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Citation for published version:
Abdalrahman, Z & Galbrun, L 2017, Soundscape assessment of a water feature used in an open-plan office. in L Brotas, S Roaf & F Nicol (eds), *Proceedings of 33rd PLEA International Conference: Design to thrive.* vol. 3, 0661, NCEUB, 33rd International Conference on Passive and Low Energy Architecture: Design to Thrive , Edinburgh, United Kingdom, 2/07/17.

Published In:
Proceedings of 33rd PLEA International Conference

Soundscape assessment of a water feature used in an open-plan office

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Abstract: Research has shown that noise masking systems can successfully mitigate the detrimental effects of noise in open-plan offices. This paper provides a new approach to noise masking in open-plan offices, through the use of water sounds generated by real water features placed inside a work space. The effectiveness of water sounds in masking noise, especially irrelevant speech, has been extensively examined in previous laboratory experiments. The current paper builds upon the findings achieved so far, by extending the study into real-life settings. A water feature, designed in accordance with preference findings obtained previously, was installed in a medium sized open-plan office (12 workstations). A satisfaction questionnaire (focusing on the soundscape) was distributed prior to the installation of the water feature, to assess the work environment in the absence of any noise masking system. Then, another satisfaction questionnaire was distributed, after the water feature had remained in the office for a period of 3 weeks. The results obtained from both questionnaires suggest that the water feature had a positive effect on the soundscape assessment of the open-plan office, as shown by an increased level of subjective satisfaction that confirms laboratory findings. According to these empirical results, carefully designed water features could substitute conventional noise masking systems, with the added benefits of being affordable and contributing to an increase in the aesthetic value of the space.

Keywords: noise masking, water sounds, soundscape.

Introduction

Despite the economic benefits associated with using open-plan offices, there is a growing body of scientific evidence suggesting that open-plan offices increase workers' dissatisfaction and cognitive workload (De Croon et al. 2005), cause fatigue and difficulties in concentration (Pejtersen et al. 2006), and cause subjective impairment of work performance (Haapakangas et al. 2008). Dissatisfaction with the acoustic environment, i.e., background noise and lack of speech privacy, has repeatedly been highlighted as the main cause of the above problems (Bodin Danielsson & Bodin 2009; Jensen et al. 2005; Sundstrom et al. 1994). Irrelevant speech coming from co-workers is one particular factor that has been identified by numerous studies to have the most negative impact on the comfort level of workers. This finding is so robust and consistent over many studies to make it safe to state that little improvement can be achieved in the acoustic environment of open-plan offices without a thorough understanding and proper treatment of this type of distraction (Venetjoki et al. 2006; Virjonen et al. 2007; Hongisto 2008; Haapakangas et al. 2011; Haapakangas et al. 2008).

Masking sounds have been reported to help in reducing the intelligibility level of speech, and thus, decreasing the detrimental effects of this type of noise. Examples of masking sounds are pink noise (Ellermeier & Hellbruck 1998; Schlittmeier & Hellbrück 2009), white noise

(Loewen & Suedfeld 1992) and filtered pink noise whose sound pressure level decreases 5 dB per octave band (Venetjoki et al. 2006; Haka et al. 2009; Jahncke et al. 2011).

Among the studies reviewed, only one study used a water sound as a mean of masking speech in open-plan offices, and its findings were promising. Haapakangas et al. (2011) examined the effect of five different masking sounds on workers' performance: filtered pink noise, ventilation noise, instrumental music, vocal music and a spring water sound. The spring water sound was most beneficial in terms of both subjective (satisfaction) and objective (performance) indicators, results that none of the other masking sounds could acheive.

On the above ground, extensive laboratory research started to examine the audio-only and audio-visual preferences of water sounds and their likely impact on people's satisfaction and performance level. The results obtained were encouraging, and therefore, it was decided to further extend the research by placing a water feature in an open-plan office for a period of 3 weeks. This allowed examining the longer-term effect of having a water feature in a work space through a satisfaction questionnaire.

Design of the water feature

A water feature (dimensions, 48H $\times$ 45W $\times$ and $\times$ 49D cm) was purchased and modified to meet the criteria set out by previous stages of the current study regarding the audio-only and audio-visual preferences of different water features used as speech maskers. A cascade-like water feature was highly preferred, and therefore, a 3-step cascade was purchased and modified to provide a pleasant sound and visual apearance. The modified water feature is shown in Figure 1.

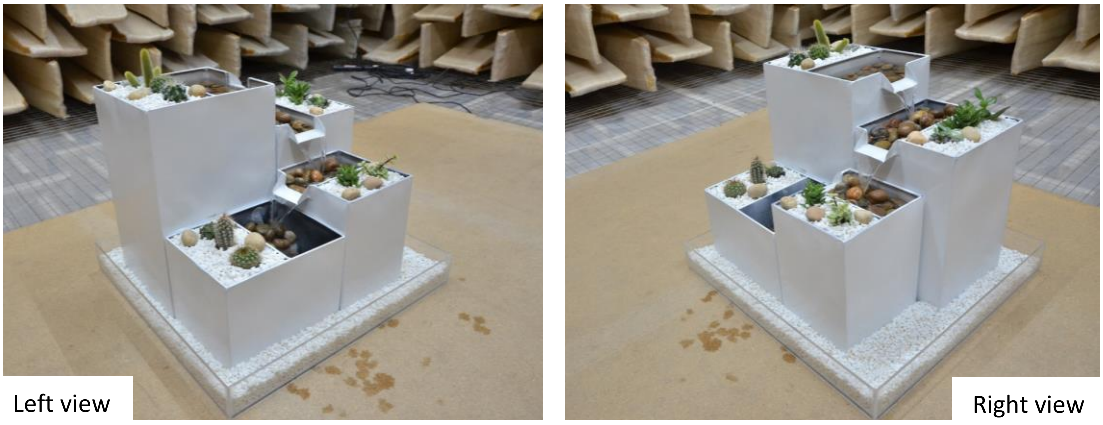

Figure 1. Three-step cascade used in this study.

After modification, the sound quality of the water feature was subjectively evaluated and the sound pressure level of the water feature was measured in the highly insulated anechoic chamber of Heriot-Watt University. The average sound pressure level (SPL) 1 meter away from the centre of the water feature was measured to be 45.5 dBA.

The open-plan office

A medium sized open-plan office with an area of 56.3 m^2 (dimensions, 7.60W $\times$8.75L $\times$2.90H m) was selected for the water feature to be installed in. Figure 2 shows a photograph of the office and its plan with dimensions. The open-plan office was located in the William Arrol building of the Edinburgh campus of Heriot-Watt University. The office accommodated 12 workstations clustered into 3 groups of working area. The finishing material of the walls was plaster and the ceiling was made of absorbent ceiling tiles. The water feature was placed at the middle of the shorter side of the space on a 0.7 m high table, as shown in Figure 2. This position was carefully chosen to minimise the space taken up by the water feature while making it both visible and audible from most of the workstations. The equivalent sound pressure level, L_{Aeq}, of the background noise in the absence of employees at each workstation was measured over a period of 15 seconds, with and without the water feature in operation. The space averaged L_{Aeq} was 33.5 dB (empty room but equipment switched on) without the water feature, and rose to 39.3 dB when the water feature was switched on.

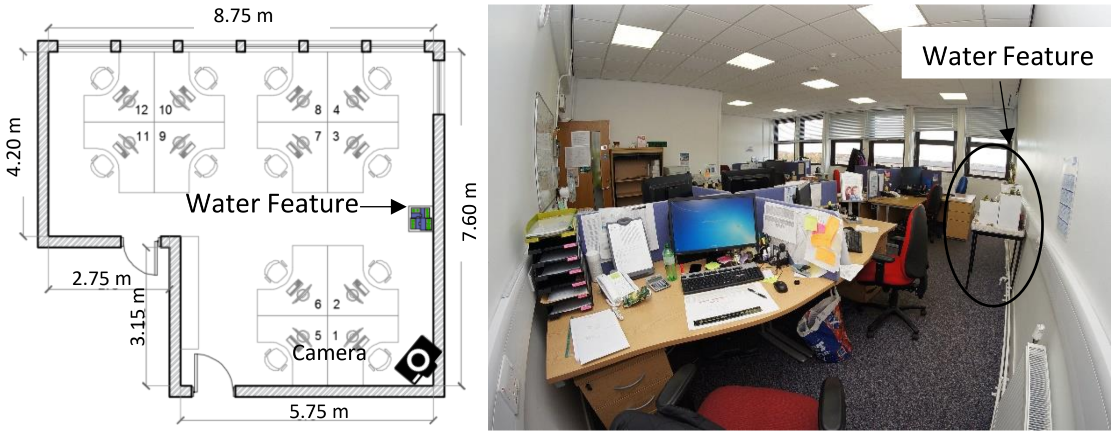

Figure 2. The open-plan office where the water feature was placed in.

Questionnaire

A modified version of the GABO questionnaire (Pierrette et al. 2014) was used to assess the initial noise environment in the open-plan office and to measure likely effects that the water feature could have on people's perception of their work environment. The questionnaire was divided into two parts, Part 1 and Part 2. Part 1 was distributed before installing the water feature, and Part 2 was distributed after the water feature had been in the space for a period of 3 weeks. The two parts were mostly identical apart from a few extra questions concerning the water feature added in Part 2.

The first section, "General information about you and your workstation", gathered background information such as age, gender and length of time working in the office. The second section, "Assessing the physical environment of your work area", assessed the employees' satisfaction with their physical working environment. This section consisted of 14 items, half of which (i.e., 7 items) measured satisfaction relating to control/privacy aspects, and the other half was about comfort/functionality aspects of the workspace.

The third section, "Assessing the noise environment of your work area", assessed employees' noise environment. Participants rated the general perceived noise level and then stated the level of annoyance caused by noise in the space. Participants were also asked about the perceived frequency of two noise sources: intelligible speech and unintelligible speech.

The fourth section, "Your perception of the sound environment", was dedicated to measuring people's perception of the sound environment in the work space. The section included questions measuring different aspects of the sound environment such as pleasantness, the possibility of concentrating on tasks, the possibility of having a meeting without distracting others, working uninterrupted, and the possibility of having private conversations. Ten questions specific to the water feature were added to this sections in Part 2 of the questionnaire, to measure how people perceived the water feature and its sound.

An 11-ponit numerical scale was used in the current study where 0 stood for “very dissatisfied/strongly disagree”, and 10 stood for “very satisfied/strongly agree”. The main aim of the study was to examine the likely effects that installing a water feature has on people’s satisfaction and perception of their work environment, small differences being more easily detectable in an 11-point scale than, for example, a 5-point Likert scale.

The fifth section, “Your relationship with noise in general” assessed how people reacted to noise, i.e., their sensitivity to noise. This section was a shorter version of the noise sensitivity questionnaire (NoiseQ) developed by Schütte, Sandrock et al. (2007), which consists of 12 items divided into 3 subscales, namely, *sleep*, *habitation* and *work*, with 4 items in each subscale. Participants stated their level of agreement with each item on a 4-point numerical scale with 1 representing “strongly disagree”, and 4 representing “strongly agree”. The answer to each question was then quantified from 0 to 3 and used to calculate the average noise sensitivity score. A score of less than 1.11 is considered as not being sensitive to noise, while a score of greater than 1.63 is considered as being sensitive to noise (Schütte, Marks et al. 2007).

Statistical analysis

Data was analysed using IBM SPSS Statistics for Windows, Version 22.0. Given the small sample size (N=14), and the violation of the assumption of normality of most scores (checked using Shapiro-Wilk test and Normality Q-Q plot), it was decided to adopt non-parametric tests for the statistical analysis. The Wilcoxon signed-rank test, which is the non-parametric version of the related *t*-test, was used for comparing scores between the two parts of the questionnaire. Bias-corrected and accelerated bootstrap method, BCa, was used to derive robust 95% confidence intervals, which are reported in square brackets throughout this paper.

Where appropriate, the effect size, *r*, is given, which is a standardised measure of the size of effect observed. The effect size is not readily available in SPSS, however, the z-scores provided as a part of the Wilcoxon signed-rank test can be converted to *r* (Field 2013).

Procedure

Part 1 of the questionnaire measured the initial satisfaction level of workers within their work environment. After all participants had filled out Part 1, the water feature was installed in the space. The water feature had remained in the office for 3 weeks (5 days/week), before Part 2 of the questionnaire was distributed. Participants were asked to keep Part 1 until after Part 2 of the questionnaire was distributed. Then, both parts were collected together. The responses obtained from both parts of the questionnaire were analysed and compared to identify any change in people’s satisfaction level and their perception of the work environment.

Participants

Fourteen participants (2 males, 12 females) filled out the questionnaires. These were staff members of Heriot-Watt University, aged between 24 and 61 yr (*M* = 39.86 yr, SD = 11.64 yr). The average time participants had spent in the open-plan office was *M* = 1.39 yr (SD = 1.15 yr), with an average attendance of *M* = 2.86 days per week (SD = 1.55 days per week), due to staff rotation. The score obtained from the noise sensitivity questionnaire revealed that, on average, participants were moderately sensitive to noise (*M* = 1.58, SD = 0.70). A slightly higher score was obtained when the sensitivity to noise was calculated based on the *work* subscale with an average score of *M* = 1.66 (SD = 0.64).

Results

Satisfaction within the physical work environment

Bias-corrected and accelerated bootstrapped 95% CIs are reported in square brackets. The results from Part 1 of the questionnaire revealed that participants were satisfied with their physical work environment, *M* = 7.06 [6.55, 7.64]. When the analysis was made separately for the two underlying subscales, the results indicated that participants were more satisfied with the comfort/functionality aspects of their work environment, *M* = 7.58 [7.09, 8.09], compared to control/privacy aspects, *M* = 6.53 [5.88, 7.24]. The difference in satisfaction between the two subscales was found to be statistically significant (z = 2.984, *p* = .001, *r* = .564).

After the water feature was added to the space, global satisfaction level within the physical work environment increased, *M* = 7.28 [6.71, 7.92], however, this increase was not statistically significant (z = 1.615, *p* = .115, *r* = .305). Having said that, the water feature significantly increased the satisfaction levels within the subscales comfort/functionality, *M* = 7.84 [7.35, 8.36] (z = 2.530, *p* = .012, *r* = .478). The satisfaction level within subscale control/privacy also increased, *M* = 6.71 [5.91, 7.56], but the increase was not statistically significant (z = 1.104, *p* = .295, *r* = .209).

The increase in satisfaction level can be attributed to 3 items within the physical work environment, namely *Item 1* "Noise environment" and *Item 2* "The cleanliness of your work area" within the subscale comfort/functionality, and *Item 3* "Possibility of concentrating in your workplace" within the subscale control/privacy. When the scores of Items 1, 2 and 3 were compared before and after installing the water feature, it was revealed that the water feature significantly increased the satisfaction level for Item 1 (z = 2.803, *p* = .004, *r* = .530), and Item 2 (z = 2.041, *p* = .041, *r* = .386), but the increase was not statistically significant for Item 3 (z = 1.876, *p* = .074, *r* = .354).

Satisfaction within the noise environment

Employees perceived the noise level in the office not to be high, *M* = 4.43 [3.14, 5.97], nor annoying, *M* = 4.14 [3.14, 5.21]. Furthermore, the water feature did not seem to have any effect on the perceived noise level, *M* = 4.29 [2.93, 5.64], nor annoyance, *M* = 4.36 [3.21, 5.43]. Statistically, no significant differences were detected for perceived noise level (z = 0.426, *p* = .672, *r* = .081), and perceived annoyance (z = -0.412, *p* = .680, *r* = -.078), before and after installing the water feature.

Participants assessed the frequency of occurrence of two noise sources, intelligible speech and unintelligible speech. Intelligible speech, *M* = 7.50 [6.64, 8.36], was perceived as being twice as frequent as unintelligible speech, *M* = 3.79 [2.14, 5.36]. After the water feature was added, the perceived frequency of intelligible speech dropped to *M* = 6.21 [5.36, 7.00], and the change was statistically significant, (z = -2.326, *p* = .027, *r* = -.440). On the contrary, the water feature resulted in an increase in the perceived frequency of unintelligible speech, *M* = 4.57 [3.14, 5.93], yet, the increase was not statistically significant (z = 0.784, *p* = .523, *r* = .148). This is understandable as the water sound must have masked a portion of the intelligible speech and made it unintelligible, hence the increase in the perceived frequency of unintelligible speech. Looking at the *r* values, it appears that the water sound had a much larger effect on reducing the frequency of the intelligible speech in comparisons to its effect on increasing the frequency the unintelligible speech. This implies that in addition to masking a portion of the intelligible speech and making it unintelligible, another portion of the intelligible speech might have become inaudible, hence the inequality in effect sizes.

In terms of annoyance, neither intelligible speech, M = 3.93 [2.57, 5.29], nor unintelligible speech, M = 2.43 [1.21, 3.86], was perceived as being excessively annoying. Furthermore, the water feature did not have a significant impact on reducing the perceived annoyance level caused by intelligible speech, M = 3.86 [2.64, 5.00] (z = -0.276, p = .783, r = -.052), and resulted in an increase in the annoyance level associated with unintelligible speech, M = 3.50 [2.07, 5.07], yet the increase was not significant (z = 1.689, p = .109, r = .376).

Perception of the sound environment

This part of the questionnaire included 6 questions, 2 of which examined people's perception of the sound environment, while the remaining 4 were related to the possibility of carrying out certain office-related activities within the sound environment. As shown in Figure 3, the water sound resulted in an increase in scores for all 6 questions.

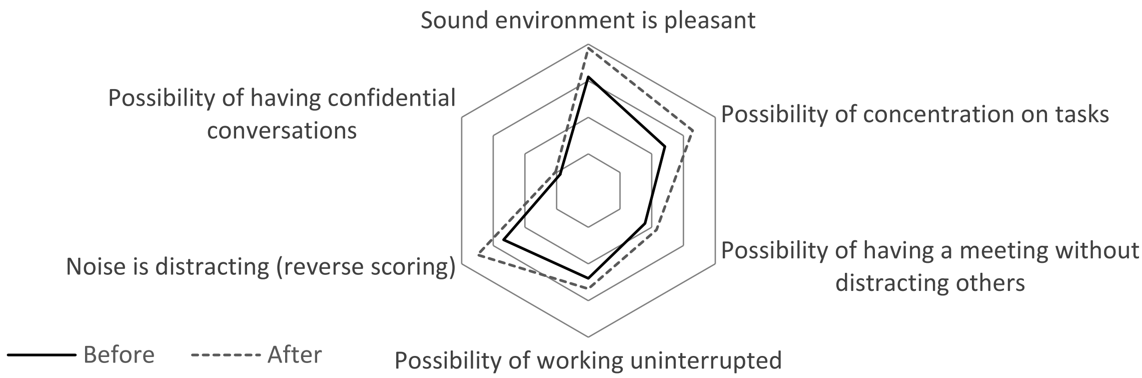

Figure 3 Satisfaction within the sound environment.

Participants perceived the sound environment of the open-plan office to be moderately pleasant, M = 6.21 [5.21, 7.14]. The inclusion of the water feature in the work space significantly increased the pleasantness level, M = 7.79 [6.86, 8.71] (z = 3.244, p < .001, r = .613). The sound environment was perceived as not being particularly effective in helping people to concentrate on their tasks, M = 4.82 [4.07, 5.61], but this score significantly increased after the installation of the water feature, M = 6.57 [5.57, 7.64] (z = 2.807, p = .003, r = .530). This suggests that the water feature was effective in helping people to carry out certain tasks. Participant were also asked if they perceived the sound environment of the work space to be distracting, and the responses suggest that they did not perceive it as being distracting even before the water feature was installed, M = 4.64 [3.71, 5.64]; however, the water feature further improved the sound environment, M = 3.00 [1.93, 4.07], and made it significantly less distracting (z = -2.505, p = 0.014, r = -.474).

Despite a slight increase, no significant differences were detected in the possibility of having a meeting without distracting others (z = 1.111, p = .344, r = .210), possibility of working uninterrupted for long periods (z = 0.905, p = .563, r = .171), and possibility of having confidential conversations (z = 0.496, p = .664, r = .094). The latter was to be expected, as confidential conversations require a greater level of privacy that the water sound was incapable of providing.

Part 2 of the questionnaire included 10 extra questions concerning the water feature. The responses to these questions revealed that the water sound was very positively perceived as being pleasant, *M* = 9.14 [8.64, 9.57], as improving the sound environment, *M* = 8.57 [7.93, 9.14], and as being visually/aesthetically pleasing, *M* = 9.57 [9.29, 9.86]. Furthermore, the water feature did not cause people to feel stressed, *M* = 0.14 [0.07, 0.36], nor its sound distracted people, *M* = 0.14 [0.07, 0.36]. Nevertheless, the water feature did not seem to have helped people to carry out private conversations, *M* = 4.43 [3.07, 5.86]. Only 2 participants thought that the water feature increased the frequency of going to the toilet with an average increase of 2 times per day, and finally, 13 out of 14 participants preferred the water feature to remain in the space on a permanent basis. The last question was an open-ended question, for which the comments were all positive; "very pleasant", "it is a pleasant soothing sound", "the feature is lovely to look at". The responses to the above questions suggest that the water feature was highly appraised by participants with very little adverse effect on the number of times that people needed to go to the toilet.

Discussion

This study provided an insight into the use of a water feature as a noise masker in an open-plan office. Generally, participants were satisfied with their physical work environment, however, the inclusion of the water feature significantly increased the satisfaction level of the comfort/functionality aspects of the work environment. This increase in satisfaction level could mainly be attributed to an increase in people's satisfaction with the noise environment and cleanliness of their work area. The water feature significantly decreased the perceived frequency of intelligible speech, which shows its effectiveness in masking speech. This was further demonstrated by an increase in the perceived frequency of occurrence of unintelligible speech, although this increase was not statistically significant.

The water feature had a positive impact on people's perception of their sound environment. After the inclusion of the water feature in the space, participant perceived the sound environment to be more pleasant, more effective in helping them concentrate on their tasks, and less distracting. The water feature did not help people in working uninterruptedly, having meetings without distracting others, and carrying out private conversations. In that respects, it should be noted that a water feature, such as the one used here, is a fairly quiet masking system that can only be effective up to a certain limit. It cannot fully compensate the disadvantages associated to an open-plan office, but it can certainly reduce its adverse effects.

The water feature itself was highly appraised, most participants asking to keep the feature in the space permanently. The water sound was perceived as being highly pleasant too, and the feature significantly improved the sound environment and added an aesthetic value to the space.

It is worth mentioning that more statistically significant results (i.e., $p < .05$) would have been possible had the sample size been larger. In a few cases, the effect sizes of the water feature exceeded .30, but no statistical differences were detected. For example, the water feature had a *medium* effect size ($r > .30$) on improving the physical work environment, and the possibility of concentrating on tasks, with *p*-values greater than .05. An effect size of .30 could be practically meaningful. For instance, even only a 1% increase in the performance of employees would result in a saving of around £3500 per annum. This calculation was made assuming an average salary of £25000/year and 14 employees (1% $\times$ 14 $\times$ 25000).

Limitations of the study

This study was carried out to extend some laboratory findings into real-life settings. The small sample size (N = 14) limits the generalisation of the findings. The study is also based on a relatively small and quiet open-plan office where people were already satisfied before the installation of the water feature. It is not clear whether even more positive findings might be achieved in crowded and larger offices with less satisfied people. Having said that, statistically significant improvements in the work environment were still possible despite the small sample size. In many cases the magnitude of the effect size was still above .30 which is considered a medium effect size. The study indicates a great potential for water features used in open-plan offices to mask noise, making it an attractive topic for further research.

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