JASA ARTICLE

Audio-visual preferences, perception, and use of water features in open-plan offices[a]

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ABSTRACT:
This paper examines the use of water features for masking irrelevant speech and improving the soundscape of open-plan offices. Two laboratory experiments were carried out, as well as acoustic simulations and field tests. Experiment 1 aimed to identify the preferred sound level of water sounds against irrelevant speech. Experiment 2 examined the audio-only and audio-visual preferences and perception of waterscapes. Acoustic simulations and field tests examined the impact of design factors. The results showed that, when played against a constant level of irrelevant speech of 48 dBA, people prefer to listen to water sounds of 42–48 dBA (45 dBA being best). These results and results from previous research suggest that water sounds work mainly as informational maskers rather than energetic maskers. Furthermore, the introduction of a water feature improved the perception of the sound environment, and adding visual stimuli improved perception by up to 2.5 times. Acoustic simulations indicated that features at each corner and one at the center (or a single feature with an array of speakers) can provide appropriate masking for a large open-plan office, whilst field tests showed that water sounds decrease the distraction and privacy distances significantly (clusters of workstations benefitting more than rows of workstations).

https://doi.org/10.1121/10.0000892

(Received 16 August 2019; revised 19 February 2020; accepted 23 February 2020; published online 16 March 2020)

[Editor: Kirill V. Horoshenkov] Pages: 1661–1672

I. INTRODUCTION

Despite their economic benefits, open-plan offices have been associated with high levels of dissatisfaction,[1] fatigue,[2] distraction, and subjective task impairment.[2,3] Ambient noise and lack of speech privacy have repeatedly been highlighted as the main causes of these issues,[4–6] and intelligible irrelevant speech has consistently been found as the main source of annoyance.[7–11]

Speech masking systems have been shown to reduce the detrimental effects of irrelevant speech in open-plan offices[11,12] by reducing its signal-to-noise ratio[9,13,14] and are now often recommended (see, for instance, guidance from the British Council for Offices[15] and from BS 8233[16]). Examples of masking sounds used in previous research include pink noise,[17,18] white noise,[19] and filtered pink noise with a -5 dB/octave slope.[8,20,21] Unlike these artificial noises, water sounds are natural sounds that have inherent positive qualities[22] and physical properties that make them potential noise maskers.[23] Such sounds have been used in urban soundscape studies to mask road traffic noise and create a more peaceful and relaxing sound environment.[23] Some studies have used water sounds as speech masking sounds in open-plan offices and suggest they could be as effective as the commonly used artificial masking sounds.[11,24,25] Furthermore, water sounds have been found to improve performance of short term memory tasks,[26] and there can also be significant cost benefits to using water features instead of artificial masking systems.[26] However, a study[27] has shown that artificial masking sounds such as pseudonoise are more effective. This discrepancy is likely to have stemmed from the lack of guidance for suitable water sounds and their preferred sound levels within the context of speech masking in open-plan offices.

A commonly used masking sound is a pink noise with a -5 dB/octave slope,[28] which broadly follows the spectrum of human speech.[29] Previous studies on waterscapes in open-plan offices[11,27] have used the -5 dB/octave for water sounds, but there is no evidence to suggest that the -5 dB/octave spectrum should be used to gauge the suitability of a water sound in masking irrelevant speech. In terms of the preferred masking sound level, research on artificial masking sounds has shown a masking level of 45 dBA to be preferred, and 48 dBA as the masking level that should not be exceeded.[28] However, there is no guidance in the literature to suggest this range is also suitable for water sounds.

The visual impacts of using water features in open-plan offices seem to have been overlooked in the literature, despite previous soundscape research reporting increased levels of preference and satisfaction when audio materials were accompanied by appropriate visual stimuli.[25,27,28,30–32]

In light of the above discussion, the current study aims to provide evidence-based guidance on the use of water features to mask irrelevant speech in open-plan offices by identifying the following:

(1) The preferred water sound levels to mask irrelevant speech.

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[a] Portions of this work were presented in "Audio-visual preferences of water features used in open-plan offices," ICSV24, London, UK, July 2017.

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(2) The effect of speech intelligibility of irrelevant speech on the preferred masking sound levels.
(3) The audio-visual effect of water sounds/features on people's preferences and perception of their acoustic environment.
(4) The practical implications of using water sounds/features in view of obtaining suitable masking sound levels across workstations, and the likely improvement in speech privacy, using objective measures.

To fulfill the aim of the study, two laboratory experiments were carried out, supplemented by three-dimensional (3 D) acoustic models and field measurements. Experiment 1, *Sound level preferences*, was used to answer objectives 1 and 2. Experiment 2, *Audio-visual preferences and perception*, was used to answer objective 3 using realistic audio-visual animations, whilst 3 D acoustic models and field measurements were used to answer objective 4.

II. METHODOLOGY

A. Water sounds

The water sounds were selected from a set assembled for a previous study carried out at Heriot-Watt University,[21] where full details can be found. In the current study, six water sounds were chosen as representative of a variety of sounds that could be used in an open-plan office. The water sounds were 20 s long binaural signals recordings of a 4-step cascade (CA), a dome fountain (DF), a foam fountain (FF), a 37-jet fountain (FTW), a large jet (LJT), and a narrow jet (NJT). Given their steady nature, 7 s long extracts of the 20 s long signals were used in the current study. The 7 s long duration has been successfully used in previous waterscapes studies.[23,33,34] The spectral properties of the water sounds are shown in Fig. 1.

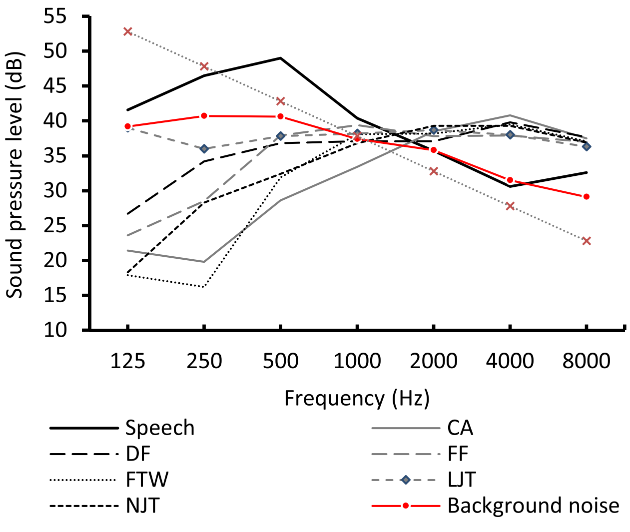

FIG. 1. (Color online) Octave-band spectra of speech (48 dBA) and six water sounds against the recommended artificial masking spectrum (−5 dB/octave), calibrated to 45 dBA. The spectrum of the background noise used in Experiment 1 is also shown (calibrated to 43 dBA).

B. Speech recording

A high-quality speech recording was used to simulate irrelevant speech. The recording was used in a previous study on masking speech in open-plan offices,[28] and consisted of 17 min of dialogues simulating one side of telephone conversations. In the recording, an actress was reading scripts (calling job candidates, making arrangements for new employees, and making personal calls).[28] As the water sounds were 7 s long, the speech signals were also divided into 7 s long signals.

Research has shown that the sound pressure level of normal-effort speech at a neighboring workstation varies between an L_{Aeq} 39 and 55 dB.[9,14,35,36] The speech signals in the current study were calibrated to have a sound pressure level of $L_{\mathrm{Aeq,7s}}$ of 48 dB. Above this speech level, a masking sound would need to be too loud to effectively mask speech, and speech levels significantly below this (e.g., 39 dBA) would likely be too quiet to require a masking system.

C. Participants

Thirty-nine participants took part in Experiment 1, *Sound level preferences*. Two participants reported having tinnitus, and nine more did not perform well in a consistency test (judgments outside a 95% confidence interval of the mean consistency), leaving 28 participants (15 males, and 13 females) aged between 23 and 48 years [$M = 30.9$ years, standard deviation (SD) = 5.8 years] for further analysis.

Thirty-three participants who reported a normal hearing ability took part in Experiment 2, *Audio-visual preferences and perception*. Two participants did not perform well in a consistency test, leaving 31 participants (16 males, and 15 females) aged between 24 and 60 years ($M = 36.3$ years, SD = 9.3 years) for further analysis. The lower level of consistency in Experiment 1 can be related to its higher difficulty (subtle differences between some of the levels tested). Participants were postgraduate students and staff members of Heriot-Watt University who worked in open-plan offices. They were given a £5-Amazon voucher for their participation.

D. Experiment 1: Sound level preferences

A schematic diagram showing the structure of the experiment is given in Fig. 2. Two water sounds were used in this experiment, the CA and the FTW, both of which were highly rated in previous urban soundscape studies.[23,33] Only two water sounds were used in order to not overburden respondents, and as previous urban soundscape research has shown that preferred water sound levels are unlikely to be affected by the type of water sounds used.[23]

These water sounds were played at five masking sound levels, namely, 42, 45, 48, 51, and 54 dBA (see Sec. III for details about the calibration procedure). This range covers the selected sound pressure level of irrelevant speech (i.e., 48 dBA) ± 6 dB, in 3 dB increments. The water sounds were played against irrelevant speech, which was played at a constant level of L_{Aeq} 48 dB but had two speech intelligibility levels (defined by the speech transmission index, STI[37]),

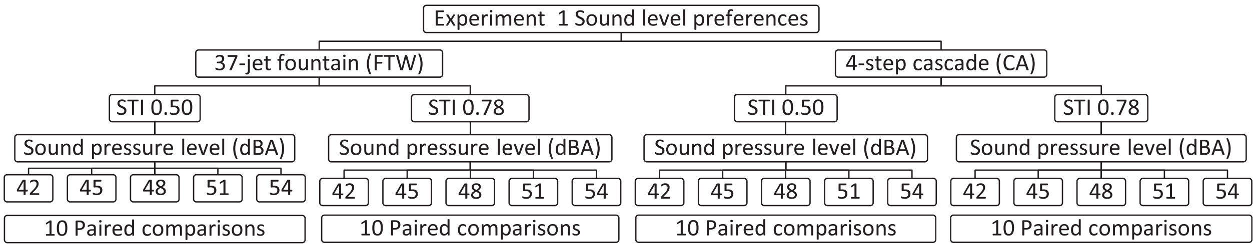

FIG. 2. Schematic diagram showing the test structure of Experiment 1.

STI 0.50, i.e., fair speech intelligibility, and STI 0.78, i.e., excellent speech intelligibility.[38] The signal with STI 0.78 was achieved using the dry speech recording and 0.5 s artificial reverberation. The signal with STI 0.50 was achieved by adding typical office background noise at a sound level of $L_{\mathrm{Aeq,7s}}$ of 43 dB (i.e., SNR $+5$) to the previous signal (STI 0.78). Digital audio processing was used to add the reverberation and background noise to the dry speech recording. A previously recorded high-quality background noise of a busy open-plan office was used. It had a steady sound level and included footsteps noise, typing and paperwork noises, and distant unintelligible speech. The octave-band spectrum of the background noise is shown in Fig. 1. These combinations resulted in each masking level being tested under four test conditions, as shown in Fig. 2.

Paired comparisons were used to compare all masking levels within each test condition. Five sound pressure levels were tested, which resulted in ten paired comparisons per condition (i.e., 40 paired comparisons in total). Each paired comparison consisted of 7 s of a water sound at a masking level, 1 s of silence, 7 s of the same water sound at another masking level, both played over a 7 s speech signal. No visual materials were included in Experiment 1.

E. Experiment 2: Audio-visual preferences and perception

A schematic diagram showing the structure of the experiment is given in Fig. 3. Experiment 2 was divided into two parts, Part 1: *audio-visual preferences*, and Part 2: *audio-visual perception*. All six water sounds were used.

1. Part 1: Audio-visual preferences

The test had a similar test structure to Experiment 1 but the sound pressure level of the water sounds was fixed to the preferred L_{Aeq} of Experiment 1 (45 dB; see Sec. IV A) and their type was changed instead. The speech intelligibility level of irrelevant speech was also fixed at STI 0.78. Six water sounds/features were compared under an audio-only condition and an audio-visual condition using paired comparisons. In the audio-only condition, each paired comparison consisted of 7 s of a water sound, 1 s of silence, and 7 s of another water sound. Both water sounds were played over a 7 s speech signal. No visual materials were included.

The audio-visual condition was similar to the audio-only condition, but each water sound was accompanied by its visual animation, presented on a monitor screen in front of the participant (see Sec. III for details about the high-quality realistic animations and the software used). A photograph of a furnished open-plan office[39] was used as a background image, and animations of the water features were embedded in the background image. The background image did not include any human figures to allow for participants to concentrate on the water features and avoid any visual distractions. Still images of the animations are presented in Fig. 4.

The test contained 15 paired comparisons per condition (i.e., 30 paired comparisons in total).

2. Part 2: Audio-visual perception

This test examined how people's perception of their sound environment changed when irrelevant speech was masked with a water sound (i.e., unmasked vs masked comparisons), and all six water sounds were used. This test also included audio-only and audio-visual conditions, with six comparisons per condition (i.e., 12 comparisons in total). In the audio-only condition, each comparison consisted of 7 s of unmasked speech, 1 s of silence, and 7 s of speech masked with a water sound. The audio-visual condition was similar to the audio-only condition, but the water sounds were accompanied by their corresponding visual animations.

F. Acoustic 3 D modelling

Acoustic 3 D models were used to identify the number and location of water features needed to achieve suitable masking levels. A large open-plan office (12.8 m

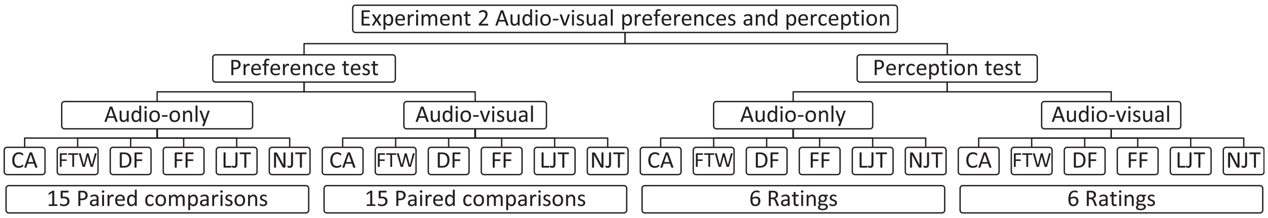

FIG. 3. Schematic diagram showing the test structure of Experiment 2.

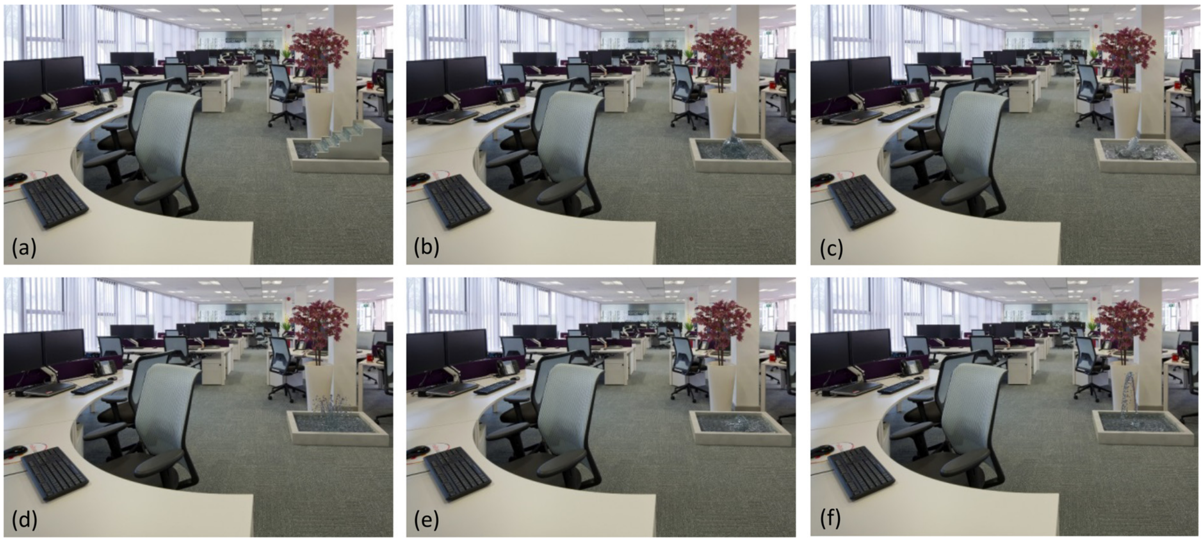

FIG. 4. (Color online) Still images from animations (Ref. 49) of the water features used in the audio-visual condition of the preference and perception tests. (a) CA. (b) DF. (c) FF. (d) FTW. (e) LJT. (f) NJT. Background image (Source: Ref. 39).

wide × 26.8 m long × 2.8 m high) containing 76 workstations was modelled. The space had a Class A sound absorbing mineral fiber ceiling, carpeted floor, plasterboard walls, and glazed windows. The height, ceiling, and floor finishes were chosen following recommendations given by the British Council for Offices (BCO).[15] The workstations were partitioned by 480 mm high sound absorbing screens. A screenshot of the 3 D model is shown in Fig. 5.

The masking sound level across the workstations were examined using the following configurations:

1. A single water feature at the center of the office.
2. One water feature at the center and four in the middle of the side walls (five water features in total).
3. One water feature at the center and four at the corners (five water features in total).
4. One water feature at the center with a 2 × 6 array of ceiling speakers redistributing the water sound over the workstations.

The water features were modelled by omnidirectional speakers placed 700 mm above the ground with a sound pressure level of 50 dBA at 1 m. This resulted in a sound level of approximately 48 dBA or lower at most of the workstations (in line with Experiment 1 findings) at a height of 1.2 m (floor to ear height of an adult seated). The ceiling speakers were calibrated to have a sound pressure level of 45 dBA at 1 m. All omnidirectional speakers were calibrated to have the spectrum of the CA (which was the preferred water feature in Experiment 2, audio-visual tests).

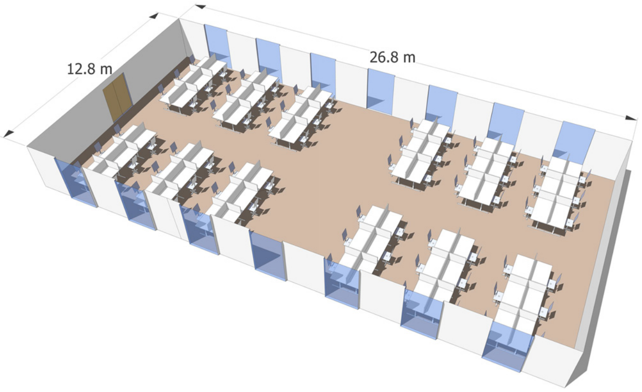

FIG. 5. (Color online) 3 D model showing the open-plan office used in the acoustic simulation.

G. Field measurements

To further add to the practical side of the study, the effect of adding a water sound on the distraction distance, r_D, and privacy distance, r_P, was tested in two open-plan offices (single-number quantities recommended in ISO 3382-3[40]). The distraction distance, r_D, is the distance from the source at which STI falls below 0.50 (above the distraction distance, concentration, and privacy start to improve rapidly[40]) and the privacy distance, r_P, is the distance from the source at which STI falls below 0.20 (above the privacy distance, concentration and privacy are very much the same as between separate office rooms[40]). These single number quantities were measured in two open-plan offices, with and without a water sound. Floor plans and photographs of Office 1 and Office 2 are shown in Figs. 6 and 7.

Office 1 accommodated 33 computer desks clustered into four working zones with no partition screens between the workstations. The space had a mineral fiber suspended ceiling, carpeted floor, and painted blockwork. Windows accounted for 7% of the total area of the walls. Office 2 was a modular open-plan office accommodating 44 workstations clustered into 13 working zones. The workstations were separated by 480 mm high screens. The space had polyvinyl chloride (PVC) ceiling panels, vinyl floor, and PVC laminated plasterboard walls. Windows accounted for 15% of the total area of the walls.

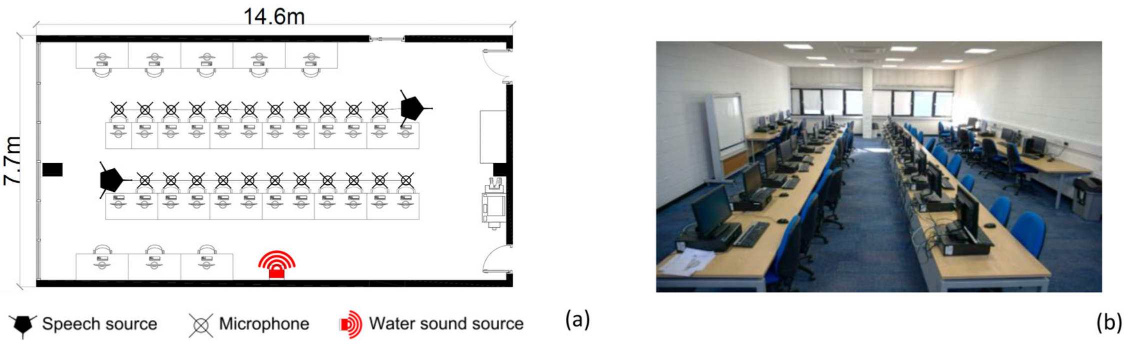

FIG. 6. (Color online) Office 1. (a) Floor plan. (b) Photograph.

Measurements were carried out in accordance with ISO 3382-3,[40] which requires having two speech source positions and between four and ten receivers for each source, positioned along a line, preferably straight, that passes through the workstations. In line with Experiment 1 findings, a loudspeaker playing the sound of the FTW was used to simulate a water feature, and its sound pressure level was set so that the water sound level did not exceed $L_{\mathrm{Aeq,1m}}$ 48 dB at the nearest workstation. Measurements were repeated with and without the presence of the water sound, with the microphone always placed at a 1.2 m height.

III. TEST PROCEDURES AND STATISTICAL ANALYSIS

Both Experiments 1 and 2 were carried out in the highly insulated anechoic chamber of Heriot-Watt University. Participants were asked 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. Participants were seated in front of a standard office desk with a monitor screen showing instructions. An evaluation form was used to state preferences and provide basic background information, such as age and gender. A practice session was run at the beginning to make participants familiar with the test (scores not included in the analysis of results). Audio materials were played through closed headphones (Beyerdynamic DT 150) and visual materials were displayed on the screen [27 in. light emitting diode (LED) monitor Samsung LS27A350]. The water sounds and speech signals were calibrated using a Brüel and Kjær handheld sound analyzer, type 2250 (Naerum, Denmark). Digital audio processing was carried out using Studio One 3 audio production software (PreSonus Audio Electronics). Autodesk 3ds MAX with Mental Ray was used to model and render the water feature animations. The simulation of the water particles was carried out using RealFlow 2015 (Next Limit). The STI in Experiment 1 was calculated using the modulation transfer function (MTF) method.[41] The detailed procedure for calculating the STI from the reverberation time and signal-to-noise ratio can be found in Ref. 42.

For each paired comparison in Experiment 1, participants were instructed to choose the sound that they preferred to work in over a long period of time by ticking either "Sound 1," "Sound 2," or "No preference" on the evaluation form. The latter was included due to the similarities and the subtle differences between the sound levels in some paired comparisons, although participants were discouraged from choosing it. Participants listened to all pairs of sounds in a randomized order and were free to take a short break after each ten paired comparisons.

For each paired comparison in Experiment 2, Part 1, participants were asked to listen/look and select the water sound/feature which they preferred working in over a long period of time, and helped them concentrate by ticking either "Option 1" or "Option 2" on the evaluation form. The sequence of paired comparisons was randomized, but the audio-only condition was always carried out before the audio-visual condition. Participants were free to take a short break between the audio-only and audio-visual conditions. In Experiment 2, Part 2, the participants were asked to listen to/look at each pair of sound/visual before and after adding a water sound. They were then asked "how your perception changed after introducing the water sound?" The evaluation scale was a 5-point Likert scale and the labels were "much

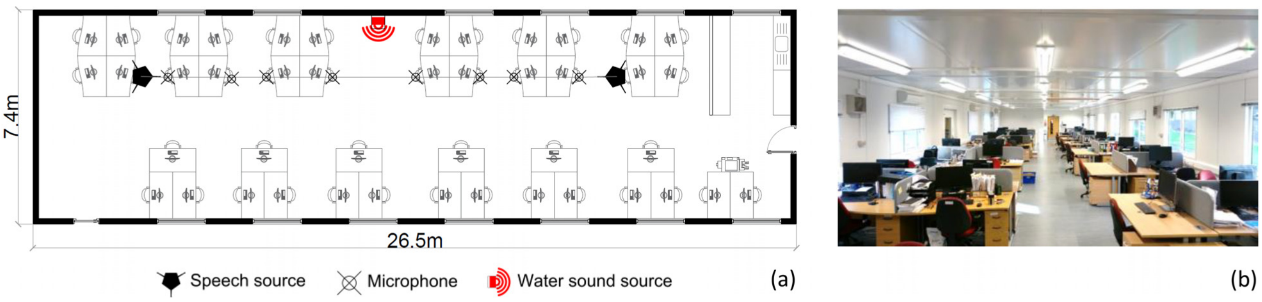

FIG. 7. (Color online) Office 2. (a) Floor plan. (b) Photograph.

worse, slightly worse, no change, slightly better, and much better." The playing order of the water sounds was randomized, but the audio-only condition was always performed before the audio-visual condition. Participants were free to take a break after completing the audio-only condition.

In both Experiment 1 and Experiment 2 Part 1, the first ten paired comparisons were repeated at the end of the test as a measure of consistency of responses given by the participant. The participant whose scores were below the lower bound of the 95% confidence interval of the mean consistency were removed from the analysis.[34] Experiment 1 lasted between 40 and 45 min for each participant, Experiment 2 Part 1 lasted between 30 and 35 min, and Experiment 2 Part 2 lasted between 5 and 10 min (all durations include short breaks and practice sessions).

Odeon Auditorium 15 and Sketch Up 8 were used to make the acoustic 3 D models and simulations. The Room Setup calculation parameters in Odeon were set to "Precision."

For the field measurements, the Maximum-Length Sequence System Analyzer (MLSSA) software (DRA Laboratories, Sarasota, FL) was used to measure the impulse response and derive the STI values used to calculate the distraction and privacy distances. The signal generated by MLSSA was played through a custom-made omnidirectional loudspeaker which met the requirements set in ISO 3382-1.[43] A KEF Coda III Type SP 3016 was used to play the water sound in the two open-plan offices.

Statistical analysis was carried out using IBM's Statistical Package for Social Sciences (SPSS) 22. Friedman's two-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 the 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.[44] Alongside the *p*-values, the effect sizes, *r*, were also calculated for various statistical analyses used in this study. In fact, reporting the *p*-value in isolation could be misleading as its value is dependent on the sample size,[45] unlike *r*. The latter can be classified into small ($r = 0.2$), medium ($r = 0.5$), and large ($r = 0.8$) effect sizes.[46] Differences in preference scores between males and females, as well as between age groups were examined using the Mann-Whitney test.[45] Pearson's chi-square (χ^2) was used to perform categorical analysis on perception ratings. Correlations between variables were tested using Spearman's correlation coefficient, r_s.

IV. RESULTS

A. Experiment 1: Sound level preferences results

Preference scores for each condition and the overall preference scores were normalized to have values between −2 (never preferred) and +2 (always preferred). These are shown in Fig. 8.

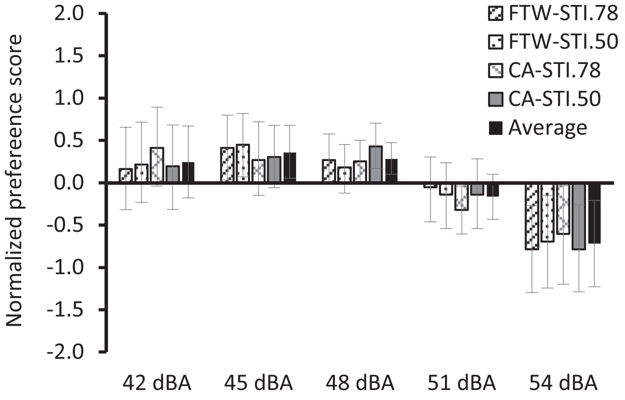

FIG. 8. Normalized preference scores for the four test conditions alongside the averaged preference scores. Error bars represent the Bias-corrected and accelerated 95% bootstrap confidence intervals.

The statistical analysis revealed that the alteration of the STI of irrelevant speech and the type of water sounds did not have a significant impact on preference scores at any of the masking levels ($p > 0.05$). The analysis suggests that at each masking sound level, people perceived the four conditions alike. Therefore, an average score from all four conditions was calculated (solid black bars in Fig. 8) and retained for further analysis.

The preferred masking sound level, irrespective of the type of water sound and the STI of irrelevant speech, was 45 dBA ($M = 0.36$), followed by 48 dBA ($M = 0.28$), and 42 dBA ($M = 0.25$), respectively. The least preferred masking sound level was 54 dBA ($M = -0.72$), followed by 51 dBA ($M = -0.17$). The 95% CI remained positive (i.e., above the zero line) only for the 45 and 48 dBA levels, which adds more confidence to the positive scores given to these masking levels.

Statistically, preference scores were significantly affected by the level of the water sound, [$\chi^2(4) = 14.268$, $p = 0.007$]. Pairwise comparisons were used to follow up this finding. The 54 dBA level was significantly less preferred than 45 dBA ($z = -3.254$, $p = 0.010$, $r = -0.435$), 48 dBA ($z = -2.916$, $p = 0.020$, $r = -0.390$), and 42 dBA ($z = -2.747$, $p = 0.020$, $r = -0.367$). No further statistically significant differences were found between preference scores of the other sound levels ($p > 0.05$). These results show that the preferred masking sound levels are 45 and 48 dBA, but 42 dBA is also acceptable (positive score and no statistically significant differences with 45 dBA and 48 dBA). The gender and age groups of participants [*below 30 years* ($n = 14$) and *30 years and above* ($n = 14$)] did not have a significant impact on preference scores at any of the masking levels ($p > 0.05$).

B. Experiment 2: Audio-visual preference and perception results

1. Part 1 Audio-visual preference results

Normalized preference scores from the paired comparisons in both audio-only and audio-visual conditions are shown in Fig. 9 and tabulated in Table I. All scores are normalized to have values between −2 (never preferred) and +2 (always preferred).

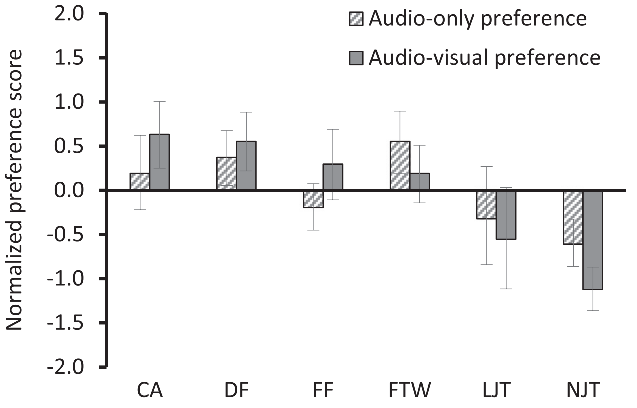

FIG. 9. Normalized audio-only and audio-visual preference scores for six water sounds used in this study. Error bars represent the Bias-corrected and accelerated 95% bootstrap confidence intervals.

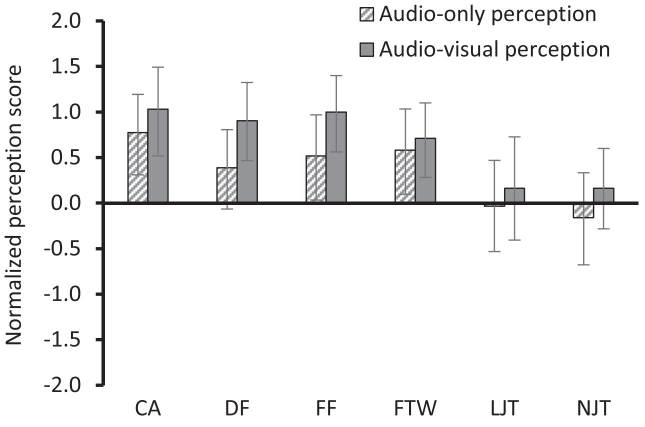

FIG. 10. Change in participants' perception caused by six waterscapes in the audio-only and audio-visual conditions. Error bars represent the Bias-corrected and accelerated 95% bootstrap confidence intervals.

The preferred water sound in the audio-only condition was FTW, followed by DF and CA, respectively. The least preferred water sounds were NJT, followed by LJT, and FF, respectively. The preferred water feature in the audio-visual condition was CA, followed by DF, FF, and FTW, respectively. The least preferred water feature was NJT, followed by LJT. The feature that most benefited from its visual stimulus was FF, whilst NJT benefited the least, followed by FTW. Given the ordinal nature of paired comparisons, it cannot be concluded from this test that some visual stimuli had a detrimental effect on preference levels. The results simply suggest that some water sounds benefited more from the visual stimuli. This is further analyzed in Part 2 of the experiment.

In both audio-only and audio-visual conditions, the gender of participants did not have a significant impact on preference scores ($p > 0.05$). Participants were divided into two age groups, *below 35 years* ($n = 16$), and *35 years and above* ($n = 15$). Preference levels towards NJT in the audio-visual condition were significantly different between the two age groups ($U = 68.00$, $z = -2.191$, $p = 0.041$, $r = -0.394$). Older participants (*35 years and above*) gave NJT a higher (but still negative) score, in comparison to younger participants. No further statistically significant differences in preferences were detected.

2. Part 2: Audio-visual perception results

The evaluation scores obtained from the audio-only and audio-visual perception tests are shown in Fig. 10 and tabulated in Table I. All perception ratings are normalized to values between −2 (much worse) and +2 (much better).

TABLE I. Normalized mean scores of the water sounds/features in Experiment 2.

	Part 1: Preference test				Part 2: Perception test			
Rank	Audio-only		Audio-visual		Audio-only		Audio-visual	
1	FTW	0.55	CA	0.63	CA	0.77	CA	1.03
2	DF	0.37	DF	0.55	FTW	0.58	FF	1.00
3	CA	0.19	FF	0.30	FF	0.52	DF	0.90
4	FF	−0.19	FTW	0.19	DF	0.39	FTW	0.71
5	LJT	−0.32	LJT	−0.55	LJT	0.03	LJT	0.16
6	NJT	−0.61	NJT	−1.12	NJT	−0.16	NJT	0.16

The results show that in the audio-only condition, four water sounds, namely, CA, DF, FF, and FTW, improved how people perceived their sound environment. The highest improvement was obtained from CA, followed by FTW, FF, and DF, respectively. LJT had a neutral impact whilst NJT had a negative impact. In the audio-visual condition, all water features had a positive impact on people's perception. The most influential water feature was CA, closely followed by FF, then DF, FTW, LJT, and NJT. LJT and NJT, which were the least preferred water features in the preference test, still improved the sound environment.

In both audio-only and audio-visual conditions, no statistically significant effect of gender was detected on perception scores for all six water sounds ($p > 0.05$). The age of participants had a significant effect on the perception rating for CA ($U = 69.00$, $z = -2.123$, $p = 0.045$, $r = -0.381$). Younger participants (*below 35 years*) perceived CA to be significantly more beneficial than older participants (*35 years and above*). No further statistically significant differences were detected between the age groups for the remaining water features.

3. Comparison between audio-only and audio-visual perception scores

As Fig. 10 shows, the average audio-visual perception scores for all water features are higher than their corresponding audio-only scores, suggesting that visual stimuli increased the level of improvement made by the water sounds alone. This was further tested for statistically significant differences between the audio-only and audio-visual scores. The results are presented in Table II and show that the inclusion of the visual stimuli did improve the sound environment. This improvement was significant for two water features, namely, FF ($p < 0.01$) and DF ($p < 0.05$). The values of the effect size, r, show the magnitude of the effect that the visual stimuli had on people's perception. Using Cohen's[46] scale, FTW marginally benefited from its visual animation with a very small r, whilst the effect of the

TABLE II. *z*-scores, *p*-values, and effect sizes (*r*) achieved by comparing the audio-only and audio-visual perception scores using Wilcoxon sign-ranked test.

Sound code	CA	DF	FF	FTW	LJT	NJT
z-score	−1.407	−2.311	−2.950	−0.511	−0.981	−1.564
p-value	0.160	0.021	0.003	0.610	0.326	0.118
Effect size (*r*)	−0.179	−0.293	−0.375	−0.065	−0.125	−0.199

animations on CA, LJT, and NJT was small. On the other hand, a medium effect size was recorded for both FF and DF. Therefore, it can be concluded that adding the visual materials further increased the improvement in people's perception made by the water sounds alone (audio-only condition), and the magnitude of this increase (i.e., the effect size) was "small" to "medium," using Cohen's[46] scale.

4. Categorical analysis of perception scores

For a water sound/feature to be accepted as being practically beneficial in improving people's perception, the number of people who positively perceived it must be significantly higher than those who perceived it as being detrimental.

For each water sound/feature, the number of times labels "slightly better" and "much better" were selected, was categorized as *positive scores*. Similarly, the number of times labels "slightly worse" and "much worse" were selected, was categorized as *negative scores*. Then, the *positive scores* were compared to *negative scores* using the Chi-square test (Table III). A statistically significant difference between the two groups would mean the magnitude of improvement or detriment in people's perception is significant, and therefore practically meaningful.

In the audio-only condition, two water sounds significantly improved the environment, i.e., CA ($p < 0.01$) and FTW ($p < 0.05$). LJT and NJT deteriorated the environment (negative mean perception scores), yet no significant results could be detected ($p > 0.05$). In other words, no water sound significantly deteriorated the environment, even when negatively perceived. In the audio-visual condition, four water features resulted in a significant improvement in people's perception., i.e., CA, FF, DF, and FTW ($p < 0.01$).

To further quantify effect sizes reported in Table II, the odds ratio between audio-only and audio-visual scores was also calculated (Table III). The odds ratio is an effect size that quantifies the relationship between variables.[45] For each water sound, the number of positive scores (i.e., "slightly better and much better") was divided by the number of negative scores (i.e., "slightly worse and much worse"), in each of the audio-only condition and audio-visual condition. Then the ratio from the audio-visual condition was divided by the ratio from the audio-only condition, to result in the odds ratio for that water sound. Any odds ratio greater than 1 suggests that the visual materials increased the likelihood of obtaining positive scores. On the contrary, odds ratios smaller than 1 suggest that the visual materials increased the likelihood of obtaining negative scores. As Table III shows, all odds ratios are positive, ranging between 1.1 and 2.5. This suggests that adding visual stimuli to the water sounds increased the likelihood of obtaining positive scores by 1.1–2.5 times, depending on the water feature. Hence, within the context of the perception test, a small to medium effect size would mean approximately a 1.1–2.5 times increase in the likelihood of making positive changes in the way people perceive their environment.

TABLE III. Chi-square (χ^2) test statistic and odds ratios between audio-only and audio-visual scores in the perception test. *χ^2 is significant at the 0.05 level. **χ^2 is significant at the 0.001 level.

Sound code	CA	DF	FF	FTW	LJT	NJT
			Audio-only condition			
Chi-Square (χ^2)	7.759*	4.481	2.793	5.452*	0.000	0.143
df	1	1	1	1	1	1
p-value	0.008	0.052	0.136	0.029	1.000	0.851
			Audio-visual condition			
Chi-Square (χ^2)	14.286**	10.704**	12.448**	9.846**	0.133	0.333
df	1	1	1	1	1	1
p-value	0.000	0.002	0.001	0.002	0.856	0.701
Odds ratio	1.909	1.853	2.526	1.718	1.143	1.442

C. Acoustic simulation results

The resultant sound pressure level contours for the four different water feature configurations are shown in Fig. 11 (levels at 1.2 m height).

D. Field measurement results

The single number quantities measured in the two open-plan offices are given in Table IV. Two source positions were used in each space and the values are reported separately for each source position. The single number quantities of both offices are similar, with a slightly shorter distraction distance in Office 2. When the water sound was added, the distraction distance in both offices dropped significantly. The reduction in the distraction distance was between 8.6 and 9.1 m in Office 1, and between 9.5 and 10.5 m in Office 2. The STI at the nearest workstations also reduced after playing the water sound in both offices.

V. DISCUSSION

A. Masking sound levels

Experiment 1 revealed the preferred masking level to be 45 dBA, which is 3 dB lower than the speech level of 48 dBA used in this study. This is broadly in line with the previously recommended range of masking levels,[28] and is also comparable to the findings obtained for water sounds used over road traffic noise.[23] 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 (48 dBA being slightly preferred to 42 dBA). This range of preferred levels (42–48 dBA) allows for some

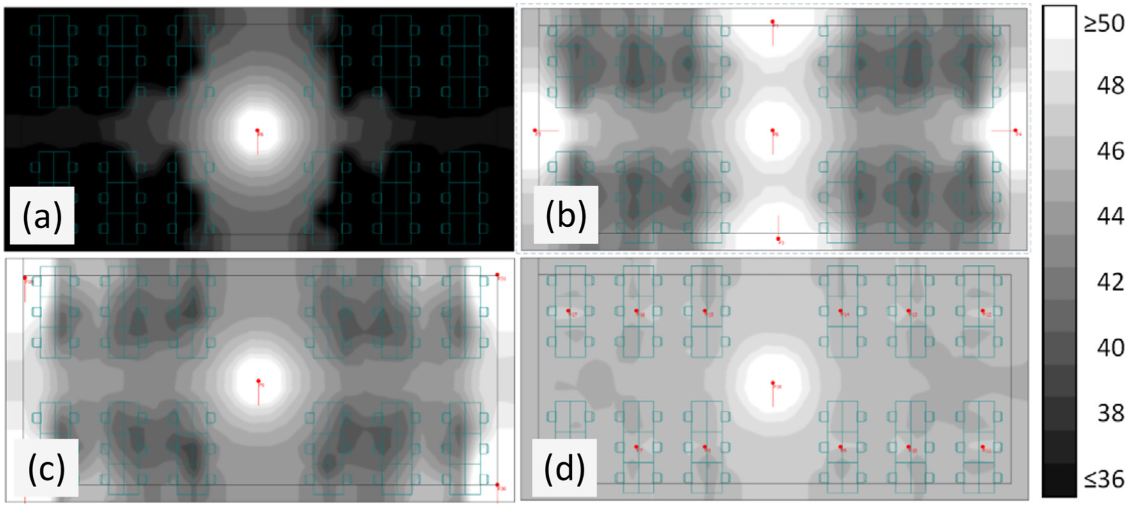

FIG. 11. (Color online) Sound pressure level contours at 1.2 m height (dBA). (a) Central water feature only. (b) Central and 4 side water features. (c) Central and 4 corner water features. (d) Central water feature with 2 × 6 speakers' ceiling array. Darker shades represent lower sound levels.

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 that source. Furthermore, this range was independent of the type of water sound and the intelligibility level of the background speech. However, the lower STI level of 0.50 of irrelevant speech used in this study may still be considered high enough, which might justify the similarity in preference scores between STI 0.50 and 0.78.

B. Audio-only and audio-visual preferences and perception

In Experiment 2, the general trend showed four water sounds/features to be preferred and to improve people's perception of their environment. The four water sounds/features were the CA, the DF, the FF, and the FTW. The preferred water sound in the audio-only condition was FTW, while the preferred water feature in the audio-visual condition was CA. Comparing these findings to those reported in previus urban soundscape studies[23,33] shows more similarities than differences, despite using two different background noises (i.e., road traffic noise[23,33] vs irrelevant speech). In the previous and current studies, CA, DF, FF, and FTW were highly preferred, while NJT was poorly rated. Hence, it is likely that the findings of this study are applicable to other background noises such as those found in hotel lobbies and supermarkets, for example.

The spectra of the preferred water sounds in the current study do not resemble the −5 dB/octave pink noise nor the speech spectrum. In fact, the water sound levels peak at around 4 kHz and their spectra have an opposite slope to the −5 dB/octave spectrum. Figure 1 suggests that the water sounds were not capable of masking speech at frequencies below 1 kHz, whilst above 1 kHz the water sounds contain more energy than speech and energetic speech masking could have happened. However, the general trend implies that there is more informational masking than energetic masking, as the signal-to-noise ratio at a critical band such as 500 Hz is ≥11 dB. Furthermore, it cannot be suggested that a particular spectral shape of the water sounds is preferred over others. For instance, both FTW and NJT have similar spectra, yet, their preference scores were significantly different. In previous urban soundscape studies, waterfalls with high flow rates were capable of producing high levels of low frequency sounds (i.e., 125 and 250 Hz)[23] but were disliked and poorly rated by people, mainly due to semantic characteristics.[33] Water sounds perceived as being natural, refreshing, relaxing, and familiar tended to be preferred over water sounds that were perceived as being artificial, weary, stressful, and unfamiliar.[33] Therefore, the semantic properties of a water sound seem to be important factors in dictating how a water sound is perceived. Water sounds in previous research on speech masking in open-plan offices have been selected so that they have a spectrum similar to that of speech (e.g., Refs. 11 and 27), which may not necessarily be an effective approach, and partly explains the discrepancy in results reported by different studies regarding the preference of water sounds when used as irrelevant speech maskers. Furthermore, adjusting the spectrum of a water sound corresponds to creating an artificial sound that might then be devoid of its nature-sounding

TABLE IV. The single number quantities measured in Office 1 and Office 2, with and without a water sound. S1, speech source position 1 [left in Fig. 6(a) and Fig. 7(a)]; S2, speech source position 2 [right in Fig. 6(a) and Fig. 7(a)].

Parameter	Office 1				Office 2			
	No masking		Masking		No masking		Masking	
	S1	S2	S1	S2	S1	S2	S1	S2
STI at the nearest workstation	0.86	0.85	0.75	0.78	0.77	0.72	0.70	0.62
r_D, in m	14.64	16.04	5.50	7.40	13.24	14.31	3.74	4.26
r_P, in m (extrapolated)	28.09	32.00	14.20	7.40	35.14	36.86	20.22	21.50

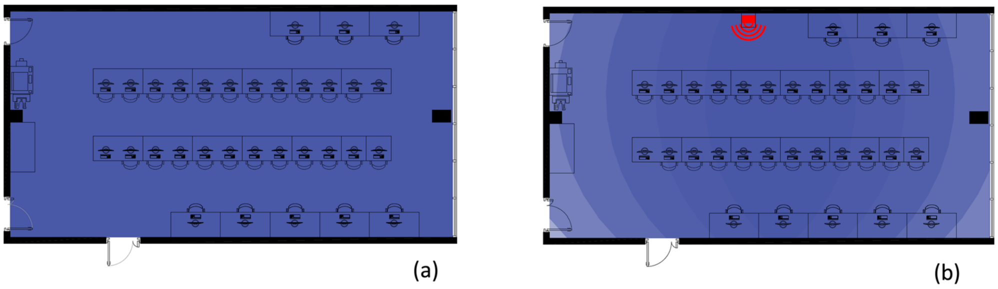

FIG. 12. (Color online) Overlapping of distraction areas of workstations in Office 1. (a) No water sound. (b) With water sound (red symbol). Darker shades represent higher levels of overlapping.

quality, a characteristic that tends to make water sounds as positively perceived.[33]

The addition of the visual materials increased the likelihood of making positive changes in people's perception by up to 2.5 times, and the visual materials never had a detrimental effect. Given the quality and lifelikeness of the visual animations used, the credibility of the findings obtained is likely to be higher than previously published studies, in which either still images of water features or video recordings were used (the background of videos can change, therefore providing less reliable results). The findings of this study support using a real water feature over just playing its sound through loudspeakers.

It is also worth mentioning that correlations between preferences and acoustic/psychoacoustic parameters were found to be weak and are therefore not reported in this paper (details can be found in Ref. 26). Furthermore, a longer term experiment carried out by the authors over several weeks[47] indicated that the preferred water sound did improve the soundscape in an open-plan office. This suggests that, although each paired comparison in the current study involved only a few seconds, the findings are reliable.

C. Acoustic simulations

The acoustic simulations showed that having only one water feature in a relatively large open-plan office is not sufficient and multiple water features are likely to be needed if a masking level of 42–48 dBA is targeted. When the water features were placed at the corners of the office, a slightly more uniformly distributed masking level was predicted compared to the side water features, albeit this option is likely to require the layout of the office to be arranged so that no workstation is located at the corners so as to avoid excessive masking noise levels. The best coverage was achieved when a central water feature was used and supplemented by an array of ceiling speakers. This configuration represents a hybrid masking system consisting of a water feature (natural) whose sound is captured by a microphone and redistributed over the workstations using ceiling speakers (artificial). This hybrid masking combines the flexibility of an artificial masking system, where the masking sound level can be precisely controlled, and the audio-visual improvements associated with a real water feature. This should be further investigated in future research.

D. Distraction and privacy distances

The addition of a water sound in two real open-plan offices resulted in a significant drop (∼9–10 m) in the distraction distance (and subsequently privacy distance). According to previous research,[48] an increase of one meter in the distraction distance is associated with a 9%–14% increase in the annoyance level, which suggests that a very large reduction in annoyance should be obtained with the addition of a water sound.

The distraction distances were converted to distraction areas ($\pi \times r_D^2$) for each workstation and plotted on the floor plan of both spaces. The plots show the extent of overlapping of the distraction areas of each workstation. Ideally, overlapping should be kept minimal to avoid workstations distracting each other. The overlap of the distraction areas before and after adding the water sound is shown in Figs. 12 (Office 1) and 13 (Office 2). Darker shades represent higher levels of overlapping, i.e., more distraction.

Both figures show that there was less overlapping after the water sound was added, as lighter shades started to appear. In Office 1, the lighter areas were located in those

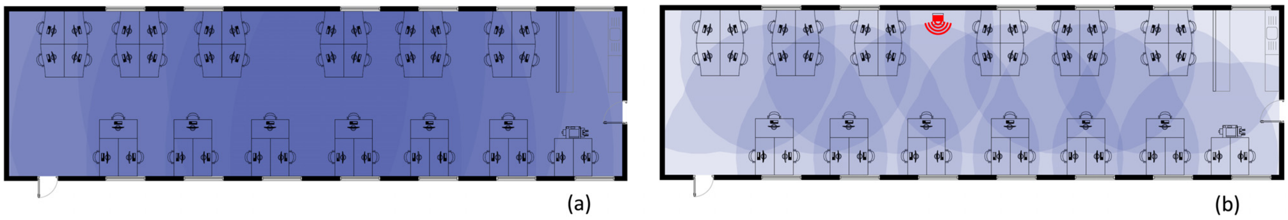

FIG. 13. (Color online) Overlapping of distraction areas of workstations in Office 2. (a) No water sound. (b) With water sound (red symbol). Darker shades represent higher levels of overlapping.

parts of the space where there were almost no workstations, which makes the benefit of reducing the distraction distance very limited. On the other hand, in Office 2, the benefit of reducing the distraction distance was much more prominent. This is likely due to the layout and room acoustics of the space, as well as using partition screens between workstations.

These results indicate that although the water sound resulted in comparable reductions in the distraction distance in both offices, Office 2 benefited more due to its layout and room acoustics, suggesting that the latter factors can play an important role in the effectiveness of masking.

VI. CONCLUSIONS

This research examined the audio-visual preferences and perception of water features and their practical implications when used to mask irrelevant speech in open-plan offices. Two laboratory experiments were carried out: Experiment 1, *Sound level preferences*, aimed to identify the preferred masking level of the water sounds when used to mask irrelevant speech in open-plan offices; and Experiment 2, *Audio-visual preferences and perception*, aimed to identify audio-visual preferences and perception of water sounds when used to mask irrelevant speech. The experiments were supplemented by acoustic simulation models and field measurements to assess the practicality of using water features in open-plan offices. The main findings of the research, related back to the four objectives listed in the introduction, are:

1. 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 (*Objective 1*). This confirms the previously recommended level of masking sounds.[11,23] The preference scores given to 42 and 48 dBA were not significantly lower than that of 45 dBA, i.e., the 42–48 dBA range of levels can be used in practice. This 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 was independent of the type of water sound and the intelligibility level of background speech (*Objective 2*).
2. Audio-only and audio-visual preference results are comparable to those obtained by Galbrun and Calarco (*Objective 3*).[33] This is significant, as the latter study examined the use of water features over road traffic noise rather than irrelevant speech, which suggests that preferences are independent of the type of background noise, as well as the context (relaxation vs working).
3. Audio-only and audio-visual perception results indicated that the introduction of a water feature improved the perception of the sound environment (*Objective 3*). This was true for four out of six water sounds in the audio-only condition and was true for all six water features tested in the audio-visual condition.
4. Audio-visual perception results indicated that visual material increased the likelihood of positive scores (*Objective 3*), i.e., had a positive impact (1.1 to 2.5 times more chance to make positive changes in people's perception when the audio materials were accompanied by visual animations).
5. Using one water feature in a typical open-plan office could provide masking only to a relatively small area. Multiple water features will, therefore, be needed if the masking sound level is to be kept within the preferred range (42–48 dBA) across most workstations (*Objective 4*). Installing a water feature in the middle of an office as well as at the corners is likely to result in more uniformly distributed masking sound levels across the workstations. Alternatively, very uniform masking can be achieved with a hybrid-type system consisting of a single water feature as the source, and an array of ceiling speakers.
6. A water sound can significantly reduce the distraction distance (and privacy distance) in open-plan offices (around 10 m reduction in r_D for the two offices tested). However, different office layouts and room acoustics might benefit differently from this reduction—clusters of workstations benefiting more than rows of workstations, for example (*Objective 4*).

Findings (1) and (2) suggest that water features work mainly as informational maskers rather than energetic maskers, as comparable results have been found irrespective of the background noise used (irrelevant speech in the current study vs road traffic noise in previous research[23,33]) and context considered (working in the current study vs relaxation in previous research[23,33]). The spectral properties of the preferred water sounds are different from that of speech as well as the recommended −5 dB/octave pink noise. It appears, therefore, that the spectral shape of a water sound is not a decisive factor in dictating how it is perceived. As such, the existing guidance regarding the preferred masking sound spectrum is not applicable to water sounds and should be avoided in future indoor waterscape studies. Findings (3) and (4) indicate that the use of water features improves the sound environment of open-plan offices and that seeing the water feature (i.e., congruence between what is heard and what is seen) is important and beneficial. Findings (5) and (6) can be used as practical guidance in terms of the number and locations of water features and the expected improvement in distraction distance.

Overall, this work highlights that water features can be used in open-plan offices as a means of masking irrelevant speech and improving the soundscape.

ACKNOWLEDGMENTS

The authors would like to express their deepest gratitude to Dr. Jennifer A. Veitch from the National Research Council Canada, Institute for Research in Construction (IRC), who very kindly provided the speech recording that was used throughout this study. The authors would also like to thank Sandy Brown Associates for granting access to use their Odeon Auditorium 15 license.

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