

**WOODS
BAGOT™**

**PUBLIC
PAPER**

**TO BE SEEN
BUT NOT HEARD**

To be Seen but not Heard

Improving acoustic conditions in open-plan offices

Written by Sean Coward & Densil Cabrera

Article at a glance

Despite well-documented complaints regarding the acoustic conditions in open plan offices, business leaders continue to overlook occupant concerns owing to the collaborative benefits associated with this design. This article highlights the circumstances under which job performance is most likely to be affected by task-irrelevant sound, and offers recommendations for improving the acoustic environment in open plan offices. A case study demonstrates how the acoustic analysis of an existing workplace can serve to benchmark current performance, identify problem areas, and offer potential solutions.

The negative impact of communal spaces

The goal of open-plan is clear: by removing walls and bringing people together one increases the connection between members of a workforce. The visual availability of others encourages communication and increases the likelihood of chance encounters, leading to knowledge exchange. Furthermore, the presence of others has been shown to have a beneficial impact on the performance of certain work-related tasks (e.g., Ferris & Rowland, 1983). When combined with the financial savings achievable over traditional cellular offices (less m² per person; reduced cost for layout alterations), the overwhelming popularity of open-plan is not surprising.

Unfortunately, the social dynamic of open-plan brings with it the potential for distraction. Research has shown that the primary criticisms levelled at open-plan by occupants are acoustic issues (Banbury & Berry, 2005; Boyce, 1974). These complaints generally take two forms: the distracting quality of task-irrelevant noise (both speech and non-speech), and the lack of privacy available for confidential conversations (in person or over the phone). Despite widespread awareness of such problems, they are seldom taken seriously due to the lure of the aforementioned benefits (Hongisto, 2005). This bias reflects the tendency of decision-makers to place business objectives, such as the desire for collaboration, ahead of staff concerns.

There is, on the surface, nothing wrong with this prioritisation: the office is there to facilitate successful business behaviours, not to make staff feel comfortable. However, if employees' concerns regarding office noise are able to negatively impact an organisation's bottom-line, then this issue warrants consideration. With this in mind, poor acoustic conditions have been found to increase both employee stress (Evans & Johnson, 2000) and fatigue (Witterseh, Wyon, & Clausen, 2004), decrease both job satisfaction ratings (Sailer & Hassenzahl, 2000) and work motivation (Evans & Johnson, 2000), and lead to negative affect in occupants (Knez & Hygge, 2002). All of these variables have the *potential* to decrease the effectiveness of human capital, but for a more direct link to business performance we must review research concerning the relationship between acoustic conditions and *job performance*.

Office noise and performance: The irrelevant sound effect

Business performance is the product of many factors, but the most influential determinant of success is optimising the performance of each individual within the organisation. The physical environment comprises countless variables capable of exerting an effect on occupants, and the research cited previously indicates that office noise influences the psychology of staff on a number of levels. However, while variables such as stress have been linked to physical well-being, they are not consistently related to performance. For instance, Sundstrom, Town, Rice, Osborn, and Brill (1994) found that noise correlates with ratings of dissatisfaction but not with performance; a recurrent theme throughout the general literature in organisational psychology. For this reason we shall henceforth focus specifically on the effects of office noise on individual work performance.

One subset of studies applicable to this research question concerns the so-called 'irrelevant sound effect'. Originally termed the 'unattended speech effect' (Colle & Welsh, 1976) or 'irrelevant speech effect' (Jones & Morris, 1992), this phenomenon concerns the observation of relatively poor serial recall performance when presented with low-intensity background speech (Beaman, 2005). However, observation of the effect using non-speech stimuli such as tones (Jones & Macken, 1993) led to a broadening of the subject matter to include all task-irrelevant sounds (Beaman & Jones, 1997). Indeed, regardless of whether the irrelevant stimulus contains speech or not, the effect is considered to be one of the more robust phenomena in psychology, as indicated by the frequency of replication in the literature.

The reliability of the irrelevant sound effect is possibly due to the fact that there appear to be few moderating variables capable of obscuring results. The deleterious effects of irrelevant sounds on performance are involuntary (i.e., participants can not choose to ignore them), and the majority of studies suggest that they do not habituate over time (Höllbrück, Kuwano, & Namba, 1996; Jones, Macken, & Mosdell, 1997). Somewhat surprisingly, the strength of effects is independent of the intensity of the stimulus, at least within the range of 48-76 dB (Tremblay & Jones, 1999). The examination of individual differences has also proven largely fruitless, with gender, intelligence, attention span, and age all failing to account for differential effects (Beaman, 2005).¹ Interestingly, there is some evidence that the trait of introversion-extraversion is capable of moderating effects, such that introverts find irrelevant sound more disrupting than do extraverts (Furnham & Strbac, 2002). The implications of this finding will be discussed shortly.

¹ Note that the reported lack of age effects pertains to adult participants (as found in offices). Young children have been found to be more sensitive to irrelevant sound interference than older children (Elliot, 2002), which has implications for primary educational settings.

There have been a number of theories proposed to account for the irrelevant sound effect. Salamé and Baddeley (1982) postulated that written material is transformed by the reader into a phonological (sound-based) code. When the reader is simultaneously presented with auditory stimuli, the encoding of the written stimuli to be recalled is contaminated by any phonological similarity between the written material and any speech-like sounds (e.g., the processing into memory of the word *cow* will be disrupted by any irrelevant words such as *now*, *row*, or *sow*). Hongisto (2005) agrees with this notion of encoding contamination but claims that the effect is based on semantic, rather than phonological, similarity. He argues that speech *intelligibility* determines the distraction value of speech: "Speech can be distracting only when it is clearly heard, i.e. intelligible" (p. 459). The implication from Salamé and Baddeley's model is that only speech-like sounds can produce an irrelevant sound effect, and Hongisto takes this a step further with the assumption that only *comprehensible* speech can produce effects. However, this speech-specific account can not explain the aforementioned decrements procured using tones (Jones & Macken, 1993), which is precisely why the literature now refers to the irrelevant *sound* effect.

In reaction to the limitations of Salamé and Baddeley's (1982) theory, Jones, Madden, and Miles (1992) proposed the *changing-state hypothesis*. According to this account, any background noise that is characterised by unpredictable change is capable of producing an irrelevant sound effect. Humans are predisposed to detect change in their environment as a warning of danger or an indicator of opportunity. As a result of this, an unpredictable auditory array consumes attentional resources in an attempt to identify the sources of sounds, which leaves fewer cognitive resources available for the primary task. Indeed, Keighley (1970) found that staff rate distinctive—rather than loud—sounds to be the most unacceptable aspect of office noise. While proponents of the changing-state hypothesis recognise abrupt changes in spoken pitch to be the most disruptive, any sound that meets the criteria of unpredictability will produce effects. In a series of experiments designed to test between these competing theories, Banbury and Berry (1998) concluded that their observation of effects using office noise without speech supports the changing-state hypothesis.

Though not formally presented as a theoretical account specific to the irrelevant sound effect, Witterseh, Wyon, and Clausen (2004) adopt *arousal theory* as a conceptual foundation. According to these authors, background noise is thought to increase arousal, which leads to a narrowing of attention for occupants (note here similarities with the attentional resources implicated in the changing-state account). Johansson (1983) claims that this increase in arousal will benefit performance for some personalities while being detrimental for others. Recall that the only personality trait that has been empirically linked to differential effects is introversion-extraversion, which Furnham and Strbac (2002) explain with reference to Eysenck's (1967) notion that introverts have higher baseline arousal levels than extraverts. Introverts are therefore assumed to shun external sources of arousal—such as noise—whereas extraverts seek out such stimuli in order to raise arousal to optimal levels.

While the consideration of individual differences is of no practical relevance to designers of office space (who are not likely to customise each workstation based on the results of intense psychological profiling), arousal theory also predicts differential performance based on the *type of task*. The literature on social facilitation suggests that increased arousal improves the performance of well-learned and simple tasks while impairing performance on novel and complex tasks (Aiello & Douthitt, 2001; Zajonc, 1965). Consistent with this prediction, Witterseh et al. (2004) found that both typing and reading speed (tasks the authors defined as well-practised) increased with background noise, while arithmetic and creative thinking was hindered. Smith (1961) claims that the same differential effects can be procured with music; of relevance to the current debate concerning iPods in the workplace. It may therefore be hypothesised—in line with the literature on social facilitation—that the effects of office noise (including speech, music, printers, etc.) will be positive for well-learned or simple tasks and negative for novel or complex tasks.

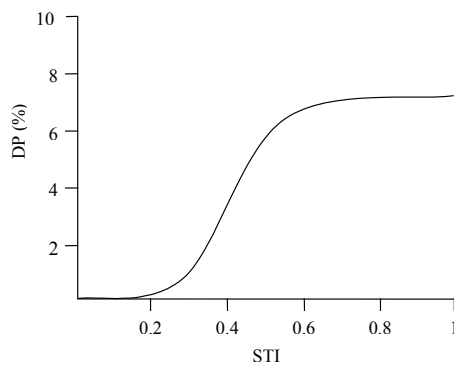
Complexity is but one of many task characteristics capable of attenuating the irrelevant sound effect. Both the strength and nature of irrelevant sound effects depend on the cognitive demands of the task performed (Beaman, 2005). Effects have been observed during arithmetic processing, whereas the meaning of irrelevant speech provides an additional degree of interruption when the task involves reading (Jones, Miles, & Page, 1990), presumably because this task requires semantic processing. Thus, it may be the case that the changing-state hypothesis is supplemented on occasion by phonological and/or semantic contamination resulting from a speech-specific encoding process, as described by Salamé and Baddeley (1982). Indeed, tasks involving memory are particularly susceptible to irrelevant sound effects (Beaman & Jones, 1997), suggesting that the distracting element of irrelevant sound impedes the encoding of both numerical and linguistic material.

Regardless of the underlying explanation, task-irrelevant office noise clearly has the potential to inhibit individual—and therefore business—performance. Hongisto (2005) analysed the results from 28 studies reporting irrelevant speech performance decrements using a variety of tasks, under conditions spanning silence to clearly intelligible speech. He calculated the magnitude of these decrements as ranging from 4-41%, and developed a mathematical model which predicts performance decrements as a function of the intelligibility of irrelevant speech. Intelligibility was measured using the *speech transmission index* (STI), which ranges from 0 (speech is completely obscured) to 1 (perfectly clear speech). According to this model, an STI of 0.6 (see Table 1 for a description of office conditions typically associated with a range of STI values) can be predicted to result in a minimum decrease in performance of 7% for all task types (see Figure 1). The challenge for organisations is to minimise this disruption—by reducing STI—as much as possible.

Table 1 STI values and their perceptual and environmental correlates.

STI	Speech intelligibility	Speech privacy	Examples in offices
0.00 – 0.05	Very bad	Confidential	Between two single-person offices (high sound insulation)
0.05 – 0.20	Bad	Good	Between two single-person offices (normal sound insulation)
0.20 – 0.40	Poor	Reasonable	Between workstations in a high-level open-plan office; or between two single-person offices (doors open)
0.40 – 0.60	Fair	Poor	Between desks in a well-designed open-plan office
0.60 – 0.75	Good	Very poor	Between desks in an open-plan office (reasonable acoustic design)
0.75 – 0.99	Excellent	None	Face-to-face discussion; or good meeting rooms; or between desks in an open-plan office (no acoustic design)

Figure 1 STI Curve from Hongisto's prediction model, which estimates the percentage of performance decrement (DP %) that accompanies background speech at varying levels of intelligibility (STI). This model was developed using published data across a range of tasks, with the asymptote of 7% considered a conservative estimate of actual performance inhibition.



Sound advice: Methods for improving acoustic conditions

There are a number of interventions capable of ameliorating the acoustic environment in open-plan offices. These recommendations can be grouped according to four categories: cultural initiatives, office design, structural materials, and acoustic masking.

Cultural initiatives

Obviously, the most effective way to reduce the impact of irrelevant sound on performance is to minimise the amount of office noise produced. Staff should be trained to avoid behaviours that needlessly increase sound levels—and subsequent distraction amongst their colleagues. For instance, Boyce (1974) found that 67% of open-plan staff report being disturbed by ringing telephones. While auditory signals for incoming calls are likely to remain a feature in offices for some time, Banbury and Berry (2005) clarified the root of this concern with their finding that phones ringing at vacant posts impair concentration more than ringing phones in general. One may therefore speculate that ringing telephones would not disturb colleagues as much if the intended recipient of the call was available to answer it promptly—or had switched the device to a silent/voicemail setting. Thus, the distraction is likely a combined result of both the persistent ringing (an external stimulus) and frustration that others have not taken steps to minimise the noise (an internal process).

This combination of external distraction and associated cognitions can result from a variety of office behaviours (e.g., loud conversations, excessive computer volume, operating noisy equipment, standing while talking so that voices travel over screens), such that efforts should be made to make staff aware of the acoustic consequences of various behaviours.

Office design

Even the most effective training programme will fail to remove all irrelevant sounds from the workplace: telephone conversations, team discussions, client visits and the footfall of human traffic are unavoidable consequences of running a business. However, clever design can help to alleviate the impact this background noise has on work performance. It might, at first, seem intuitive to divide the workforce into job-specific teams housed in smaller, enclosed offices. Unfortunately, it seems that occupants are less satisfied with the acoustic conditions of these environments than they are with large, high density offices (Boyce, 1974). There are two reasons for this. First, smaller rooms contain more sources of reverberation because lateral reflections of soundwaves off walls assume greater importance than they do in larger offices, where the ceiling is the primary cause of sound propagation (Chusid, 2001). Second, the reduced number of occupants renders the occasional sound perceptually isolated, and therefore more salient; the defining characteristic of changing-state and, therefore, a primary source of distraction. In support of this idea, Jones and Macken (1995) found that incrementally adding voices to background speech increases the irrelevant sound effect up to a point, but that greater than 6 speakers greatly reduces effects—presumably because each individual sound-source becomes less distinguishable from the overall chatter. Ironically, it seems that the numerous sources of background noise present in a large office wash out individual sounds, somewhat diluting the irrelevant sound effect (Jones & Macken, 1995).

However, it is generally recommended that the workplace contains a number of acoustically-isolated spaces for solitary tasks or intimate meetings (Venetjoki, Kaarlela-Tuomaala, Keskinen, & Hongisto, 2006). Interestingly, Banbury and Berry (2005) found that the provision of enforced quiet areas was the least popular hypothetical solution for improving acoustic conditions. This is possibly due to the fact that employees do not wish to leave 'their workspace' every time they require quiet working conditions. One solution to this would be to divide the workplace into zones which vary both in the types of behaviour permitted and in the degree of spatial/acoustic separation from others. Quiet zones for solitary, concentrated work could then be physically separated from communal spaces, with behavioural instructions specific to each area.

Structural materials

According to Chusid (2001), the best way to attain speech privacy is to follow the ABC of *absorb, block* and *cover*. Absorption of sound is best achieved by using acoustic ceilings with a noise reduction coefficient above .60, while blocking the propagation of soundwaves to neighbouring colleagues can be accomplished by means of partitions with a high sound transmission class. ('Cover' refers to acoustic masking and will be dealt with in the next section.) Screens can serve to decrease speech level by 10-15 dB, but only if combined with effectively absorbent walls and ceilings (Hongisto, 2005). While a discussion of the technical aspects of such materials is beyond the scope of this paper (see Wang & Bradley, 2002, for an experimental investigation into the impact of structural variables on speech privacy between workstations), the changing-state hypothesis once again warns that absorbing and blocking sound too effectively will increase the salience of noises that are perceived, leading to greater distraction and decrements in performance. This suggests that one should minimise absorption to increase reverberation as a means of drowning out individual sounds, but, unfortunately, this would reduce speech intelligibility for those engaging in conversation—which then causes people to raise their voices (Hongisto, 2005; Strasser, Gruen, & Koch, 1999/2000). Furthermore, high absorption surfaces also serve to dampen background noise and make speech less intelligible (Banbury & Berry, 2005). Therefore, the best means of achieving minimal distraction and speech privacy, while maintaining speech intelligibility for conversational purposes, is to use materials that block and absorb sound. The goal of decreasing the salience and intelligibility of any remaining irrelevant sound is best achieved using specialised sound masking techniques.

Acoustic masking

Acoustic masking refers to a range of methods that employ the strategic use of noise generators, usually for the purpose of 'drowning out' irrelevant speech. From a theoretical perspective, masking makes use of the changing-state hypothesis by reducing the ability to perceive distinct auditory events, including non-speech sounds capable of distracting workers. A range of stimuli can serve to mask office noise, including 'white noise' (uniform intensity over all frequencies), 'pink noise' (higher intensity at frequencies that predominate in human speech), water features, and even the building's HVAC system. The key characteristic of any effective masking stimulus is its uniformity (i.e., no distinct sounds) and its *signal-to-noise ratio* (S/N). This latter measure indicates the intensity of a target stimulus (in this case an irrelevant sound) relative to the masking stimulus, as measured in decibels (dB), and is calculated by subtracting the amplitude of the mask (noise) from the amplitude of the target (signal).

A number of companies provide noise generators and output systems designed to provide a consistent and uniform masking stimulus throughout the workplace. Loewen and Suedfeld (1992) found that these types of masking systems improved performance over unmasked office noise, but Ellermeier and Hällbrück (1998) argue that the S/N ratio necessary to obscure irrelevant speech may be too high for most offices (i.e., the masking agent itself may prove intrusive for occupants). For instance, Venetjoki et al. (2006) argue that the masking stimulus should not be louder than 50dB (the noise level in most offices), yet effective speech masking usually requires the masking stimulus to be presented at significantly higher levels that the signal to be masked. Digital signal processing techniques can reduce this S/N ratio (e.g., see Urban, 1992), yet the masking stimulus will invariably be louder than the sources of distraction that it is designed to obscure. Furthermore, most masking stimuli target the frequencies used in human speech, meaning that they are poorly equipped to obscure non-speech sounds. Nonetheless, evidence suggests that workers find the typical 'hiss' of masking to be less annoying than speech (Venetjoki et al., 2006), and the changing-state hypothesis predicts that the homogenous acoustic environment provided by masking will reduce distraction and associated decrements in performance.

Case study: Acoustic analysis of the Sydney studio

In light of the preceding material, the assessment and optimisation of office acoustics should be seen as an essential process in developing a high performance workplace. Unfortunately many organisations do not appreciate the consequences of poor workplace acoustics; particularly those based in Australia, who are well behind their U.S. and European counterparts regarding both the understanding and treatment of office noise. To illustrate the benefits of such analysis, Dr Denis Cabrera—an academic expert in building acoustics—was commissioned to provide an assessment of the current Woods Bagot Sydney studio.

General background noise

Background noise was measured at six positions distributed through the office (see Appendix A for noise levels recorded at various points in the studio). Figure 2 shows the averaged background noise level, illustrating that there is substantially more low frequency energy than high. This is typical, and indeed desirable, for background noise, so long as the levels are not excessive. The low frequency noise is largely due to external noise sources (mainly traffic) and air conditioning.

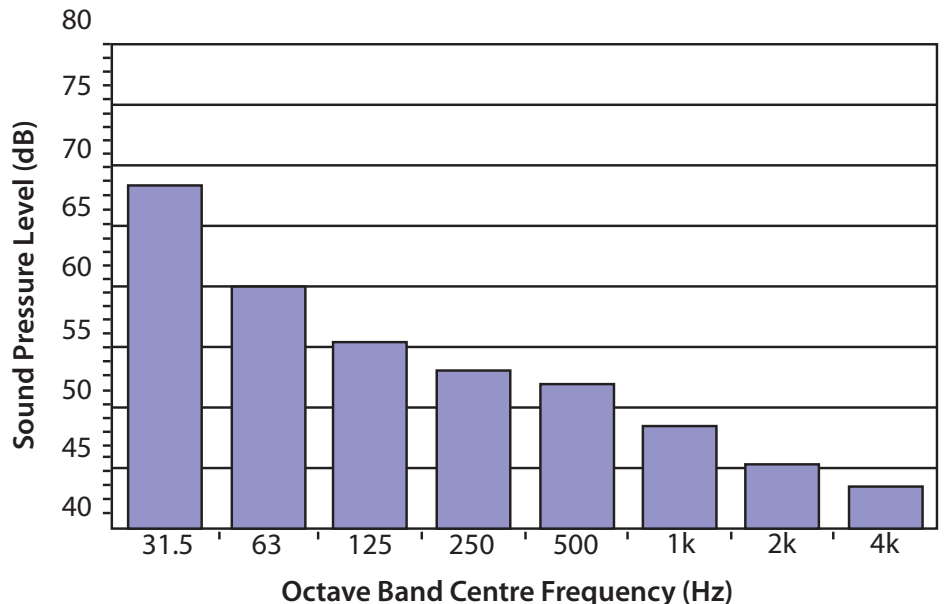


Figure 2 Spatially averaged octave band sound pressure levels in the office.

There are several ways in which background noise can be quantified. A-weighted level is very commonly used for noise measurements. The spatially averaged A-weighted sound pressure level for the studio is 54 dBA, with measurements ranging between 51 and 57 dBA depending on the measurement location. By way of comparison, AS/NZS 2107:2000 gives a sound pressure level of 40 dBA a rating of ‘satisfactory’ for design offices (unoccupied, with services operating), with 45 dBA being the recommended maximum level.

Another approach, known as Speech Interference Level (SIL), is to do a simple average of the octave band values from 500 Hz – 4 kHz. As the name suggests, this frequency range is the most important for speech intelligibility (and therefore for speech privacy). The spatially averaged SIL is 47 dB, which can be interpreted as meaning that conversational speech is satisfactorily intelligible to a distance of 1.8 m. A raised voice would be satisfactorily intelligible over twice this distance.

Intermittent ventilation noise source

There is an intermittent sound source at the far end of the office that seems to be related to ventilation. Measured at a nearby desk, the octave band sound pressure levels show a substantial increase in noise level in the mid-frequency range (see Figure 3). The A-weighted level is 62 dBA (or SIL of 53 dB), compared to 54 dBA (SIL of 48 dB) at the same location when the source is off. The noise source reduces the maximum distance for satisfactorily intelligible conversational speech from 1.7 m to 0.9 m in this area.

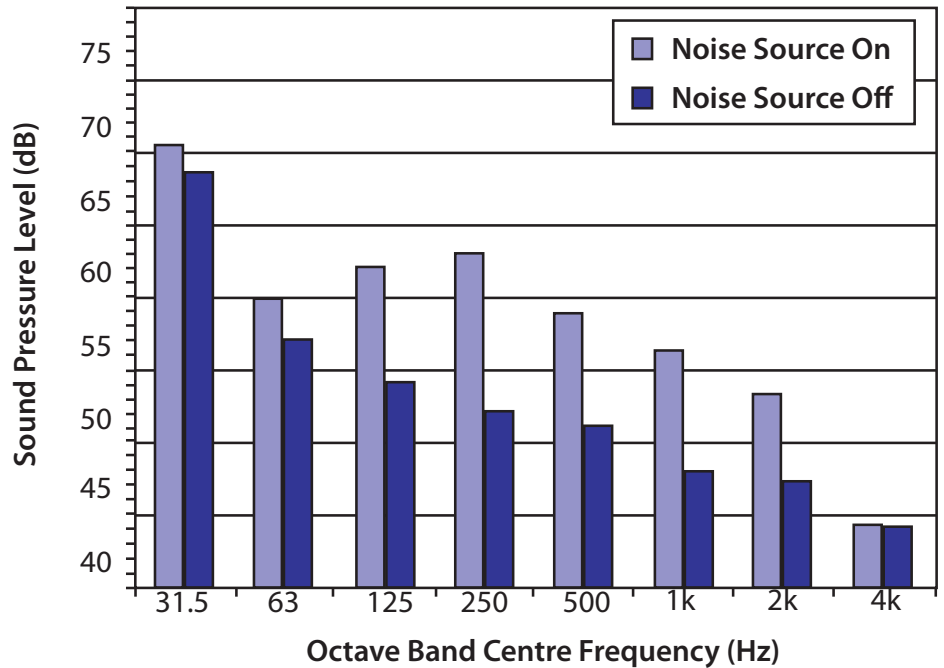


Figure 3 Comparison between the octave band sound pressure levels with and without the ventilation noise source operating at the measurement position nearest to the source.

Note that while this noise is effective at increasing speech privacy, it is intrusive. The octave band spectrum of the noise, with its peak at 250 Hz (rather than a simple negative spectral slope), indicates that this noise is spectrally 'imbalanced', and consequently draws attention to itself. This noise would be described as a 'roar' using the *Room Criterion* method of background noise rating, which is particularly suited to rating mechanical services noise in rooms.

Speech intelligibility and the use of partitions

The acoustical effect of desk partitions was assessed by measuring from a small loudspeaker (NTI Talkbox) at the head height of a desk position to a microphone at the head height of another position on the opposite desk. The loudspeaker is designed to have a directivity similar to a person talking. The test signal used simulates the rhythm of speech, and the extent to which this is degraded by the environment is assessed at the microphone position.

Intelligibility can be degraded by background noise and/or room reverberation, and these two processes can be separated in the analysis. If the office was completely silent, the STI between opposite desks with the partition would be 0.80, and without the partition the STI it would be 0.88. The main effect of the partition is to attenuate the direct sound, but most other sound paths are not affected by the presence or absence of the partition. Both measurements would be described as 'excellent' intelligibility, and this highlights the role of background noise in introducing some speech privacy. The reverberation time of the office is about 0.5 seconds, which is short for a large room and therefore unlikely to affect intelligibility (and it is the recommended value for a design office according to AS/NZS 2107:2000).

When background noise is introduced into the calculation, the STI with the partition is 0.45, and without a partition it is 0.48. This indicates that the background noise makes the strongest contribution to speech privacy, and the presence or absence of the partition has a very small effect on the parameters of the measurement. The just noticeable difference of STI is thought to be 0.05, so the 0.03 effect of the partition should not be noticeable (in purely acoustic terms). Of course, the partition also obscures vision, and vision contributes to speech communication.

Conclusions

The general findings of the measurements are as follows:

- Background noise is fairly high compared to design recommendations;
- The intermittent ventilation noise adds substantially to the background noise level, contributing an obtrusive ‘roar’ to the office sound environment (it may be worth treating this);
- In purely acoustic terms, the desk partitions make very little contribution to speech privacy.

One question arising from this is whether the office could be quietened whilst maintaining (or even improving upon) the current level of speech privacy. A possibility for this could be to add sound absorption to the ceiling—which would reduce both the general noise level, as well as the strength of speech sound reflected off the ceiling. If both the speech and noise could be quietened equally, there would be little change in speech privacy. However, since adding absorption has no effect on the direct sound from one person to another, the current level of privacy may not be fully preserved if that is the only intervention. A more refined approach might be to use targeted sound absorption on the ceiling—that is, put the absorption at the location of acoustic reflections of speech (which is directly above the desks). While that would reduce both speech and noise levels, it would have a relatively stronger effect on speech than sound absorption distributed evenly across the ceiling.

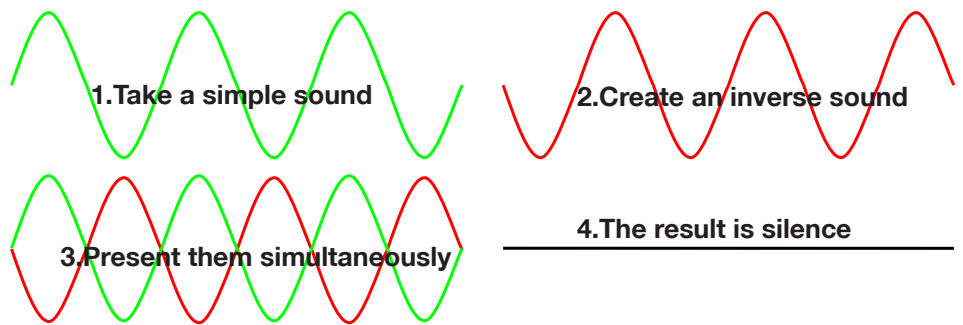
Recommendations and future directions

As the previous case study illustrates, the theory and analysis of building acoustics is a highly technical discipline practised by knowledgeable and experienced specialists. While acoustic consultants can provide significant benefits in terms of increasing staff performance, to date they have been under-utilised, particularly by Australian corporate property professionals. Organisations that make the effort to understand and optimise the acoustic conditions of their workplace are likely to gain a significant competitive advantage over those who continue to underestimate the impact of office noise on their business performance.

While the literature concerning office noise, particularly the wealth of research concerning the irrelevant sound effect, has highlighted the deleterious effects of poor acoustic conditions, opportunities remain to further our understanding of the conditions capable of moderating effects. Regarding the workplace, it appears that task characteristics represent the most promising variable for investigation. Research on the irrelevant sound effect tends to use memory-based tasks based on either linguistic or numerical data, yet a number of industries exist that rely on different cognitive processes. For instance, the work of designers requires conceptualising and manipulating spatial information: it remains to be seen how irrelevant sound affects these processes. Also, the role of arousal warrants further consideration, particularly the possibility that increased arousal—as elicited by ostensibly ‘poor’ acoustic conditions—may actually *improve* the performance of well-learned or simple tasks. If polarised effects of office noise can be linked to task characteristics, this may assist in dividing the workplace into zones offering an appropriate acoustic environment for a variety of roles and/or tasks. This is an empirical question that requires further testing prior to implementation.

Despite the promise of ongoing research concerning noise and performance, technological developments may eventually render this literature redundant. Chusid (2001) discusses improvements in sound absorption provided by materials such as SoundTex,² which transforms sound vibration into heat. However, even advances in sound blocking and absorption will become obsolete according to some predictions. Smith (2007) argues that the future offers an open-plan working environment in which background noise is all but eliminated. He reviews pioneering work from Napier University, where researchers are attempting to develop sound nullification software based on the principle of active noise cancellation. The physical analysis of sound reveals that it is comprised of pressure waves containing numerous peaks and troughs: active noise cancellation refers to the fact that sound can be negated by obscuring the acoustic signal with the simultaneous presentation of an inverse pattern of waves. ‘Soundscaping’ researchers believe that it may be possible to develop software which can recognise an acoustic event within the first few milliseconds, and then play the inverse of this sound through speakers placed around an individual workstation—producing what they term “silent pools” (see Figure 4). While some predict the availability of active noise-cancellation desks within 20-30 years, others consider such forecasts overly optimistic.

Figure 4 A simplified schema illustrating the potential application of active noise cancellation to sound nullification software: (1) Sound recognition software samples the initial onset of environmental noise and matches it with the event it is most likely to become; (2) The program inverts the predicted soundwave; (3) The inverted soundwave is synchronised with the environmental sound and presented to the listener via speakers; (4) The peaks and troughs of the synchronised waves cancel each other out, resulting in silence.



In the meantime, designers must work with the available materials and technology to provide a working environment to suit the particular requirements of each organisation. Indeed, for those businesses who place a high priority on minimising acoustic distraction and maximising speech privacy (e.g., for reasons of confidentiality), it may be prudent to forgo the advantages of open-plan and retreat to individual offices. However, with the combined aid of acoustic consultants and informed designers, it is likely that most organisations will be able to come up with an acceptable compromise that enables colleagues to be seen but (barely) heard.

References

- Aiello, J. R., & Douthitt, E. A. (2001). Social facilitation from Triplett to electronic performance monitoring. *Group Dynamics: Theory, Research, & Practice*, 5, 163-180.
- Banbury, S., & Berry, D. C. (1998). Disruption of office-related tasks by speech and office noise. *British Journal of Psychology*, 89, 499-517.
- Banbury, S. P., & Berry, D. C. (2005). Office noise and employee concentration: Identifying causes of disruption and potential improvements. *Ergonomics*, 48, 25-37.
- Beaman, C. P. (2005). Auditory distraction from low-intensity noise: A review of the consequences for learning and workplace environments. *Applied Cognitive Psychology*, 19, 1041-1064.
- Beaman, C. P., & Jones, D. M. (1997). The role of serial order in the irrelevant speech effect: Tests of the changing-state hypothesis. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 23, 459-471.
- Boyce, P. R. (1974). User's assessments of a landscaped office. *Journal of Architectural Research*, 3, 44-62.
- Chusid, M. (2001). Public musings on acoustical privacy. *Architectural Record*, 189, 163-168.
- Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning & Verbal Behavior*, 15, 17-31.
- Ellermeier, W., & Höllbrück, J. (1998). Is level irrelevant in 'irrelevant speech'? Effects of loudness, signal-to-noise ratio, and binaural masking. *Journal of Experimental Psychology: Human Perception & Performance*, 24, 1406-1414.
- Elliott, E. M. (2002). The irrelevant speech effect and children: Theoretical implications of developmental change. *Memory & Cognition*, 30, 478-487.
- Evans, G. W., & Johnson, D. (2000). Stress and open-office noise. *Journal of Applied Psychology*, 85, 779-783.
- Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, Illinois: Thomas.
- Ferris, G. R., & Rowland, K. M. (1983). Social facilitation effects on behavioural and perceptual task performance measures: Implications for work behaviour. *Group & Organization Studies*, 8, 421-438.
- Furnham, A., & Strbac, L. (2002). Music is as distracting as noise: The differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. *Ergonomics*, 45, 203-217.
- Höllbrück, J., Kuwano, S., & Namba, S. (1996). Irrelevant background speech and human performance: Is there long-term habituation? *Journal of the Acoustical Society of Japan*, 17, 239-247.
- Hongisto, V. (2005). A model predicting the effect of speech of varying intelligibility on work performance. *Indoor Air*, 15, 458-468.
- Johansson, C. R. (1983). Effects of low intensity, continuous and intermittent noise on mental performance and writing pressure of children with different intelligence and personality characteristics. *Ergonomics*, 26, 275-288.
- Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory & Cognition*, 19, 369-381.
- Jones, D. M., & Macken, W. J. (1995). Auditory babble and cognitive efficiency: Role of number of voices and their location. *Journal of Experimental Psychology: Applied*, 1, 216-226.

- Jones, D. M., Macken, W. J., & Mosdell, N. (1997). The role of habituation in the disruption of recall performance by irrelevant sound. *British Journal of Psychology*, 88, 549-564.
- Jones, D. M., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *The Quarterly Journal of Experimental Psychology*, 44A, 645-669.
- Jones, D. M., Miles, C., & Page, J. (1990). Disruption of proof-reading by irrelevant speech: Effects of attention, arousal or memory? *Applied Cognitive Psychology*, 4, 89-108.
- Jones, D. M., & Morris, N. (1992). Irrelevant speech and serial recall: Implications for theories of attention and working memory. *Scandinavian Journal of Psychology*, 33, 212-229.
- Keighley, E. C. (1970). Acceptability criteria for noise in large offices. *Journal of Sound & Vibration*, 11, 83-93.
- Knez, I., & Hygge, S. (2002). Irrelevant speech and indoor lighting: Effects on cognitive performance and self-reported affect. *Applied Cognitive Psychology*, 16, 709-718.
- Loewen, L. J., & Suedfeld, P. (1992). Cognitive and arousal effects of masking office noise. *Environment & Behaviour*, 24, 381-395.
- Sailer, U., & Hassenzahl, M. (2000). Assessing noise nuisance: An improvement-oriented approach. *Ergonomics*, 43, 1920-1938.
- Salamé, P., & Baddeley, A. D. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning & Verbal Behavior*, 21, 150-164.
- Smith, L. (2007, March 10). How sound technology will ensure a quiet day at the office. *The Times* (UK), p. 32.
- Smith, W. A. (1961). Effects of industrial music in a work situation requiring complex mental activity. *Psychological Reports*, 8, 159-162.
- Strasser, H., Gruen, K., & Koch, W. (1999/2000). Office acoustics: Analyzing reverberation time and subjective evaluation. *Occupational Ergonomics*, 2, 67-80.
- Sundstrom, E., Town, J. P., Rice, R. W., Osborn, D. P., & Brill, M. (1994). Office noise, satisfaction, and performance. *Environment & Behavior*, 26, 195-222.
- Tremblay, S., & Jones, D. M. (1999). Change of intensity fails to produce an irrelevant sound effect: Implications for the representation of unattended sound. *Journal of Experimental Psychology: Human Perception & Performance*, 25, 1005-1015.
- Urban, M. J. (1992). Auditory subliminal stimulation: A re-examination. *Perceptual & Motor Skills*, 74, 515-541.
- Venetjoki, N., Kaarlela-Tuomaala, A., Keskinen, E., & Hongisto, V. (2006). The effect of speech and speech intelligibility on task performance. *Ergonomics*, 49, 1068-1091.
- Wang, C., & Bradley, J. S. (2002). Sound propagation between two adjacent rectangular workstations in an open-plan office – part II: Effects of office variables. *Applied Acoustics*, 63, 1353-1374.
- Witterseh, T., Wyon, D. P., & Clausen, G. (2004). The effects of moderate heat stress and open-plan office noise distraction on SBS symptoms and on the performance of office work. *Indoor Air*, 14, 30-40.
- Zajonc, R. B. (1965). Social facilitation. *Science*, 149, 269-274.

Acknowledgement of images

Table 1.

From “A model predicting the effect of speech of varying intelligibility on work performance,” by V. Hongisto, 2005, *Indoor Air*, 15, p. 459. Copyright 2005 by Blackwell Munksgaard. Adapted with permission.

Figure 1.

From “A model predicting the effect of speech of varying intelligibility on work performance,” by V. Hongisto, 2005, *Indoor Air*, 15, p. 465. Copyright 2005 by Blackwell Munksgaard. Adapted with permission.



About the authors

Sean Coward is a member of Woods Bagot's Workplace Consulting team specialising in the psychological effects of the physical environment.

sean.coward@woodsbagot.com.au

Densil Cabrera is the Head of the Acoustics Research Laboratory in the Faculty of Architecture, Design and Planning at the University of Sydney.

densil@usyd.edu.au



© All Rights Reserved. No material may be reproduced without prior permission. While we have tried to ensure the accuracy of the information in this paper, the Publisher accepts no responsibility or liability for any errors, omissions or resultant consequences including any loss or damage arising from reliance in information in this paper.