In the light of the above discussion, it was decided to carry out two experiments under controlled conditions. The first experiment, *sound level preference test*, aimed to identify the preferred sound pressure level of water sounds used over irrelevant speech, and the second experiment, *audio-visual tests*, aimed to identify the types of water sound/water feature that would be preferred in open-plan offices. The audio-visual preference test was included as previous soundscape research reported increased levels of preference and satisfaction when the audio materials were accompanied by appropriate visual stimuli [23–28].

2. Water sounds

The water sounds used as a masking noise in this study were taken from a previous study carried out at Heriot-Watt University [21]. Six water features were selected as representative of a variety of designs that could be installed in an open-plan office. The water features were a 37-jet fountain (FTW), a dome fountain (DF), a foam fountain (FF), a large jet (LJT), a narrow jet (NJT), and a cascade (CA). More specific information regarding the water features and their properties can be found in the original paper [21]. For the sound level preference test, only two water sounds were included, CA and FTW, which had been identified as being preferred in a previous study [28]. For the audio-only and audio-visual preference tests, all six water sounds were included.

3. Speech recordings

A high-quality recording of speech was used as a source of irrelevant speech. The speech recording was the same as the one used by Veitch et al. [22] in their study on masking speech in open-plan offices. The original recording consisted of 15 minutes of almost continuous speech of a single female voice speaking at a realistic speech level. The speech comprised one-sided dialogues simulating one side of telephone conversations, represented by the voice of an actress reading scripts of telephone conversations, in which she called job candidates to arrange for interviews, made internal arrangements for new employees and made personal social calls [22]. The water sounds used in this study were 7s long and therefore, the speech signal was divided into 7s long sentences to match the length of the water sounds.

Each 7s speech recording was separately calibrated to have an equivalent A-weighted sound pressure level, L_{Aeq} of 48 dB. According to laboratory experiments [9], the sound pressure level of normal effort speech at a neighbouring workstation in an open-plan office varies between an L_{Aeq} of 39 dB and 55 dB. Similar measurements were made by Hongisto et al. [29] and Virjonen et al. [14], however, the level of speech did not fall below 45 dBA in the nearest workstation. In addition, when the background speech level exceeds 48 dBA, it would be too loud for a masking system to work effectively [30]. The study from which the speech recording is obtained [22] set the speech level to 54.5 dBA at 1m from the speaker. This setting resulted in speech levels ranging from 41.16 to 44.44 dBA across workstations. The reference level of 54.5 dBA is around 3 dB lower than the speech level of 57.4 dBA recommended by the ISO 3382-3 [31] for open-plan offices. The speech level of 48 dBA used in the current study is, therefore, justifiable on the ground of the above field evidence. This level represents the highest level of speech at which a masking system could be beneficial. Improving speech privacy at this speech level would ensure a greater benefit at lower speech levels.

3.1 Participants

Thirty-nine participants took part in the sound level preference experiment. Two participants reported having tinnitus, and 9 participants did not perform well in the consistency test (consistent judgments within a 95% confidence interval). Therefore, 28 participants (15 males, and 13 females), aged between 23 to 48 yr (M = 30.93, SD = 5.70) were retained for further analysis.

For the audio-only and audio-visual preference tests, 33 participants who reported a normal hearing ability took part in the tests, and 31 of those (16 males, 15 females) passed the consistency test (consistence judgements within a 95% confidence interval). The age distribution of retained participants ranged between 24 yr and 60 yr (M = 36.35 yr, SD = 9.32 yr).

3.2 Audio processing and calibration

Digital audio processing was achieved through using Studio One 3 audio production software (PreSonus Audio Electronics) installed on a personal computer (PC) connected to an external M-Audio USB sound card. Calibration of the audio files was carried out through using a Brüel & Kjær handheld sound analyser, Type 2250, connected to the external sound card.

3.3 Statistical analysis

The ordinal nature of the data made non-parametric statistical models more appropriate for the statistical analysis of the data [32]. The data were analysed using IBM SPSS 22 for Windows. Since the same participants took part in the tests, Friedman's 2-way Analysis of Variance (ANOVA) was used to test the statistical differences among preference scores. Pairwise follow-up analysis was carried out whenever Friedman's ANOVA showed a significant difference among preference scores. The p-values were adjusted using Benjamini-Hochberg procedure which controls the expected proportion of falsely rejected hypothesis i.e., the false discovery rate [33]. In addition to the significance value, the effect sizes, r, of the pairwise comparisons were also calculated. It is worth mentioning that both the Benjamini-Hochberg procedure and effect size calculations are not readily given by SPSS and therefore, Microsoft Excel was used. Differences in preference scores between males and females, as well as different age groups were examined using the Mann-Whitney test [32]. Bias-corrected and accelerated bootstrap method, BCa, was used to derive robust 95% confidence intervals, which are reported in square brackets throughout this paper.

4. Design of tests and procedures

In all tests, participants had to imagine that they were working in an open-plan office where they could hear a water sound and a colleague speaking over the phone at a nearby workstation. The tests were carried out in the highly insulated anechoic chamber of the acoustic laboratory at Heriot-Watt University. The sounds were played through a pair of Beyerdynamic DT 150 closed headphones which were connected to a personal computer (PC) through the M-Audio external USB sound card. The sound output level was adjusted to 48 dBA for the speech signal. Paired comparisons were used for all tests, as these have been proven successful in previous soundscape research [21,28,34–36]. Paired comparisons inherently result in ordinal data that makes preference ranking easy. They are preferred to verbal or numerical rating scales because of their simplicity and greater accuracy [37]. The order of the paired comparisons was randomised among participants and therefore a slide presentation was prepared for each participant. The slide presentations were displayed on the 15 in. screen of the PC for the sound level preference test and on a 27 in. LED monitor (Samsung LS27A350) for the audio-only and audio-visual preference tests. The PC/monitor was placed on a standard office desk, and the participants were seated on an upholstered office chair. Detailed instructions were presented both onscreen and verbally prior to the tests. One participant at a time carried out the tests and each of the two tests lasted between 35 and 40 minutes. A practice session was provided in both tests which allowed participants to become familiar with tests. An evaluation form was prepared to allow for the participants to stated their preferences. Background information such as age, gender, nationality and any sign of hearing impairments were asked in the form. In both tests, the first 10 paired comparisons were repeated at the end of each test to be used as a measure of consistency of the responses. Participants whose scores were below a certain level were removed from the analysis.

4.1 Sound level preference test

The preferred sound pressure level was tested under four scenarios; two water sounds (CA and FTW) and two speech transmission index (STI) conditions (STI 0.50 and 0.78). For each STI condition, the water sounds were played at 5 sound pressure levels (42, 45, 48, 51, and 54 dBA) against a constant speech level of 48 dBA. The higher STI speech signal (STI = 0.78) was achieved through using a dry speech signal plus its reverberant field. Digital Audio Processing was used to add an average reverberation time of 0.5 seconds. The lower STI speech signal (STI = 0.50) was obtained through mixing the dry signal with its reverberant field and a background noise of an L_{Aeq} of 43 dB (i.e., SNR +5). A previously recorded high-quality background noise was selected from the catalogue of "audiosparx.com" after being subjectively reviewed in terms of audio quality, sample length and speech content. The background noise of a busy open-plan office was selected, which had a steady sound level and did not contain any intelligible parts in order not to interfere with the irrelevant speech used in the tests. The inclusion of speech signals with different STIs allowed for the identification of the preferred masking level as a function of the STI of speech.

Two water sounds were tested under two STI conditions which resulted in 40 paired comparisons in total. Each paired comparison consisted of a 7s long water sound played at a certain sound pressure level (SPL) over the speech signal, followed by another 7s long of the same water sound at a different SPL played over the same speech signal. There was a gap of 1 seconds between the two audio signals. Participants would then state their preference by choosing either option 1 or option 2 on the evaluation form. Given the similarities and the subtle difference between the two options, participants were given a third option which was "no preference", although they were discouraged from choosing it. A different speech signal was used for each paired comparison and hence 40 $\times$ 7s speech signals were extracted from the original 15 min long speech recording. Each 7s long speech signal was separately calibrated to have an L_{Aeq} of 48.0 dB.

4.2 Audio-visual tests

After the preferred sound pressure level of the water sound had been identified in the previous stage of the study, audio-only and audio-visual preference tests were carried out in view of identifying the type of waterscape that would be preferred as a speech masker. For these tests, the L_{Aeq} of the water sounds were fixed at 45 dB (more explanations on this level is given in Section 5.1). Paired comparisons were used and 6 water sounds were examined. Visual materials consisted of high quality realistic 3D animations of the water features merged with a photograph of an open-plan office as shown in Fig. 1. The animations were created and rendered using the modelling software Autodesk 3DS MAX 2016. The simulation of the water particles was carried out using RealFlow 2015.

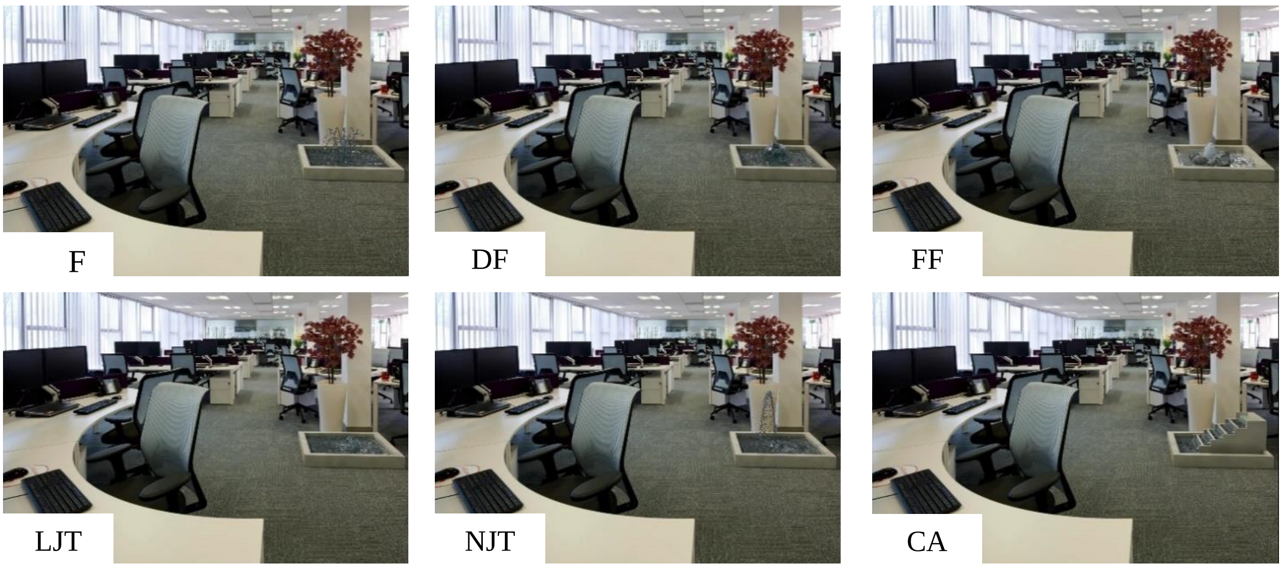

Figure 1: Still images from the 3D animations of the water features. Background image: Flickr [38]

For each paired comparison of the audio-only test (no animations used), participants had to select the water sound which they preferred working in over a long period of time. In the audio-visual preference test, participants could listen and see pairs of water features and they had to select the options they preferred working in over a long period of time. Six water features were used and hence 15 paired comparisons were included for each of the audio-only and audio-visual tests, plus 10 additional ones to account for the participants' consistency in giving preference scores. To avoid order effects, the sequence of paired comparisons was randomised for each participant, but the audio-only test was always carried out before the audio-visual test. Participants were free to take a short break between the audio-only and audio-visual tests, to avoid fatigue and to maintain a high concentration level. Each paired comparison consisted of 7s of item 1 (sound only or sound and animation), 1s of silence/blank slide, 7s of item 2, and 3s of silence/blank slide before the next pair was played.

5. Results

5.1 Sound level preference

Preference scores for each condition, i.e., FTW-STI.50, FTW-STI.78, CA-STI.50, and CA-STI.78, plus the overall preference scores were normalised to have a value between -2 (never preferred) to +2 (always preferred). Fig. 2 shows the normalised preference scores of each condition alongside the average preference score.

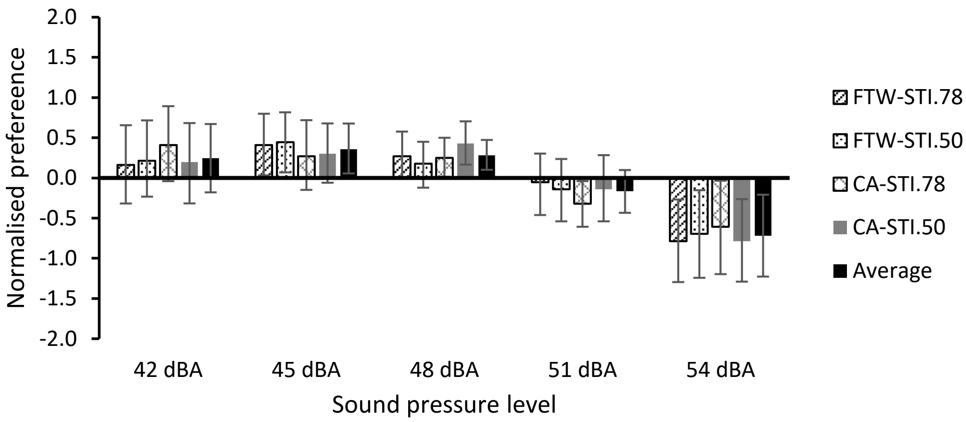

Figure 2: Normalised preference scores for the four conditions alongside the averaged preference scores. Error bars represent the Bias-corrected and accelerated 95% confidence intervals.

The statistical analysis revealed that the alteration in STI and types of the water sound did not have a significant impact on preference scores at 42 dBA ($\chi^2(3) = 2.683$, $p = .443$), 45 dBA ($\chi^2(3) = 0.451$, $p = .929$), 48 dBA ($\chi^2(3) = 1.967$, $p = .579$), 51 dBA ($\chi^2(3) = 0.904$, $p = .824$), and 54 dBA ($\chi^2(3) = 1.739$, $p = .628$). The analysis suggests that at each level, people perceived the four conditions to be similar. Therefore, an average score from all four conditions was used for further analysis.

Bias-corrected and accelerated bootstrap 95% CIs are reported below in square brackets. The average preference score at each sound level was calculated and the preferred SPL was found to be 45 dBA, *M* = 0.36 [0.06, 0.68], followed by 48 dBA, *M* = 0.28 [0.10, 0.47], and 42 dBA, *M* = 0.25 [-0.18, 0.66]. The least preferred SPLs were 54 dBA, *M* = -0.72 [-1.23, -0.21], followed by 51 dBA, *M* = -0.17 [-0.43, 0.10]. The confidence intervals provide valuable information regarding the preference scores. For 45 and 48 dBA, the 95% CIs remain positive on average, i.e., do not cross zero, which give more confidence to the positive preference scores given to 45 and 48 dBA. Similarly, the 95% CI for the 54 dBA level remains negative, adding more certainty to the lower scores given to this level. However, for the 42 and 51 dBA levels, their 95% CIs pass through zero, making the positive score for 42 dBA and the negative score for 51 dBA less reliable. Therefore, it can be suggested that a sound pressure level between 45 and 48 dBA is preferred for water sounds to be used as a speech masker in an open-plan office.

Statistically, preference scores were significantly affected by the level of the water sound, $\chi^2(4) = 14.268$, $p = .007$. Pairwise comparisons with Benjamini-Hochberg adjusted *p*-values were used to follow up this finding. It appeared that the 54 dBA level was significantly less preferred than 45 dBA (z = -3.254, $p = .010$, $r = -.435$), 48 dBA (z = -2.916, $p = .020$, $r = -.390$), and 42 dBA (z = -2.747, $p = .020$, $r = -.367$). No further statistically significant differences were found between preference scores of the other sound levels ($p > .05$).

The gender of participants did not have a significant impact on preference scores for all the sound pressure levels tested ($p > .05$). Furthermore, participants were divided into two age groups, *below 30 yr* (N = 14), and *30 yr and above* (N = 14). No statistically significant differences were detected between these two groups at any sound level ($p > .05$).

5.2 Audio-only and audio-visual preferences

Preferences obtained from the paired comparisons of both audio-only and audio-visual tests are shown as a bar chart in Fig. 3, with error bars representing the BCa 95% confidence intervals. All preference values were normalised to an arbitrary -2 to +2 scale with -2 representing never preferred and +2 denoting always preferred.

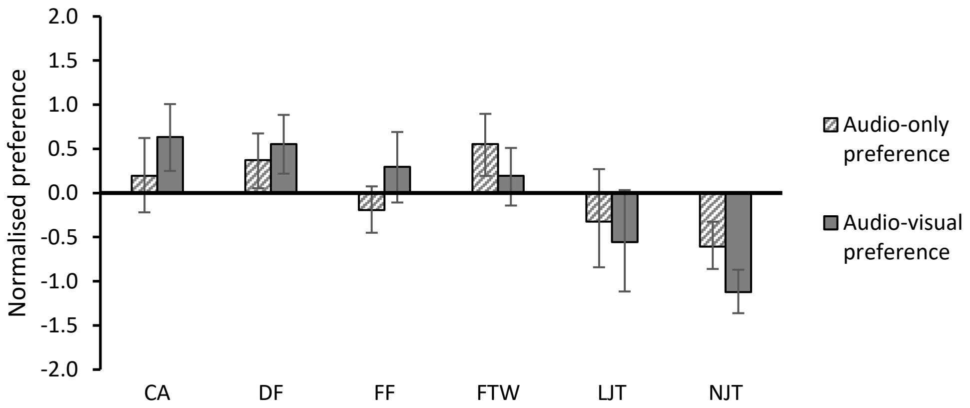

Figure 3: Audio-only and audio-visual normalised preference scores. Error bars represent the Bias-corrected and accelerated 95% confidence intervals.

Audio-only preferences show preferred water sounds to be FTW (*M* = 0.55 [0.19, 0.90]), DF (*M* = 0.37 [0.05, 0.68]), and CA (*M* = 0.19 [-0.22, 0.62]). The least preferred water sounds were NJT (*M* = -0.61 [-0.86, -0.33]), LJT (*M* = -0.32 [-0.84, 0.27]), and FF (*M* = -0.19 [-0.45, 0.08]). Statistically, preference scores were significantly affected by type of the water sound, $\chi^2(5) = 18.535$, $p = .002$. Pairwise comparisons with Benjamini-Hochberg adjusted *p*-values indicated that NJT was significantly less preferred than FTW (z = -3.530, $p < .001$, $r = -.448$), and DF (z = -3.123, $p = .015$, $r = -.397$). No statistically significant differences were detected between the preference scores of the remaining water sounds.

Audio-visual preferences revealed the preferred water feature to be CA (*M* = 0.63 [0.25, 1.01]), followed by DF (*M* = 0.55 [0.22, 0.88]), FF (*M* = 0.30 [-0.11, 0.69]), and FTW (*M* = 0.19 [-0.14, 0.51]), respectively. The least preferred water feature was NJT (*M* = -1.12 [-1.36, -0.87]), followed by LJT (*M* = -0.55 [-1.12, 0.03]). Preference scores were significantly affected by the type of water feature, $\chi^2(5) = 35.472$, $p < .001$. Pairwise comparisons with Benjamini-Hochberg adjusted *p*-values indicated that NJT was significantly less preferred than CA (z = -4.718, $p < .001$, $r = -.599$), DF (z = -4.480, $p < .001$, $r = -.569$), FF (z = -3.632, $p < .001$, $r = -.461$), and FTW (z = -3.724, $p < .001$, $r = -.473$). Moreover, NJT was significantly less preferred than CA (z = -3.157, $p = .006$, $r = -.401$), and DF (z = -2.919, $p = .010$, $r = -.371$). No statistically significant differences were detected between the preference scores of the remaining water features.

The addition of the visual animations seemed to have helped people to be more confident in stating their preferences. The difference between the most and least preferred water features was larger for the audio-visual test, in comparison to the audio-only test. The feature that most benefited from the visual stimuli was FF which was negatively perceived in the audio-only preference test, but then positively perceived after its sound was accompanied by a visual animation. On the other hand, NJT benefited the least from its visual animation, followed by FTW. It is worth mentioning that due to the use of paired comparisons, it cannot be concluded that the visual stimuli had a negative impact on people's perception of the water feature. The results simply suggest that some water sounds benefited more from the visual stimuli.

6. Discussion

The experiments carried out in this study resulted in the identification of the preferred sound pressure level and types of water sound to be used as a speech masker in open-plan offices. The preferred sound level was found to be 45 dBA, which was 3 dB lower than the speech level of 48 dBA used in this study. This confirms the previously recommended level of masking sounds [11,21]. It should also be noted that, preference scores given to 42 and 48 dBA were not significantly lower than that of 45 dBA, suggesting that these levels can also be advantageous. This range of preferred levels (42 dBA – 48 dBA) allows for some flexibility in designing a masking system, by having higher than ideal levels close to a noise masking source i.e., a water feature, and lower than ideal levels farther from the source. Furthermore, this range seems to be independent of the type of water sound and the intelligibility level of background speech. The lower STI level of 0.50 may still be considered high enough, which might justify, the similarity in preference scores. More research is needed to attain more conclusive finding regarding whether the preferred level of water sound is affected by the intelligibility level of the background speech.

The audio-only and audio-visual preferences were not alike and different water sounds seemed to have benefited differently from the visual stimuli. The preferred water sounds from the audio-only test were FTW, DF and CA, while the preferred water features from the audio-visual preference test were CA, DF and FF.

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