Planning for Psychoacoustics:

A Psychological Approach to Resolving Office Noise Distraction

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Acoustics terminology used in this report

Term	Definition
AC	Articulation class
AI	Articulation index
C_{50}	Clarity – the early to late arriving sound energy ratio
D_2S	The sound pressure level decay per distance-doubling
dB	Decibels
DL_f	The average excess of sound pressure level with respect to a free field
EDT	Early decay time – the reverberation time measured over the first 10 dB of the decay
LA_{eq}	The A-weighted equivalent sound level and describes a sound level with the same energy content as the varying acoustic signal measured
L_{eq}	The equivalent continuous noise level
L_{pAS4m}	The A-weighted sound pressure level of normal speech at a distance of 4m from the sound source (in dB)
rD	Distraction distance (sometimes known as comfort radius)
RT	Reverberation time – the rate at which sound energy dissipates in a room
SII	Speech intelligibility index
SPL	Sound pressure level
STI	Speech transmission index

Executive summary

Background

Sound waves are known to induce a range of physical, physiological and psychological effects in humans. It is also widely accepted that unwanted sound – noise – affects people's health and wellbeing, mental state and performance in many ways.

Noise is one of the top causes of dissatisfaction and loss of productivity in the workplace. The psychological impact of noise is the main cause of concern in office environments. In offices, noise can result in annoyance, heightened stress levels and reduced performance.

Traditionally, control of noise in buildings falls into the domain of acousticians – experts concerned with the properties of sound. Although it is widely recognised that acoustics is an interdisciplinary science, many architectural acousticians have a physics or engineering background and their approach to mitigating noise is mostly, but not entirely, focused on physical solutions.

But the demands of 21st-century workplaces call for a more rounded approach, with experts working together to offer a combined psychological, physiological and physical solution to acoustic problems. This report therefore offers a fresh outlook to resolving noise distraction in the workplace based on a psychoacoustic, people-centred approach, focussing on perception, attitudes, mood, personality and behaviour. The report is predominantly based on a literature review, with more emphasis on psychophysical research papers than pure acoustic ones.

The report is aimed at people who are interested in resolving noise issues in workplaces, particularly offices, including: acousticians, architects and interior designers, facilities managers, property developers, occupants and heads of business. It begins with a review of the theoretical aspects of noise, relating to acoustics, psychoacoustics and psychology, then discusses how this knowledge can be used to create people-centred work environments based around four key factors: task and work activity; context and attitude; perceived control and predictability; and personality and mood.

Acoustics and psychoacoustics

Acoustics is a complex and interdisciplinary science. Even measuring sound level is not as simple as it may first appear. Most acousticians agree that the raw reading from a sound-level meter does not correlate with perceived loudness, even though measurements of sound pressure level (SPL) are routinely weighted to account for various adjustment factors.

For instance, the human ear is less sensitive to low audio frequencies and so the SPL is adjusted to account for this. In addition, sounds may be ambient (steady) or intermittent (transient), and a time-averaged value (in decibels, dB) is usually used for comparing the ambient sound exposure in different environments. However, this does not account for disturbances caused by unexpected intermittent sounds. Indices for reverberation time (RT) and speech transmission (ST) are also used, especially in room acoustics, yet these are complex measures that can be difficult to predict. The A-weighting, dB(A), is the most commonly used weighting, but the debate continues among acousticians as to the most appropriate weightings for use in office acoustics.

Noise perception starts with the human brain processing the sound (pressure) waves hitting the ear drum and converting this into a meaningful signal, and continues with the brain organising and interpreting the sound and applying meaning to it (cognition). The crux of the matter is that the term "noise" (unwanted sound) is subjective and based on a range of factors including a person's evaluation of the necessity of the noise, the meaning attached to the sound, whether it can be controlled, and the context (e.g. if it is normal and expected for the place where the sound is generated).

Reported noise annoyance does correlate with sound level measurement, but it is generally accepted that the sound level accounts for only 25% of the variance in annoyance. The research literature assessed for the purposes of this report suggest that there are four key non-physical factors that affect noise perception and performance in office environments:

- Task and work activity,
- Context and attitude,
- Perceived control and predictability,
- Personality and mood.

Research into the impact of noise on performance has resulted in mixed and often confusing results, because of the complex interplay between these four factors and the difficulty in quantifying the noise source.

Noise is clearly a psychophysical matter and it relates as much, if not more, to the interpretation and meaning attached to the sound and how distracting it becomes as to the sound level *per se*. Therefore a well-considered solution to noise in the workplace will reduce distraction caused by perceived noise rather than simply reducing the sound level, or perceived loudness.

In acoustics, much performance research has focused on the impact of ambient versus intermittent sound, and on relevant versus irrelevant speech. Donald E Broadbent, the leading expert in the field of psychoacoustics, concluded from his decades of pivotal research that performance is affected by continuous loud noise when the "listener" is multi-tasking or paying attention to multiple sources. He actually found that noise hinders people who are performing complex tasks, but sometimes improves their performance of simple tasks.

More recently, studies have found that concentration is impaired by various components of office noise, particularly unanswered telephones and people talking in the background, but – unexpectedly – it seems that some employees are *unable* to habituate to office noise over time and it continues to disrupt performance on more complex cognitive tasks. So whilst there is plenty of laboratory-based evidence to indicate that people habituate to background noise, but real world studies indicate that generalising this finding is not so straightforward.

Psychoacoustic researchers theorise that our ears are "always on" and we unconsciously listen to and analyse background sounds all the time. In the workplace, this natural reflex action of the ear and brain means that unconsciously "listening" to colleagues can be distracting and counter-productive, but only when the information being processed is irrelevant to the performance of the individual. Background conversation may not be considered noise *per se* when it contains useful information, i.e. "meaningful speech", whereas irrelevant conversation will be perceived as noise and found annoying.

However, more importantly, meaningful speech has been found to have a greater impact than meaningless speech on disrupting cognitive tasks, in particular those requiring memory (recall) or semantic assessment. So from a practical point of view, for offices and the associated work tasks, the key is to reduce the effect of meaningful speech distracting those carrying out cognitive tasks involving memory, such as complex analysis and authoring original prose, and thus reducing their work performance.

Psychology

Psychologists generally agree that different personality types have different innate levels of arousal, which in turn affects how noise has an impact on their performance. People can perform better if they are stimulated or motivated (which increases their level of arousal), but there is a limit because too much stimulation can lead to stress and thus reduce performance. There is also evidence that stress from noise continues to affect performance for some time after exposure to the noise source.

The implication is that, in general, we should design stimulating but not over-stimulating environments in order to maximise the performance of office workers. However, psychologists have also identified that individuals have different base levels of arousal and therefore need different magnitudes of stimulation for optimal performance. For example, people who are predominantly extroverts have a low natural level of arousal and should perform better than introverts in noisy environments because the noise is stimulating. However, difficult and complex tasks are in themselves demanding and therefore increase the level of arousal, so subdued environments are preferable to maximise performance. In contrast, repetitive or menial tasks require more stimulating environments to increase the level of arousal.

Theories indicate that an introvert conducting a complex task would thrive in a quiet environment and an extrovert conducting a simple task requires a stimulating/noisy environment. Several studies, mostly laboratory based, have confirmed that extroverts perform better than introverts at cognitive tasks under noisy conditions.

Other personality factors also have an impact on the way people respond to noise. For instance, more anxious (neurotic) personality types generally perform more poorly in complex mental tasks in noise than emotionally stable individuals. Studies have also shown that there is a correlation between acceptable levels of noise and openness or conscientious personality dimensions. Personalities categorised as being more open to new experiences may accept more noise, while people categorised as more conscientious (who generally desire fewer distractions when focusing on a task) accept less background noise.

Listening to music in the workplace is becoming more commonplace, usually through headphones but occasionally played in the background. Much research has been carried out into the impact of music on performance, primarily by Adrian Furnham and his colleagues at University College London, who found that introverts who listened to music while completing a reading comprehension task performed significantly less well than extroverts. In a later study they also found that, whereas the performance of the introverts was impaired by the introduction of music, extroverts' performance was enhanced.

Preconceptions of the working environment also affect our perception of noise in that environment. Environmental psychologists use the term "behavioural setting" to describe a situation where the pre-conceived social etiquette associated with a particular setting unconsciously influences the behaviour (e.g. how we behave in churches and libraries). In such environments even quiet sounds are unexpected and considered disturbing. Thus, if workers expect an office to be quiet, based on previous experience, then a situation where this is not the case will lead to dissatisfaction and is likely to result in reduced performance.

Evolutionary psychologists point to *biophilia* (our affinity to natural environments) as a possible way to alleviate noise-related stress, arguing that people feel refreshed after sitting in a natural environment and people innately prefer noise to be at a similar level to that found in the natural world – with a slight background buzz of activity. Research has shown that sounds from nature, such as birdsong or rippling water, promote faster recovery from stressful tasks compared with traffic noise and ambient building noise, such as that generated by air-conditioning equipment. Furthermore, there is research evidence that watching a nature movie (with sound) during a break period can increase energy levels, arithmetic performance and motivation, compared to just listening to office noise. So using pleasant sounds from natural environments to mask background workplace noise could decrease employee stress and increase worker productivity.

Finally, perceived control of noise can also affect performance. Having the power to manage interruptions is another factor in the complex equation. People who are able to anticipate interruptions can deploy preventive coping tactics to minimise disruption and frustration when the interruptions occur. Significantly, from an office perspective, individuals need not actually prevent interruptions from happening in order to be benefited but simply believe they can prevent them.

Solutions

The interpretation of sound as "noise" depends on a range of personality and circumstantial factors. This means that individual office workers will react differently to the same acoustic conditions in their workplace. Therefore actions to resolve noise distraction need to account for individual differences and not assume that a single physical acoustic solution will work for all office occupants.

Physical solutions can help to reduce speech intelligibility and the distractions caused by meaningful speech, but a psychoacoustic approach to noise distraction indicates that other people-centred solutions are also required. Such solutions are more behavioural, educational, managerial and organisational rather than physical. These are summarised below.

Task and work activity

Individuals and teams typically conduct a range of work activities throughout the day. For example, part of the day may involve meeting colleagues or clients and some of the working day may be spent solo, carrying out information processing or analysis. Such activities are better performed in different work environments which are specifically designed to support the activities. A core principle of "activity-based working" (or "agile working") is that employees can choose from range of work-settings that support their different work activities.

Activity-based working environments typically include:

- Meeting and teleconference rooms that have good acoustic properties to reduce sound transference and increase sound attenuation, offering acoustic privacy and also reducing noise distraction to and from outside the room.
- Focus rooms or pods, located on the fringes of more verbally intensive areas such as those with high telephone usage or with regular team discussions, used as a place for carrying out work that requires concentration, or for confidential calls, and is free of distractions from colleagues.

Rather than offer rooms for focused work, some organisations are now creating larger quiet zones as part of the activity-based working options. Such zones tend not to have desk phones, prohibit impromptu meetings and can evoke a culture sensitive to interruptions and noise distractions. Part of the agile working approach is to allow remote working, including home-working, where employees can more easily control the level of distraction.

Although activities may vary throughout the day, different teams will usually have core work activities that take up the majority of their day. For example, a sales team is likely to spend more time on the phone than a team of analysts. The working environment for the team can therefore usually be planned around core work activities, and teams conducting similar activities can be placed together. Generally, those involved in complex or detailed tasks, tasks requiring memory and recall, or people who are multi-tasking are likely to require a quieter environment than those involved in simple single tasks. Obviously, it would be preferable to avoid locating teams who generate noise and prefer buzzy environments next to those requiring quiet for concentration.

Many organisations are aiming to break down team silos and facilitate interaction between teams. Nevertheless, if the primary work activity of the team is heads-down work, then the space should be designed to support that, and additional work-settings away from the main open-plan workspace should be provided for interaction and collaboration.

Creativity and innovation is an increasingly important attribute of any business. Stimulating spaces are required to promote creativity, but it should also be acknowledged that much of the creative process takes place in solitude, away from distraction.

Personality and mood

The research literature shows that some personality types are better at coping with noise distraction than others, in particular people who are predominantly extrovert compared with those who are more introverted. Research into collaboration has shown that the most productive teams are those with a rich mix of personality types but the design of many modern workplaces is often more suited to extroverts.

Psychological profiling is often used to determine whether a person has the relevant personality and attitude for joining an organisation. However, they may then be placed in a workspace designed with other personality types in mind.

Instead, personality profiling should also be used to cluster people who prefer and function better in similar acoustic environments. Thus people who are primarily categorised as introvert, neurotic and conscientious personality types could be accommodated together in spaces that facilitate quiet work. In contrast, those who are primarily extrovert and more open personality types could be allocated space in stimulating (loud) environments. Better still, the different personality types could be offered choice over where they wish to work and select their preferred location.

Mood affects our willingness to help other people under noisy conditions, and perception of noise can affect mood. In organisations seeking to enhance collaboration, it is important that noise annoyance is not increased due to perceived unnecessary noises.

Perceived control and predictability

It is fairly common to find that people are distracted by loud telephone conversations or nearby discussions, but believe they cannot alleviate such problems. While research indicates that it is *perceived control* rather than actual control of noise that has alleviating effects, it is not always practical to give full control over noise, particularly in open-plan environments. But there are other solutions.

Offering a choice of work settings (e.g. by implementing activity-based working) gives people the option of moving to a quiet zone or room and thus distancing themselves from the noise source. In this solution, it is important that the people affected fully understand that they have options, and they are given full choice.

Another approach is to introduce some form of “office etiquette” around noise. The people who find noise distracting tend to be the ones who carry out work requiring quiet, and they tend to be the personality types that avoid unnecessary confrontation. Having office protocols, which is a type of charter or policy document, can be particularly helpful to those personality types. The office etiquette should set out acceptable behaviour and acknowledge that unacceptable behaviour can be challenged by all. It can be presented in written format and posted online, similar to office sustainability and other environmental guidelines.

For example, the etiquette document could cover:

- What the team member can do when disturbed by unanswered phones, loud teleconference calls, unnecessary chatting and local meetings.
- Guidelines on acceptable use of mobile phones (e.g. set to voice mail after four rings or put on silence when in the office) and note it is acceptable to switch off unanswered phones.
- Protocols that suggest lengthy discussion are continued away from the desks.

The agreed protocols would need to be backed up with alternative work settings. The important point is that each team needs to agree on the preferred behaviour and team members must feel they have some control over unnecessary noise.

Finally, it is important to provide methods of controlling interruption from colleagues. Some organisations use visual cues to indicate when a person is busy, such as small "busy" flags on the desk (or use of headphones). There are mixed views over such techniques but if a team likes the idea then it is worth incorporating into the office etiquette. A similar option is to use PC presence indicators, which can be set to "busy" or "available", so that colleagues refer to the status set by a person before approaching them, or they would ping an instant message to see if they are free. At minimum we should be cognisant of when a colleague is in "mid-flow" before approaching them.

Context and attitude

Perception of noise is affected by attitudes towards the source of the noise. If people feel that a sound source is justified (e.g. an important announcement) or they are more familiar with those generating the sound (such as close team mates) they will be more tolerant of the distracting noise. So grouping teams together such that background speech may be of value to them rather than a distraction can be helpful. Management should clearly explain to new members of the team whether it is a noisy or quiet team and what the norm is. If it is a noisy team then the manager should justify the business reasons for it and explain the benefits.

The facilities management team should announce any unusual planned noises in the workplace (e.g. building works). If they explain the reasoning behind the noise, the resulting benefits and the timescales, then the occupants are likely to be more tolerant of the noise. In addition, flexibility of alternative working locations could be implemented (e.g. options to work from home or another office while the work is in progress).

Conclusion

The solution to noise distraction is as much to do with the management of the space and guidance on behaviour as it is about the design and acoustic properties. A choice of different types of space with different acoustic properties and agreed behaviours is essential for reducing noise distraction.

People-centred acoustic solutions can thus be summarised by DARE:

- Displace – Displace the noise distraction by providing easy access to informal meeting areas, breakout and brainstorming rooms. Provide quiet areas for the staff to retreat to, including quiet booths, phone-free desk areas or a library-type space plus the option to work from home occasionally. Good design and visual cues can be used to indicate how people should behave in a space and the expected noise levels (e.g. consider the layout and design of a library compared with a café).
- Avoid – Avoid generating noise distraction (e.g. do not provide hands-free speaker phones in open-plan or meeting tables in the middle of workstations where people are carrying out work requiring concentration). Locate noisy teams together and away from the quieter teams. Co-locate team members, because people are more tolerant of noise from their own team. Consider the personality of the staff and perhaps separate the extroverts who thrive in noisy environments from the introverts who prefer quiet.
- Reduce – Reduce the noise distraction by controlling the desk size and density (high-density environments with people closer to each other generates more noise distraction). Use good acoustic design to reduce speech intelligibility across open-plan areas and noise transference between rooms. If sound masking is to be used, consider using more natural soundscapes rather than white noise.
- Educate – Introduce some form of office etiquette which reinforces consideration towards colleagues. Etiquette should cover phone use, loud conversations, music, headphones, managing interruptions, how different work-settings are used and so on. It may also include "do not disturb" signals. Explain to staff how the office layout works, the facilities available to them and how they can control noise disruption. If required, explain and justify why there is a noisy/buzzy environment.

1.0 Project background

1.1 Purpose of this report

Noise is one of the main causes of dissatisfaction and loss of productivity in the workplace; and the psychological impact of noise is felt more often in office environments than in other workplaces. In offices, noise can result in annoyance, heightened stress levels and reduced performance.

Issues with noise and resolving them go back a long time. Texts written on clay tablets at around the time of the Sumerians (3500–1750 BC) mention how the god Enlil was angered by the noise of an overpopulated city, so apparently flooded the city to remove the noise problem. Several thousand years later, the Romans passed a law that prohibited chariot driving through the cobblestone streets at night, in order to reduce noise disturbance. More recently, since the late 19th century, much empirical research has been carried out on reducing noise in the workplace.

Traditionally, noise falls into the domain of acousticians – experts concerned with the properties of sound. Although it is widely recognised that acoustics is an interdisciplinary science, many architectural acousticians have a physics or engineering background and the approach to mitigating noise is mostly, but not entirely, focused on physical solutions.

This report offers a fresh outlook to resolving noise distraction in the workplace. Our perspective is more psychoacoustic, it is a people-centred approach focussing on psychology – perception, attitudes, mood, personality and behaviour. The report is predominantly based on a literature review, with more emphasis on psychophysical research papers than pure acoustic ones.

The report is aimed at people who are interested in resolving noise issues in workplaces, particularly offices, and will appeal to: acousticians, architects and interior designers, facilities managers, property developers, occupants and heads of business.

1.2 Acoustic issues in offices

Acoustician Julian Treasure (2012) reminds us that "Despite huge advances in almost every area of architecture and interior design … sound and acoustics, for the most part, have remained secondary concerns. They are possibly the two most pressing issues in architecture today". Similarly, Perham, Banbury and Jones (2007) commented that "The acoustic design of offices often does not receive the attention that most other architectural systems would. However, unwanted levels of ambient noise, often caused by an excessively reverberant environment, can cause difficulties with communication as well as with concentration at work".

Abbot (2004) reviewed numerous research studies and concluded that noise, in addition to causing nuisance and disturbance in an office environment, is a primary cause of reduction in productivity and can contribute to stress and illness, which in turn can also contribute to absenteeism and turnover of staff. Jensen, Arens and Zagreus (2005) undertook an extensive post-occupancy evaluation survey of 142 commercial buildings in the United States with 23,450 participants. The primary finding from their study was that dissatisfaction was highest with internal acoustics. Furthermore, they found that half of the respondents reported that poor acoustics interfered with their daily work.

The Leesman Index (Oldman, 2014) is the largest independent measure of workplace effectiveness with 64,062 survey responses from 554 office buildings (in October, 2014). The survey participants were asked "Which features do you consider to be an important part of an effective workspace?" and then asked to rate their satisfaction with their selected important feature. Figure 1 shows that noise is considered the 10th most important feature in the workplace but, more importantly, it is the second biggest cause of dissatisfaction with almost half (47%) of the occupants dissatisfied and only 28% satisfied with noise levels.

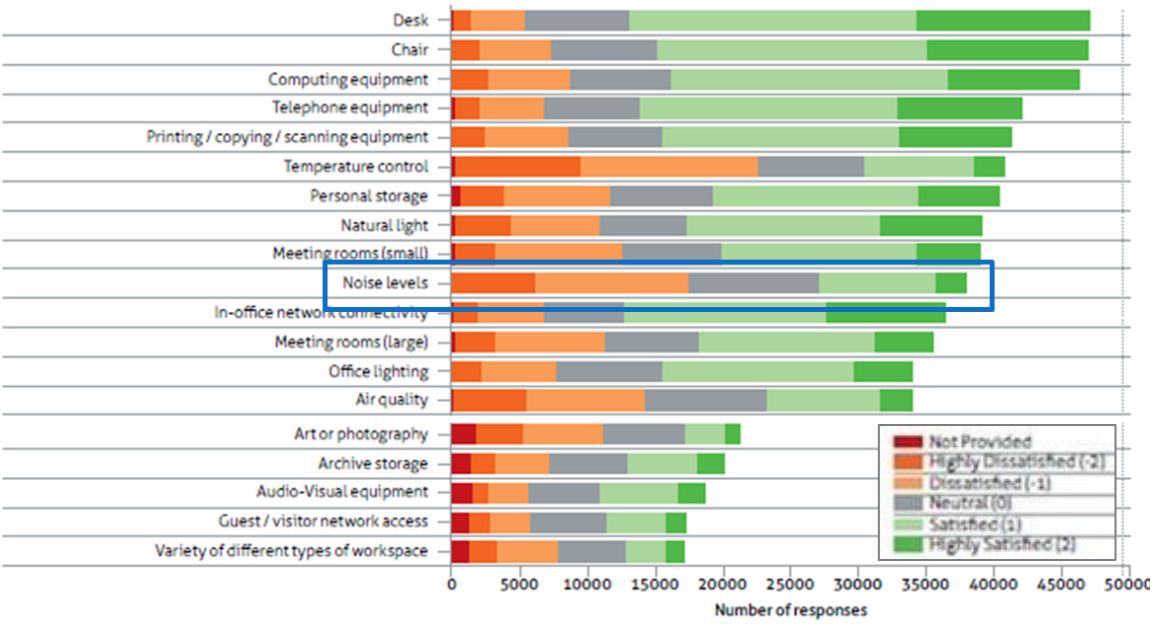

Figure 1. Satisfaction with office features (source: Leesman Index)

Oseland and Burton (2012) carried out a literature review of studies showing a quantified impact on productivity from environmental conditions, including temperature, light and noise (acoustics). They conducted a meta-analysis of 75 studies that they considered credible, including 21 studies exploring the impact of noise. They found that, after noise was reduced, the average increase in productivity is 27.8%. Oseland and Burton went on to weight the results for their relevance to offices, accounting for the environment in which the study was carried out, the type of metrics used and the relevance of the activity carried out by the participants. The revised impact of noise on productivity is 1.7%. Although this figure appears low, a report published by the British Council for Offices (Richards *et al*, 2014) suggests that "a 1% improvement in productivity swamps utility costs" and it is estimated that a change in productivity of just 5% may cover annual property costs.

Noise remains a significant problem in office environments, affecting worker satisfaction and productivity, but nevertheless the problem is often ignored. Research on noise in the office environment is often used as part of the on-going debate over the pros and cons of open-plan versus private office layout. Our intention is not to enter that debate in this report – in most business sectors in the UK and much of Europe the open-plan office is the norm. Rather, we consider our task here is to help mitigate noise in these mainstream working environments.

1.3 Impact of noise on people

Noise affects people in many ways – it affects our health and wellbeing, our mental state and our performance. Sound level can have a physical, physiological and psychological effect.

- Physical effect – Continuous levels of sound above 140 dB[1] can cause pain and may have physical effects on the body, some of which are immediate. Sound at this level produces mechanical changes in a person, such as heating of the skin, rupture of the eardrum and vibration of the eyeballs or internal organs. However, the energy created by such sound levels is at least ten million times more than is found in the office environment, so physical effects on the human body are unlikely to occur in the office. In workplaces with extreme sound levels, such as factories, airports or road works, ear defenders are worn to protect the workers rather than alleviate the sound. This strategy does not prevent the high levels of sound affecting the unprotected non-workers, who may then be affected physiologically or psychologically.
- Physiological effect – Raised sound levels can cause biological changes, such as elevation of blood pressure, increased heart rate, hearing loss and stress. For example, long-term exposure to levels of 85 dB or more during a typical 8 hour work day can damage the eardrums and put people at risk of moderate hearing loss. This level of exposure does not usually occur in offices, so such physiological effects are not a major concern for us. However, Figure 2 shows the current prevalence of hearing loss in the UK population and relevance to the working population. It is estimated by Action on Hearing Loss that by 2032 some 14.5 million people in the UK will suffer some sort of hearing loss[2]. This is a cause for concern if current workplace design criteria do not often take occupant hearing conditions into account. More people are using personal music systems at work to reduce distraction. Sound levels below 70 dB pose no known risk of hearing loss but extended intense use of personal stereos in the workplace, or elsewhere, may have a physiological effect. One study reported that the equivalent 8 hour continuous noise exposure level for people using personal stereos was 80 dB (Williams, 2005). In fact, the European Commission for Electrotechnical Standardisation (Commission for European Communities, 2009) has accepted a mandate to control exposure to excessive volume from personal music players to avoid hearing damage. At 80 dB, exposure is limited to 40 hours per week, where 89 dB exposure shall be limited to 5 hours per week.
- Psychological effect – This relates to mental changes in a person due to exposure to sound that they consider unnecessary or disturbing. Psychological effects are mostly manifested as annoyance, heightened stress levels or reduced performance. Such effects can occur at any sound level. For example, a dripping tap in the home at sound levels of 30 dB may create annoyance, especially at night, whereas sound levels of 120 dB caused by a passing ambulance may be acceptable, depending on the time of day. Attendees at a rock concert generating 120 dB will find the sound level acceptable, whereas neighbours to the venue may not. The response to the sound level is totally subjective and, as such, the psychological effects of sound are the main concern in the office environment.

[1] The intensity of sound is measured on the decibel (dB) scale; the decibel scale has different weightings, the A weighting dB(A) being most common. The threshold for hearing is 0 dB and normal conversation is around 40 dB. The noise on a busy street is around 70 dB and a rock band might produce 120 dB.

[2] Source: Action on Hearing Loss <www.actiononhearingloss.org.uk/your-hearing/about-deafness-and-hearing-loss/statistics.aspx>.

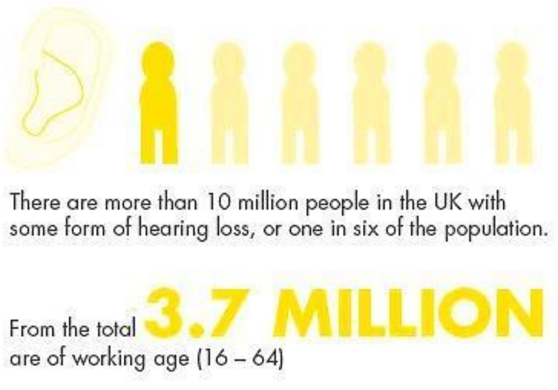

Figure 2. Current prevalence of hearing loss in the UK population (data source: Action on Hearing Loss UK; image by Ecophon)

Our discussion so far has mostly focused on the impact of different sound levels. Recognising the psychological effects of sound introduces the notion of unnecessary or disturbing sound (noise) having an effect on people, regardless of the actual sound level. In Section 3, below, we discuss the nuances of noise and sound and why noise in the workplace is a psychophysical problem. However, we first need to discuss how to actually measure sound and noise.

2.0 Measuring sound

2.1 Acoustic metrics

Acoustics is a complex and interdisciplinary science spanning physics, engineering, physiology and psychology. Even measuring sound level is not as simple as it may first appear. It is important to keep in mind that simple, controlled sounds are used to describe how sound works; but using them in practice, as noted by Horowitz (2012) "is like asking a physicist to describe the motion of a herd of cows – the behaviour can be modelled as long as the cows are spherical and moving on a frictionless surface in a vacuum".

A major challenge is simply identifying what to measure. Small meeting rooms or private office acoustic conditions can be controlled adequately by measuring sound insulation and reverberation times. Common metrics used are sound pressure level, reverberation time and speech transmission. Open-plan acoustic conditions, on the other hand, are more difficult to measure and control. For this reason, we will focus primarily on the acoustic metrics for open-plan offices.

2.1.1 Acoustic descriptors and parameters for open-plan offices

Ideally, one descriptor would be used to solve all room acoustic problems, but as hearing is multidimensional and room shapes, locations, material content and activities are so varied, multiple descriptors are still necessary to create an optimum acoustic solution. One of the key questions is how to control sound propagation to reduce disturbances from unwanted speech.

Sound propagation is the movement of sound waves through a medium (in this case air), and the laws of physics mean that the sound level decreases as the distance from the sound source increases. Sound propagation is a challenge for acoustic design in open-plan offices and contributes to the two of the main complaints about noise in offices: i) distraction caused by irrelevant speech; and ii) lack of speech privacy (Virjonen, Keränen and Hongisto, 2009). These factors are discussed in detail in Section 3.3.

For the purposes of measuring and calculating sound propagation, acousticians use a parameter, D_2S, which describes the extent to which the sound decreases when the distance is doubled (i.e. the rate of spatial decay of A-weighted sound pressure level of speech per distance doubling). D_2S is measured in decibels (dB) and determines the slope of the sound propagation curve. Another common parameter is L_{pAS4m}, the A-weighted sound pressure level (SPL) of speech at a distance of 4 metres from the sound source, in dB. This value is used to determine the *level* of the sound propagation curve, and is particularly important when controlling noise to avoid disturbances.

SPL is defined as the deviation in pressure from the ambient atmospheric pressure caused by a sound wave. SPL is a logarithmic measure of the effective pressure of a sound wave relative to a reference value, also measured in dB. It is relatively straightforward to measure SPL using a meter approved by International Standards. Nevertheless, most acousticians agree that the raw reading from a sound level meter does not correlate with perceived loudness.

For instance, the human ear is less sensitive to low audio frequencies and so the SPL is adjusted to account for this and provide a measurement that corresponds more closely to hearing sensation or loudness. Thus, arithmetic weightings (filters) are applied to the SPL; the A, B, and C weightings currently used in sound-level meters are aimed at mimicking perceived loudness over different frequency ranges. The A-weighting, expressed as dB(A), is the most commonly used weighting particularly in measuring and specifying sound levels in office environments. Debate continues among acousticians on the appropriate weightings and many recognise that the A-weighting was designed (and is possibly only valid) for use at relatively quiet sounds (~40 dB) and for pure tones. It is worth noting that the reported sound level, in dB(A), is only an approximation of loudness for the average human; it does not account for individual hearing differences due to age or other factors.

Sounds may be ambient (steady) or transient (intermittent). Ambient sound is continuous and long-term, such as the background sound of an air-conditioning system. Transient (intermittent) sounds are short-term, such as telephone rings, alarms or even people starting a conversation. The impacts that ambient and transient sounds have on noise perception, distraction and performance are discussed in more detail in Section 3.3.

In order to get an approximation for actual sounds (ambient and transient), an integrating-averaging meter is used to measure time-averaged sound. Time-averaged sound level is usually referred to as the "equivalent continuous sound level" represented by the symbols L_{AT}, L_{eq} and LA_{eq} (the A-weighted equivalent sound level). The integrating-averaging meter automatically measures sound levels over a set time interval, divides the sound exposure by the time and takes the logarithm of the result, presenting a single value in dBA.

Acousticians and standards agencies debate the best methodology for representing sound exposure with peaks and troughs. Although a single dBA value can be generated so that it is possible to compare ambient sound exposure in different environments, the value does not reflect the actual impact of, or disturbance caused by, unexpected intermittent sounds.

2.1.2 Speech transmission indices

The speech transmission index (STI) measures communication channel characteristics on a scale of 0–1 (with 0 as bad and 1 as excellent), and predicts the likelihood of words, sentences and syllables being understood. In effect, it measures the ability of a channel, in our case a room, to deliver the characteristics of speech across the space. It is frequently used for open-plan environments and is a key parameter in the guidelines set out by the Association of Interior Specialists (AIS, 2011) and others (see Section 2.3).

A report by Hongisto *et al* (2010) links STI to performance by assuming a certain relation from general speech intelligibility theory. Hongisto tested a model which predicts that the performance of complex tasks may be reduced by 7% when unattended speech is highly intelligible (STI>0.60, poor open-plan offices), but no effect is found when speech intelligibility is low (STI<0.20, conventional offices). Hongisto's findings strengthen the use of STI as an important parameter as intelligibility determines the level of distraction, not the sound level.

Other descriptors related to STI are: i) the speech intelligibility index (SII) (the amount of audible speech information in specific frequency bands, highly correlated with the intelligibility of speech); and ii) the privacy index (PI), a measurement of speech privacy or lack of speech intelligibility.

2.1.3 Measurement criteria for open-plan offices

The published research provides further insight into the complexities of reducing disturbances caused by unwanted speech while simultaneously aiding speech privacy.

Bradley and Gover (2004) identified the ideal ambient noise level to be approximately 45 dBA "If the noise level is much less, speech privacy will be substantially reduced. If it is much higher, the noise will be a source of annoyance and may reduce speech privacy because people will talk louder". The latter is known as the Lombard Effect (Reflex), an involuntary response whereby speakers will increase their vocal effort in order to be heard over background noise levels. Bradley and Gover therefore suggest that the maximum noise level should therefore not exceed 48 dBA.

While increasing the ambient noise level will increase speech privacy, too much noise will not lead to optimum acoustic comfort. Interestingly, well-known researchers Banbury and Berry, (2005) state that "the disruption reported by office workers was unrelated to the level of the ambient noise; secondly, distinctive or salient sounds, such as peaks of office noise, were reported to be highly unacceptable; and thirdly, background speech is reported to be the most bothersome noise source in the office environment".

From this, we can deduce that speech privacy may be dependent on an ambient sound level around 45 dBA and, although disruption may be unrelated to ambient noise levels, it is affected by peak noise and possibly by background speech. How this can be measured and controlled seems straightforward enough, yet in practice the solutions are much more complicated.

Wang and Bradley (2002) investigated the importance of various office design parameters on calculated speech privacy. They found that "The propagation of speech sounds between workstations is influenced by many variables, including: the screen and ceiling heights, the sound absorption of the ceiling, floor and screens" and noted the difficulty in obtaining speech privacy without optimising all the important design parameters. This does raise the question of controlling speech propagation at further distances – an important point made by Hongisto *et al* (2013) – which led to the development of a model to predict speech propagation at further distances. Before 2013 most research focused on speech sounds between adjacent workstations. In addition, Virjonen *et al* (2009) refers to "the A-weighted background noise level as probably the most important room variable affecting speech privacy. Therefore it must be adequately determined".

Nilsson and Hellström (2009) explained the need for complementary parameters to be used for the acoustic evaluation of open-plan offices and emphasise the fact that ordinary parameters such as reverberation time (RT) are not sufficient for a useful characterisation.

RT is linked to the speed at which sound energy dissipates in a room and is not a consistent descriptor for typical open-plan offices. Nilsson and Hellström further point out the influence of the interior design on sound propagation over distance and measuring for the design of the room (shape, furnishing, surface finish and so on) influences the extent to which the sound level decreases along with the distance. DL_2 ($D_{2,}S$) and DL_f are indicated as appropriate measurements for open-plan spaces. In addition, these parameters can be used to create what is termed a distraction radius (*rD*) (comfort radius), to give an indication of the distance needed to achieve a specific sound level from the sound source.

2.2 Physical means of controlling sound

Ceilings and vertical barriers (screens) dominate the literature as a means to minimise sound propagation. Schlittmeier *et al* (2008) conducted two experiments exploring the interrelation between background speech coherence and its impact on reading comprehension as a verbal task. One of the conclusions of their study is that "reducing intelligibility of background speech is a leading goal of acoustic optimization measures".

It is clear that the physical properties of the materials in a room can have a significant effect on how sound will travel across the space. Utilising materials to control sound is a crucial part of solving problems of office acoustics. *A Guide to Office Acoustics* (AIS, 2011) states that "ceilings have the biggest impact on the acoustic quality of open-plan offices by providing a surface that can be either sound absorbing or sound insulating or a combination of the two". This builds on earlier research from Pirn (1971) who discusses the relative effects of speech effort, speaker orientation, background noise, speaker-to-listener distance using an articulation index (AI) – a measure of speech intelligibility – and supports the need for consistent and efficient absorption. As Pirn states "Flanking surfaces, particularly the ceiling, must be sufficiently absorptive so that transmission by reflection will not seriously impair the barrier's potential shielding qualities".

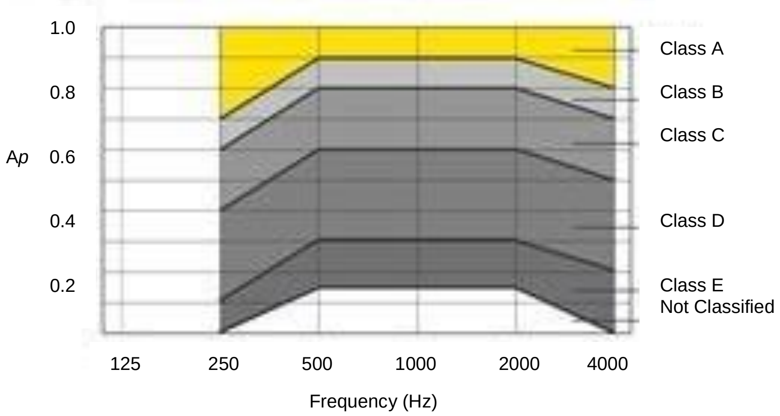

Figure 3. Absorption classifications (image: Ecophon)

The AIS guide goes on to clarify "For sound absorption a Class A material: mineral wool products are inherently effective sound absorbers and most will achieve Class A unless heavily painted. Class A is a classification derived from the testing methodology set forth in the ISO 11654, determined by the absorption coefficient of a particular material covering at least 10 m^2."

Class	***D_2S*** **(dB)**	***L_{pAS4m}*** **(dB)**	***rD*** **(m)**
A	>11	<48	<5
B	9–11	48–51	5–8
C	7–9	51–54	8–11
D	<7	>54	>11

Table 1. Target values, distinguishing the highest acoustic classification (data source: AIS)

Virjonen *et al* (2009) proposed and introduced measurement methods to include the parameters "distraction distance" in metres, STI as a function of distance and a method consisting of measuring the SPL of speech. STI and background noise level are measured at several distances from the speaker. The measurements can be reduced to three single number quantities (*rD*, DL_2 and L_{pAS4m}) for which target values are presented. It was not considered beneficial to characterise the acoustical conditions using RT, because RT describes only the temporal decay of sound at one point and does not predict the spatial attenuation. A low value for *rD* is possible without high masking SPL when the room volume is large and room absorption is high.

Another factor affecting the ability of the sound absorbing material to reduce propagation of unwanted speech is the articulation class (AC). This is a value measured in the laboratory which focuses on speech frequencies, to allow the evaluation of how well a product will absorb the noise generated by people talking. An AC value greater than 200 is considered high, whereas an AC value of less than 150 is considered low. According to Dirac Delta3 "American acoustic consultants usually refer to suspended ceiling systems with minimum AC 180 in order to achieve some kind of acceptable speech privacy for normal working tasks". The higher the AC value, the lower the distance of propagation of unwanted speech. AC rates a ceiling's suitability for achieving normal speech privacy in open office spaces by absorbing noise reflected at an angle off the ceiling into adjacent workstations. The measurement criteria for AC, as described

[3] Dirac Delta, the online science and engineering encyclopedia <www.diracdelta.co.uk/science/source/a/r/articulation%20class/source.html#.VK_VJ9BFDIU>.

in the international standard *ASTM E1111/E1111M-14 Standard Test Method for Measuring the Interzone Attenuation of Open Office Components*,[4] account for the noise reflected over office partitions in the frequencies critical to speech intelligibility and conversational privacy, as follows.

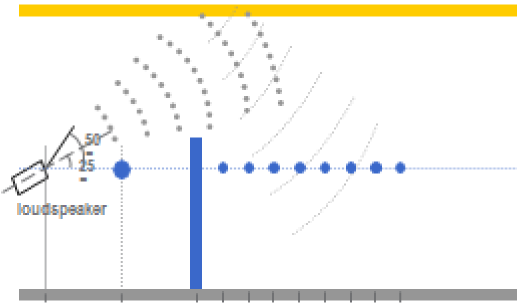

Figure 4. Articulation class measurement (image: Ecophon)

When evaluating the AC performance for ceilings, sound is generated by a speaker on one side of a 1.5-m (60-inch) high partition. The axis of the source point is tilted upwards at an angle of 25 degrees from the horizontal, so that the lower edge of a 50-degree included angle is parallel to the floor. Data is collected on the attenuation of sound (how much quieter it is) on the other side of the partition at frequencies from 100 to 5000 Hz (very low pitch to very high pitch). The noise reduction data is then used to calculate the AC value of the product being tested. In calculating AC, the sound reduction that occurs at higher frequencies (>1000 Hz) is treated as more important than that occurring at low frequencies.

The use of screens in combination with an absorbent ceiling has been shown to help increase speech privacy and also control sound propagation. A field study report by Warnock (1973) indicated that “the propagation of sound from one side of a screen to a point on the other side is the core problem in obtaining privacy in the open office”. Chu and Warnock (2002) measured sound propagation in open offices and showed that screen height affects sound propagation. Higher screens led to lower sound attenuation, which aids speech privacy. We can see the higher the AC the better the speech privacy, but this raises a question as to what figures are achievable?

Chigot (2007) discussed the impact on AC of different configurations of screens and free-hanging units, together with a fully covered ceiling, and found that it is possible to achieve AC values greater than 200 by combining these elements. With the right combination of materials and measurement criteria it is possible to reach what may be perceived as acceptable levels of speech privacy and reduced disturbances from unwanted speech.

[4] The standard is available at <www.astm.org/Standards/E1111.htm>.

2.3 Regulations, standards and guidelines

2.3.1 Regulations

In the UK, regulations currently in force with regards to building acoustics come from the *Building Regulations Part E Resistance to the Passage of Sound* and primarily address residential premises and schools, with mention made of non-domestic room acoustics when attached to a residential dwelling. The regulations, Section 0: Performance, 0.8 state "a high standard of sound insulation may be required between spaces used for normal domestic purposes and communal or non-domestic purposes" and suggests specialist advice may be needed to establish whether a higher standard of sound insulation is required. There are no specific references for open-plan office acoustics.

2.3.2 Standards

The standards in place specific to general office acoustics are *BS 8233:2014* and *BS EN ISO 3382-3*.

It is important to note that *BS 8233:2014*, which replaces *BS 8233:1999*, is identified for guidance and recommendations only; no claims of compliance can be made against it as a specification or code of practice. With regard to indoor building acoustic conditions, the guidance refers primarily to outside noise disturbances such as traffic and noise generated by indoor mechanical systems. In *BS 8233:2014*, Section 7.2 under "Design criteria for different types of buildings", consideration is given for speech, telephone communications, acoustic privacy, work requiring concentration and listening relative to the control of indoor ambient sounds caused by outside traffic or indoor mechanical systems. Noise level recommendations are given for study and work requiring concentration in staff meeting/training rooms (35–45 dB $LA_{eq,\ T}$) and for executive offices (35–40 dB $LA_{eq,\ T}$). BS 8233 also acknowledges the need to reduce speech intelligibility between offices and recommends minimum sound insulation at approximately Dw = 38 dB. For privacy, the minimum sound insulation should be Dw = 48 dB.

With specific regard to open-plan offices, expectations for a maximum reduction of dB levels between screened workstations is 15–25dB (at 2.5 m–3 m distance). Corresponding with AC testing methods (see above) the recommended screen is absorbent-facing and a minimum of 1.5 m tall. A Class A rated ceiling is recommended on ceiling heights above 3 m.

However, a new standard was required for rooms where the room acoustic could not be described by RT alone. Therefore the international standard for measurement of acoustics in open-plan offices, *BS EN 3382-3/ISO 3382-3*, was introduced to reduce distraction caused by speech propagation and increase privacy.

BS EN 3382-3/ISO 3382-3 defines four target values using different measurement descriptors for reducing sound propagation in open-plan spaces:

1. Spatial decay rate of A-weighted SPL of speech, D_2S and measures how quickly sound decays over a doubling of distance: Target value ≥7 dB.
2. A-weighted SPL of speech at 4 m, L_{pAS4m}. A nominal S-weighted sound pressure level of normal speech at a distance of 4 m from the sound source. Target value of ≤48 dBA at ≤4 m from the sound source.
3. Average A-weighted background noise level, L_{PAB}, is measured at each position and an average value is calculated. There is no target set for this descriptor.
4. Distraction distance is distance from the speaker where STI falls below 0.5. This STI value determines how clearly speech can be understood. Target value ≤0.5 STI at ≤5 m.

Hongisto, Keränen and Virjonen (2013) point out that "The effectiveness of a specified room acoustic solution is difficult to predict exactly, because the most important room acoustic variables, i.e. ceiling absorption, furnishing absorption, screen height, masking sound level, speech effort and room dimensions, interact in a very complex way … The predicted results are spatial decay curves of the A-weighted sound pressure level of speech and the speech transmission index, STI."

Other Standards are listed below for the sake of completeness, but will not be discussed in any detail:

- *BS EN 12354, Building acoustics – Estimation of acoustic performance in buildings from the performance of elements*
- *BS EN 12354-3, Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 3: Airborne sound insulation against outdoor sound*
- *BS EN 12354-6, Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part 6: Sound absorption in enclosed spaces.*

2.3.2 Guidelines

The most widely recognised guidelines in the UK are AIS (2011) *A Guide to Office Acoustics* and the *BCO Guide to Specification* (Pennell *et al*, 2014). Increasingly, environmental assessment methods such as BREEAM (the Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design) and the SKA Rating are providing some guidance to office acoustics[5]. Post-occupancy evaluations have shown that some offices constructed more recently to sustainable design criteria have poor acoustic satisfaction ratings. This could be due to thermally activated systems and other energy-efficiency design factors which limit the absorption areas needed to control sound.

The AIS *Guide to Office Acoustics* was one of the first more-comprehensive guides to office acoustics in the UK. Many of the open-plan performance criteria in that guide are based on research and good practice from Parkin's report (2009), and the guide sets out the key measurement parameters as shown in Table 2 below.

Noise issue	Within a working cluster	Between working clusters
Background noise level	46 dBA	46 dBA
STI	≥0.60	≤0.40
Absorption per m^3	≥0.21	≤0.36
Physical factors	Ceiling α_w 0.5-0.7 across the speech frequencies Soft floorcovering	Ceiling α_w ≥0.9 across the speech frequencies Absorbent screens 1.4–1.8m high Lower ceiling height between clusters to break up skimming across the ceiling

Table 2. AIS targets for open-plan offices

The *BCO Guide to Specification* raises awareness of the importance of office acoustics and emphasises sources of noise and vibration and design criteria. It primarily addresses externally

5 For further details of these rating systems, see BREEAM <www.breeam.org>, LEED <www.usgbc.org/leed> and SKA Rating <www.rics.org/uk/knowledge/ska-rating-/>.

generated noise sources, internal noise from plant and equipment, occupant noise from operations and equipment. There is additional guidance on the degree of separation vertically between walls and horizontally between floors. The guide advises that consideration should be given to noise control from the building structure and the surface finishes.

Confidentiality and privacy levels are considered by the guide to be the important design features. Specific open-plan design criteria include floor to ceiling height (not to exceed 3 m) and high sound absorption, giving as an example 0.9 averaged over the frequency range (500–2,000 Hz). Floors should be carpeted in offices and adjacent circulation areas. Emphasis on RT is the key measurement criteria and refers to the maximum recommended values in *BS8233:1999* and the *BCO Guide to Specification*.

Although much of the focus in this review is on the UK, there are considerable efforts in other countries to include specific standards for measurement in open-plan offices. In the Netherlands, for instance *NPR 3438:2007 EN* refers to noise in the workplace as an ergonomic concern and provides information on how to determine the amount of disturbance to communication and concentration.

Country	Regulation or Standard	Key points
France	*HQE Label target 9*	EAA >0.7 floor surface for the performance Level
France	*NF S 31-080*	RT and DL_2
France	*NF S 31-199 (publication 2015)*	Defines four types of measurements: D_2S, SPL in activity, attenuation, RT
Germany	*DIN 18041 (Standard under revision)*	RT and A/V depending on room type
Germany	*VDI 2569*	D_2S, L_{pAS4m}, RT in different classes depending on activity
Sweden	*SS25268*	RT 0.4 at 250–4,000Hz
Netherlands	*DIN 18041/handboek bkk*	Acoustic quality in small to medium-sized rooms
	Nen 5077-2012	Methods for performance on sound levels caused by technical services and RT
	NPR 3438-2007	Determination of the amount of disturbance of communication and concentration
Poland	*PN-B-02151-4*	Acoustic absorption of the room on the basis of 1 m^2 floor area: 1.1 for open-plan offices for general purposes and 1.3 for call centres

Table 3. Regulations and standards in other countries

2.4 Limitations of the physical approach

Given the lack of specific regulations, designers and building owners may be confused about where to find definitive guidance on office acoustics. There does not appear to be collective agreement on which parameters and/or descriptors should be adhered to. This may explain why acoustic solutions are often under-valued or ignored altogether. Although *BS EN ISO8832-3* offers a more comprehensive open-plan measurement standard, a question remains as to how often it is actually used.

Hongisto, Keränen and Larm (2004) note that screens and absorbent surfaces are never so effective that the speech level from the nearest desk could be attenuated below 40 dB(A). Jones and Macken (1993) argued that the main strategy for reducing the effect of irrelevant speech was to reduce it to below the threshold of hearing. This may be possible in some circumstances, but reducing the level of noise by some 40 dB would, in most cases, be technically challenging and financially prohibitive. Although it could be argued the 40 dB threshold is relatively low, perhaps the main point is that the one-size-fits-all approach to office design and acoustics is simply not effective.

The suggestion that activity-based design principles can help to improve office acoustics is further supported by the fact that it is relatively easy to design offices that provide freedom to move into a space, as needed, for speech privacy, concentration or collaboration. Implementing such principles, however, would require significant changes in organisational culture and design criteria – including a willingness to prioritise acoustic conditions.

There is an approach proposed for office design which may provide some insight to the way forward. Bodin-Danielsson and Bodin (2008) use a comprehensive categorisation which allows future office concepts to be more precisely defined and studied, the "people-centered approach to design". The method integrates the complexities of the organisation, people, processes and technology with the construction and architectural aspects of design by taking a systems view to generate performance and sustainability benefits. The approach includes a flexible framework and a toolkit to support each stage of design. The authors write "We believe that theory-based practical methods and toolkits developed through such people-centered multidisciplinary working will ultimately provide a real way forward for improving building design".

To summarise, the key considerations for optimum open-plan office acoustic planning include providing speech privacy and controlling sound propagation to reduce disturbances from unwanted speech. RT should not be the only parameter used – additional parameters such as D_2S, L_{pAS4m} and STI should also be considered. The use of adequate materials, particularly absorbent ceilings with a Class A rating and high AC and screens, can have a significant impact on the acoustic quality of an open-plan office environment. The right acoustic conditions would be best provided in activity-based settings and this requires prioritisation throughout the design process.

3.0 Introduction to psychoacoustics

3.1 Difference between sound and noise

Noise is often defined as "unwanted sound", and occasionally as "unwanted or harmful sound". In contrast desirable and beautiful sound is called euphony. Noise perception starts when sound pressure waves hit the eardrum and structures within the ear convert the pressure waves into a stimulus (signal to the brain), continues as the brain organises and interprets the signal and applies meaning to it (cognition).

The crux of the matter is that the term "unwanted sound" is totally subjective and based on a range of factors including a person's evaluation of the necessity of the noise, the meaning attached to the noise, whether it can be controlled and the context (i.e. if the sound is considered normal and expected for the place where the sound is generated).

Benfield *et al* (2012) point out that "The rumbling of a thunderstorm can be an exciting and pleasant experience to some but terrifying or depressing to another. Likewise, a parent trying to lull a newborn to sleep or a night shift worker trying to rest during the day perceives bird chirps, garbage trucks, and telephone rings differently from those who are currently less motivated for quiet conditions". Gifford (2007) states that "As the source of the sound becomes more relevant to an employee, as its meaning grows, and as its controllability and predictability decrease, sound is more likely to be perceived as noise and to negatively affect work behaviour".

We are always unconsciously listening to sounds and processing information, in the workplace or elsewhere. In a TED talk titled "*Why architects need to use their ears"*, Julian Treasure (2010) commented that "your ears are always on", compared with eyes which we can shut and thus switch off from visual stimuli. Similarly, Horowitz (2012) states "Hearing is the only sense which is reliable, even when we sleep".

Psychologists refer to the "cocktail party effect" as the ability to differentiate important or relevant messages, such as your name, from background noise (Cherry, 1953). In the workplace, a natural reflex action means that such unconscious "listening" to colleagues can be distracting and counter-productive when the information being processed is irrelevant to the performance of the individual (Broadbent, 1958). However, background conversation may not be considered noise if it contains useful information, whereas *irrelevant* conversation will be perceived as noise and found annoying and distracting, possibly leading to loss of performance.

Jones *et al* (2008) commented that research on the effects of noise on performance can be split into two eras: up to the 1970s the research was concerned with how loud white noise interfered with cognitive and motor tasks, but from the 1980s it was recognised that sound need not be loud to be distracting. Jones *et al* note that our understanding of how mental activities are susceptible to distraction from quieter sounds has broadened appreciably. Researchers are now preoccupied with how the content of the sound together with the nature of the mental activity results in distraction.

Put simply, interpreting sound requires obligatory processing without conscious attention, and this in turn can impair the performance of concurrent cognitive tasks. This process harps back to how humans evolved – a balancing act is required of the brain's attention system so that we can focus on the task at hand while remaining open to changes in the environment that might have important consequences for survival.

Summing up his psychoacoustics research, Jones (2014) writes:

> "Distraction is the price we pay for being able to focus on an event of interest while also gleaning some information from other sources of information. This arrangement has the undoubted advantage of allowing flexibility and adaptability – we can quickly move to new or potentially significant events – but it does mean that extraneous events of no significance can 'capture' attention. Distraction from sound is particularly pervasive because we are obliged to process sound – whether we want to or not. Very low levels of sound can be quite damaging to cognitive performance, deficits of 20–30% being commonly found in the laboratory."

In conclusion, noise is clearly a psychophysical matter and it relates as much, if not more, to the interpretation and meaning attached to the sound and how distracting it becomes as to the sound level *per se*. Therefore a well-considered solution to noise in the workplace will facilitate a reduction in the possibility of distraction from perceived noise rather than simply reducing the sound level, or perceived loudness.

3.2 Non-physical factors

Reported noise annoyance does correlate with sound level measurement, but it is generally accepted that the sound level only accounts for 25% of the variance in annoyance. Borsky (1969) suggests that sound level is only a minor factor in noise annoyance, accounting for less than a quarter of the variance in individual noise annoyance reactions. Smith and Jones (1992) propose that noise intensity only accounts for 25% of variance in annoyance whereas psychological factors account for 50%, and conclude that perception and control of noise is more important than physical aspects. Job (1988) concurs, writing "Even with the full range of exposure covered and very accurate noise and reaction measurements, noise exposure may only account for 25–40% of the variation in reaction". According to his review of 27 studies, Job found that sound level only accounted for 18% of the variation in individual annoyance reactions, for those exposed to long-term traffic noise. Marans and Spreckelmeyer (1982) pointed out that the quantified effects of sound do not necessarily parallel the subjective experience of the same sound.

Tracor (1971) identified seven non-acoustical variables that are strongly correlated with aircraft noise annoyance: i) fear of aircraft crashing in the neighbourhood; ii) susceptibility to noise or noise sensitivity; iii) distance from the airport; iv) noise adaptability or perceived control; v) city of residence; vi) belief in misfeasance on the part of those able to do something about the noise problem; and viii) the extent to which the airport and air transportation are seen as important. Sound pressure level measurements explained only 14% of variance in Tracor's noise annoyance scores. The amount of variance increased to 61% when he included the above mentioned non-acoustical variables. Although none of these variables are directly relevant to the office environment, the study illustrates the importance of subjective and non-physical variables.

Similarly, Borsky (1969) observed that annoyance is heightened when: i) the noise is deemed unnecessary; ii) those making the noise appear unconcerned; iii) those being exposed to the noise dislike other aspects of the environment; or iv) the noise is considered harmful or associated with fear. In their review of population density and noise, Glass and Singer (1972) found noise affects behaviour depending on the perceived context in which the noise occurs.

In his study of annoyance and sensitivity to noise, Vastfjall (2002) found that people in a bad mood respond more negatively to noise than those who are not. If a person is irritated or annoyed, they will make a more negative evaluation of a perceived annoying noise. So it appears that mood is also an important factor in how a person reacts to noise. For example, Cohen and Spacapan (1984) found that people are less likely to help others under high noise conditions, which may have an impact on collaboration in the workplace.

Maris (1972) points out that, in general, models of noise annoyance do not consider the social side of noise annoyance and non-acoustic influences may even be treated as error variance. Maris maintains that sound is usually considered to be an external stimulus and the evaluation of the perceived sound is studied as if it were an external process taking place in a social vacuum. With this in mind, he proposes that "The social psychological model of noise annoyance (Stallen, 1999) considers as external stimuli both the sound ('sounds at source') and a social dimension of the exposure situation ('noise management by source'). The perception of these two stimuli influences an internal evaluation process that can result in noise annoyance. This internal evaluation process includes the appraisal of perceived disturbance and perceived control."

Maris concludes that several attempts have been made to improve our ability to predict the impact of sound levels on noise annoyance, saying the approach to noise annoyance research remains "purely descriptive and exclusively acoustic".

It is clear that reaction to noise is not simply related to perceived loudness – psychological factors play a key role. Based on the research literature there appear to be four key non-physical factors relevant to office environments that affect noise perception and performance:

- Task and work activity – The nature of the task in hand or work activity; whether it involves cognition or memory; the complexity of the task; whether it involves multi-tasking; and whether the task requires quiet (e.g. for concentration or sleep).
- Context and attitude – Feelings towards those creating the noise; the perceived need for the noise; the meaning attached to the noise; and whether the noise source (e.g. conversation) is perceived as being useful.
- Perceived control and predictability – Whether the noise source is intermittent or steady; whether it is predictable; and whether the people who are exposed to the noise can control it.
- Personality and mood – Differences in those who are more noise sensitive, and in those who seek stimulation versus those that prefer solitude; and the effect of moods such as anger.

These factors will be explored further in Section 6. Clearly, psychological and social factors affect our response to sound level and whether we even consider the sound to be noise. A psychophysical, or more specifically a psychoacoustic, approach to workplace noise is required.

3.3 Noise source and effect on performance

Research into the impact of noise on performance has resulted in mixed and often confusing results. As Matthews *et al* (2013) point out:

> "The study of noise effect on performance is deceptively difficult; noise can affect the efficiency of task performance, usually for the worse but occasionally for the better … Individuals may not find a particular noise level annoying but their task performance may nevertheless be impaired. Conversely, they may find a particular noise level extremely annoying and yet their task performance may be unaffected."

The reason for the confusing results is the complex interplay between the four factors described above and the difficulty in quantifying the noise source, as discussed in Section 2.1. In acoustics, much performance research has focused on the impact of ambient versus intermittent sound and relevant versus irrelevant speech.

3.3.1 Ambient versus intermittent sound

Ambient sound refers to long-term steady background sounds, whereas intermittent sound refers to short-term transient or sporadic sounds. Chanaud (2009) explains that, in general, long-term steady sound becomes "normal" to the listener and is not noticed. In contrast, transient sounds generally distract a person's attention, and strongly so if the level is high relative to the steady sound (e.g. an increase of 10 dB). Chanaud goes on to say that the distraction is further strengthened if the sound has high information content, such as meaningful conversation. As Atkinson, Atkinson and Hilgard (1983) point out in their introduction to basic psychology, predictability is key "We are much more able to 'tune out' chronic background noise, even if it is quite loud, than to work under circumstances with unexpected intrusions of noise". Their views are backed up by many research studies, but most studies also emphasise the relevance of the task being performed.

Donald Broadbent, an experimental psychologist at Cambridge University, was the leading authority on the impact of noise on performance. After many years of pivotal research, Broadbent (1979) concluded that performance will not be affected by continuous loud noise when an employee: i) performs a routine task; ii) merely needs to react to signals at certain times; iii) is informed when to be ready; and iv) is given clear visual signals. However, performance is affected when the person is multi-tasking or paying attention to multiple sources. Broadbent found that noise hinders complex tasks but sometimes improves simple tasks. Rabbitt (1968) reported that unpredictable or irregular noise disrupts performance of mental tasks that require learning or short-term retention of new information.

Another seminal piece of research exploring the impact of noise on performance was conducted by David Glass and Jerome Singer. They subjected people to soft and loud bursts of sound; for some participants the sounds were timed 1 minute apart, but for others the sounds were random. Glass and Singer (1972) found that interrupting their participants with unpredictable noise resulted in them making more errors in a proofreading task than participants who were exposed to regular sound bursts (38.4 errors on average compared with 29.6 errors). In a further experiment, Glass and Singer found that participants who were given information that allowed them to anticipate loud sound bursts performed better than those who could not predict the intermittent sound. Glass and Singer proposed that uncontrollable noise is a source of stress that results in reduced performance. Their results also have consequences for providing control over noise (see Section 5.4).

Many studies on the impact of noise on performance take place in a laboratory or simulated office environments. Respected researchers Banbury and Berry (2005) assessed subjective reports of distraction from various office sounds among employees at two different office locations. Their study measured the amount of exposure the workers had to ambient sound in order to determine any evidence of habituation (i.e. workers no longer noticing the background sounds). They found that almost all respondents reported that their concentration was impaired by various components of office "noise", particularly unanswered telephones and people talking in the background. Unexpectedly, the study showed that employees are *unable* to habituate to noise in office environments over time and office noise, with or without speech, can disrupt performance on more complex cognitive tasks, such as memory of prose and mental arithmetic.

So, on the one hand there is plenty of laboratory-based evidence to indicate that people habituate to background noise, but real-world studies indicate that generalising this finding is not so straightforward – a fact argued by environmental psychologists for some time (Oseland, 2009). For example, the background office sounds used in the earlier laboratory study may have been considered a novel source of sound which the subject knows is not long-term, whereas office workers spend a large amount of their time exposed to the noise in their offices. Participants of experiments conducted in laboratories will also have different motivations and attitudes to those being studied in the real world. Another important factor, more important than the sound level or time period, is whether the background noise (such as that in an actual office) includes relevant speech, as discussed below.

3.3.2 Relevant versus irrelevant speech

"Relevant speech" refers to background speech that is intelligible or possibly has content that has meaning to the listener, whereas irrelevant speech is less intelligible and does not include content that is meaningful for the listener.

Jones *et al* (2008) report that memory is particularly sensitive to disruption by background or irrelevant sound, with negative impact of around 30%. More importantly, the effect on memory underpins many of the other reported effects on performance. For example, short-term memory plays a key role in language skills, particularly when the person is unskilled or stressed, which explains why people who are performing tasks involving memory while being subjected to meaningful speech are more likely to be affected than people who are exposed to irrelevant speech.

Marsh, Hughes and Jones (2009) conducted four experiments "centred on auditory distraction during tests of memory for visually presented semantic information". Basically, they asked their English-speaking subjects to assign various objects to four different categories and then recall their responses under states of quiet, pink noise[6], meaningful speech (English prose) and irrelevant sound (Welsh prose). They found that meaningful background sound caused higher distraction and disrupted recall (memory) more than meaningless sound. The effect was exacerbated when the speech was semantically related to the material to be remembered. The effects of meaningfulness and semantic relatedness were shown to arise only when instructions emphasised recall by category rather than by serial order. They concluded that their experiments "illustrate the vulnerability of attentional selectivity".

The irrelevant speech effect was first identified by Colle and Welsh (1976) and has been replicated by a number of researchers using simple serial-recall tasks. Irrelevant speech effects have also been observed using more complex cognitive tasks such as proofreading and text comprehension. The evidence is overwhelming: the "irrelevant speech effect" that occurs in memory, especially in tasks where the order of information is important, is mostly due to the *meaning* of the speech and is independent of the intensity of the sound.

The ground-breaking research carried out on speech disruption is that of Banbury and Berry (1997). They examined whether people can become habituated to background noise by testing people's ability to recall prose under three speech conditions. In Experiment 1 they found that background speech can be habituated to after 20 minutes exposure and that meaning and repetition had no effect on the degree of habituation seen. Experiment 2 showed that office noise without speech can also be habituated to. Finally, Experiment 3 showed that a five-minute period of quiet, but not a change in voice, was sufficient to partially restore the disruptive effects of the background noise previously habituated to. These three experiments showed that irrelevant speech, and office noise that does not contain speech, can be habituated to after a prolonged exposure to the noise stimuli. However, as previously mentioned, a later study by Banbury and Berry (2005), carried out in real offices, actually found that employees are unable to habituate to background noise over time.
Beaman *et al* (2012) explored the impact of English and Welsh background speech on memory of English words among English speakers and bilingual Welsh speakers, and found that English

[6] Pink noise is a variant of white noise (a random signal containing all the frequencies within the human range of hearing) which has been filtered to create sound waves with uniformly distributed energy at each octave.

monolinguals displayed less disruption from the Welsh speech indicating that the meaning of the background speech had an effect on performance. In a second experiment, only English-speaking monolinguals participated and English was used as background speech, but the task complexity was increased. Participants were asked either to simply count the number of vowels in words or to rate them for pleasantness before recalling them. Greater disruption to recall was observed from the meaningful background speech when rating the words for pleasantness compared to counting vowels. These results indicate that background speech is analysed for meaning, but whether the background speech causes distraction depends on the nature and complexity of the task.

Jahncke (2012) conducted a series of experiments investigating the impact of speech intelligibility on performance. He actually found decreased word memory performance, increased fatigue and poorer motivation when the background sound level was increased by 12 dB. More importantly, he showed that cognitive performance decreased as a function of background speech intelligibility – the higher the intelligibility the worse the performance. He also demonstrated that performance is more impaired by background speech if the main task requires “episodic memory and rehearsal” (i.e. word memory and information search tasks).

Veitch *et al* (2002) explored the impact of simulated ventilation noise (steady sound) and simulated telephone conversations (intermittent relevant speech) on noise satisfaction. They found that acoustic satisfaction increases as subjectively rated speech intelligibility decreases and concluded that office workers require speech privacy.

Many experiments have been conducted to determine whether sound masking (i.e. low background sound using white noise or pink noise) can reduce speech intelligibility and therefore reduce noise distraction and increase performance. The research in this area has mixed results. For example, Veitch *et al* (2002) found that noise masking which matches the speech spectrum is more effective at making speech less intelligible. However, they also noted that simply making the masking noise louder is not a guarantee of improved speech privacy. Indeed, they found that masking sound levels much greater than 45 dB(A) were judged to be too loud.

Haapakangas *et al* (2011) examined how room acoustic design affected cognitive work performance in a full-scale simulated open-plan office (90 m^2). Four acoustic conditions with different speech privacy levels were built, plus a silent condition. The conditions were created by changing the acoustic environment using screens, absorbers and a speech-masking system. Performance was measured for several cognitive tasks considered essential for office work. As might be expected, they found that the silent condition was the most beneficial acoustic condition for cognitive tasks. In contrast, the condition with the lowest speech privacy (highest intelligibility) was the least beneficial. Unexpectedly, they found that damping (absorption) without sound masking had a similar effect to damping with masking. More importantly, they found that masking, without any acoustic damping, had the worse effect on cognitive performance. In conclusion, this study places some doubt on the value of sound masking in open-plan offices without adequate absorption.

In the previous section, we presented evidence that showed people are more distracted by intermittent sound than steady background sounds. The evidence also indicated that people could habituate to long-term ambient sound. However, these conclusions were drawn from controlled office simulations, whereas real-world office studies indicate that background sound cannot be habituated to. Further (mostly laboratory) studies suggest the lack of habituation is more prevalent when the background sound has meaning, such as intelligible and relevant speech. Relevant speech has been found to have a greater impact on disrupting cognitive tasks, in particular those requiring memory (recall) or semantic assessment. So from a practical point of view for offices, the key is to reduce meaningful speech from distracting those carrying out cognitive tasks involving memory e.g. complex analysis and authoring original prose.

3.4 Errors in predicting performance

In most scientific studies the relationship between the dependent variable (Y axis or ordinate) and independent variable (X axis or abscissa) is explored. In psychophysical studies the dependent variable, such as noise annoyance, is usually subjective (albeit quantified) and the independent variable is usually more objective, such as sound level. The objective independent variable may be used to predict the subjective response and any (error) variation in prediction is usually associated with the more subjective dependent variable.

As noise (unwanted sound) is both perceived and subjective, it follows that sound level is only a proxy measure of the dependent variable and as a consequence it comes with in-built (error) variation. If there are measurement errors in both the Y (dependent) and X (independent) axis then the combined variance due to the product of X and Y will be significantly larger than an error on only one axis and thus results in the unreliability of the predicted relationship of Y and X.

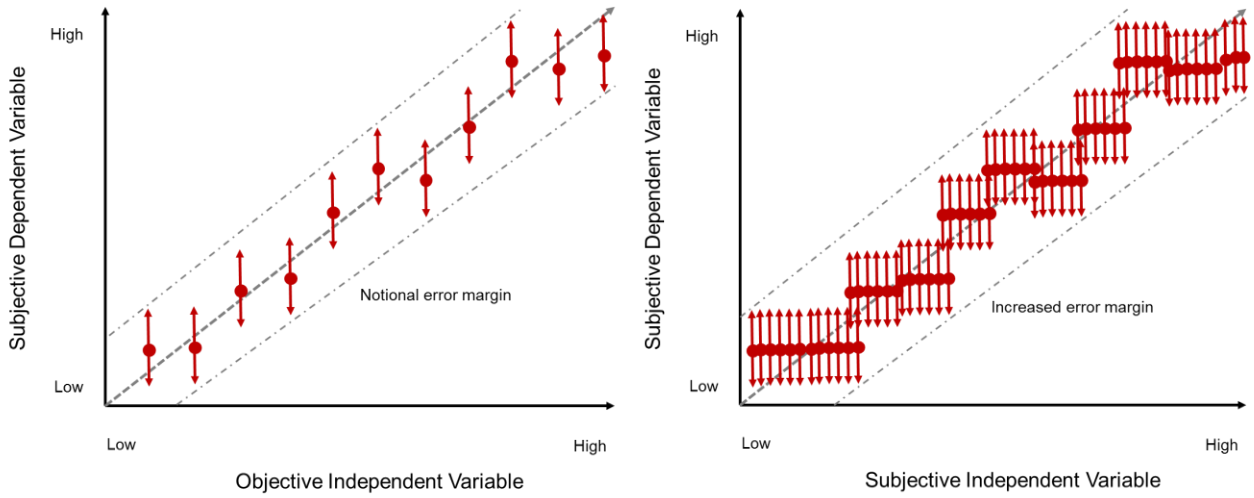

Figure 5. Subjective independent variables increase error and unreliability

Office worker performance is notoriously difficult to measure accurately. The studies described above mostly use laboratory-based performance tasks such as word recall, word searches, basic mathematics and proofreading. Environmental psychologists question how such tasks relate to the multi-tasking and complex processes that take place in real office work.

The key measures in performance tasks are speed and accuracy, and there is usually a trade-off between the two. In the real world, although speed and accuracy are important, quality and creativity are also important. Most laboratory studies usually focus on individual performance, but in real offices the output is often the combined effort of a team. So performance tasks are a proxy measure and do not completely represent the impact on office worker performance.

Performance tasks generally provide objective quantified data. So, in the acoustical studies described above, we have the unusual situation that the dependent variable is objective and the independent variable is a proxy metric for subjective data.

4.0 Relevant psychological meta-theories

4.1 Personality theory and arousal theory

Oseland (2012) explains that:

> "Personality theories date back to ancient Egypt and Mesopotamia but the ancient Greeks are most recognised as developing the first structured theory of personality. At the turn of the century the psychoanalysts, Freud and Jung, developed the psycho-dynamic theory of personality … Eysenck's (1967) two super-traits model is derived directly from Jung's theories and … he proposed two personality dimensions: extraversion (E) and neuroticism (N). Full extroverts and introverts sit on opposing ends of the extraversion dimension: an 'extrovert is a friendly person who seeks company, desires excitement, takes risks, and acts on impulse, whereas the introvert is a quiet, reflective person who prefers his or her own company and does not enjoy large social events' (Eysenck and Eysenck, 1975). Neuroticism is a dimension of emotional stability that ranges from fairly calm and collected people to ones that experience negative emotional states such as anxiety and nervousness."

Psychologists propose that introverts and extroverts have different innate levels of arousal, which in turn affects how noise affects their performance, as explained by Oseland (2009):

> "A key fundamental theory is the Yerkes-Dodson Law (Yerkes and Dodson, 1908) which proposes an inverted U-shape relationship between a person's performance and their level of arousal, i.e. excitement or interest. The theory states that people can perform better if they are stimulated or motivated (which increases their level of arousal), but there is a limit, as too much stimulation can lead to stress and thus reduce performance. We might therefore assume that to maximise the performance of office workers we need to design stimulating but not too over-stimulating environments. Unfortunately, one complication is that individuals have a different base level of arousal and therefore need different magnitudes of stimulation for optimal performance. For example, extroverts have a low natural level of arousal and enjoy thrill-rides whereas introverts who have a higher level of arousal might find such rides distressing."

Noise is considered to be a form of stimulation so it follows that extroverts should perform better than introverts in noisy environments.

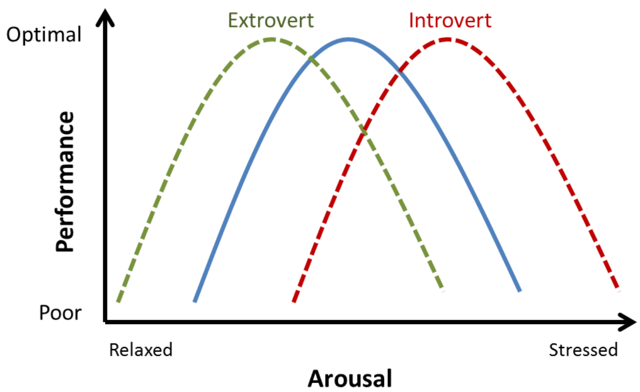

Figure 6. Performance is affected by arousal which is affected by personality type

Oseland (2009) continues:

> "A further complication is that difficult and complex tasks (or working under time pressure) are in themselves demanding and therefore increase the level of arousal, thus people need subdued environments to maximise performance. In contrast, repetitive or menial tasks require more stimulating environments to increase the level of arousal. So, in simplistic terms, stimulating environments with music or noise and a buzz of activity may enhance the performance of extroverts or those conducting simple tasks, but more calming environments will better suit introverts or those involved in more complex tasks."

Much of the earlier research on the impact of noise on task performance, notably by Broadbent (1958), generated results in support of arousal theory. Szalma and Hancock (2011) report that Broadbent (1978) proposed that noise "increases arousal which decreases the breadth of attention. At relatively lower levels of arousal, the attentional narrowing facilitates performance because it causes the individual to exclude irrelevant cues. Beyond an optimal level, however, increases in arousal cause increased narrowing so that task-relevant cues are also excluded, and performance is thus impaired". They also note that Poulton (1979) supports arousal theory but "argued for a composite model of noise effects involving arousal and masking of inner speech … the gains in performance in continuous noise early in the task occur because the increase in arousal compensates for the deleterious effects of masking".

However, Szalma and Hancock (2011) also point out that the negative effect of intelligible versus unintelligible speech, explained in the previous section, is inconsistent with Broadbent's or Poulton's version of arousal theory. They would expect that noise should increase arousal regardless of the content of the noise, so proposed the adoption of the Maximal Adaptability Theory described by Hancock and Warm (1989). This theory relates to the adaptive response of the individual to noise as Szalma and Hancock (2011) believe it is more useful:

> "From this perspective, intermittent speech noise of relatively short duration is most disruptive because it consumes information-processing resources that the individual cannot effectively replenish through compensatory effort because of the limited exposure to the stressor. In contrast, for conditions of continuous noise of longer duration, individuals can develop more effective coping strategies."

Regardless of which theory is adopted, it is clear that accounting for introversion/extraversion and task is of utmost importance when designing environments that minimise noise distraction. For example, the theories indicate that an introvert conducting a complex task would thrive in a quiet environment whereas an extrovert conducting a simple task requires a more stimulating/ noisy environment.

Eysenck's super-traits model (based on extraversion and neuroticism) underpins the most popular current theories of personality such as the Big Five model (John and Srivastava, 1999). The five factors are Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism, and are often referred to as OCEAN.

- Openness – refers to being open to new experiences and is a trait of those who are creative, curious, with broad interests, are imaginative and artistically sensitive.
- Conscientiousness – relates to those who are more responsible, hard-working, organised, dependable, self-disciplined and persistent.
- Extraversion – refers to those who are more sociable in nature and prefer keeping company; they are also more impulsive, gregarious, assertive, talkative and are thrill-seekers.

- Agreeableness – is seen in those who are more cooperative, affectionate, good-natured, helpful, forgiving, caring and trusting.
- Neuroticism – refers to emotional instability and the tendency to experience negative emotions and experience anxiety.

The impact of different personality traits on performance under noisy conditions is explored in Section 5.

4.2 Environmental psychology and behaviour

Environmental psychology is a relatively new field of psychology which explores the interrelationship between people and their physical settings. The main focus of this paper is the research related to perceived noise, and corresponding behaviour, in office buildings. Environmental psychology theories provide further insights into psychoacoustics and why it is important to address psychological as well as physical variables when investigating and resolving noise distraction.

As Oseland (2009) explains "Traditional psychology took the view that behaviour is simply a deterministic response to the physical world, but Kurt Lewin (1943) proposed a different perspective, summed up by his equation $B = f(P, E)$, declaring that behaviour is a function of the person (P) as well as the environment (E)". So how we perceive and interact in an environment is dependent upon our individual experiences and different expectations of that environment. Such factors will affect whether we consider a particular sound to be a noise.

Oseland continues "Roger Barker (1968) introduced the notion of behavioural settings where the pre-conceived social etiquette associated with a particular setting unconsciously influences the behaviour in that setting, for example consider the behaviour of people in churches and libraries". In such environments even quiet sounds are unexpected and considered disturbing. In contrast, the high sound levels at a football match or rock concert are considered acceptable by participants; they are expected and viewed as the norm.

So our preconception of the working environment will affect our perception of noise in that environment. If workers are going into the office expecting to carry out work requiring concentration, based on previous experience, then a situation where this is not the case will lead to dissatisfaction and likely result in reduced performance. Part of the solution is therefore managing expectations (informing staff what to expect) and agreeing the acceptable sound levels (from speech and equipment) in different parts of the office.

4.3 Evolutionary psychology and biophilia

Evolutionary psychology is one of the newest fields of psychology, as Oseland (2009) explains:

> "Evolutionists believe that over time physiology develops, through natural selection, to ensure the survival of the species. Similarly, evolutionary psychologists argue that innate human behaviour is governed by adaptations of psychological processes which evolved to aid our survival and well-being. *Homo Sapiens* evolved around 400,000 years ago in natural environments, but people have only worked in offices for around 100 years. As a consequence a person's psychological processes are probably more adapted to living on the African savannah than they are to working in offices."

A key theme within evolutionary psychology is *biophilia*, a term coined by Wilson (1984), which explains our affinity to natural environments. Some evolutionary psychologists argue that people feel refreshed after sitting in a natural environment because nature provides a setting for "non-taxing involuntary attention". They also propose that people innately prefer noise to be at a similar level to that found in the natural world (i.e. a slight background buzz of activity).

Alvarsson, Wiens and Nilsson (2010) observed that sounds from nature, such as birdsong or rippling water, promote faster recovery from stressful tasks compared with traffic noise and ambient building noise, such as that from air-conditioning equipment. Jahncke (2012) studied the impact of breaks and rest periods on performance. He found that watching a nature movie (with sound) while taking a break increases energy ratings, arithmetic performance and motivation, compared with just listening to office noise. Continued exposure to office noise gave the lowest ratings of motivation and decreased task performance. Researchers Fitzgerald and Danner (2012) and Jahncke (2012) suggest that using pleasant sounds from natural environments to mask background workplace noise could decrease employee stress and increase worker productivity.

The jury is out on whether white (or pink) noise masking helps reduce noise distraction, but an alternative might be more natural sound masking. Soundscaping, or acoustic ecology, is the relationship mediated through sound between living beings and their environment. Organisations such as Sustainable Acoustics and Julian Treasurer's The Sound Agency are exploring the benefits of implementing soundscaping systems in the office in order to strengthen the connection to outside positive sound sources and help mask the unwanted elements of noise.

5.0 Acoustics and personality

5.1 Task performance affected by personality type

5.1.1 Extraversion

Several studies, mostly laboratory-based, have shown that extroverts perform better than introverts at cognitive tasks under noisy conditions. For example, in an early study Morgenstern, Hodgson and Law (1974) found that extroverts performed better in the presence of distractions than they did in silence, while introverts showed a deficit in performance. The subjects were tasked with remembering words from a list read to them while they were being distracted by German words, versus performing in silence. Similarly, Standing, Lynn and Moxness (1990) found that introverts and extroverts performed equally well in comprehension tasks in silence, but white noise (at 60 dB) impaired introverts' performance whereas the extroverts continued to perform at the same level.

In a mental arithmetic task applied on medical students under quiet laboratory conditions at 42 dB(A) and noisy ones at 88 dB(A), extroverted subjects performed significantly faster in noise (Belojevic Slepcevic and Jakovljevic 2001), and concentration problems and fatigue were more pronounced for the introverts.

More recently, Alimohammadi *et al* (2013) compared attention and concentration (Cognitrone test by Vienna Test System) in quiet conditions and under road traffic noise of 71 dB(A). Performance, in particular speed, was enhanced in extroverts in the noisy condition but no significant difference was found in introverts. In a series of experiments, Geen (1984) allowed his subjects to adjust the level of background noise to an optimum during a learning task and discovered that extroverts selected higher sound levels. His studies also showed that the heart rate of introverts increased under noisy conditions, whereas that of extroverts did not; which is in line with arousal theory.

The impact of extraversion on performance under noisy conditions has also been observed outside the laboratory. For example, Campbell and Hawley (1982) demonstrated that when studying in a library, introverts were significantly more likely to choose a place to work away from the buzz and bustle of certain areas, whereas extroverts were more attracted to the latter as a their place of work.

5.1.2 Neuroticism

More anxious (neurotic) personality types have displayed worse performance in noise compared to emotionally stable individuals, for example in complex mental tasks such as retrieval from semantic memory (von Wright and Vauras, 1980) or learning prose (Nurmi and von Wright, 1983). Eysenck and Graydon (1989) suggest that neurotic introverts are more adversely affected by noise than emotionally stable extroverts when carrying out work-life tasks.

Benfield *et al* (2012) propose that "Arousal and stress perspectives posit that noxious sound increases negative affect, generalized anxiety, and frustration in the listener, which in turn causes stress and/or arousal with subsequent changes in blood pressure, sleep patterns, immune functioning, and hormone levels". Or as Kryter (1970) explains "The general finding that the performance of the more anxious personality types is more affected by noise than that of non-anxious types would attest to the existence of a stimulus-contingency factor. In terms of learning or conditioning, the task becomes disliked and is performed relatively poorly because it is related to or contingent upon the aversive noise". Matthews *et al* (2004) propose that, for people with predominantly neurotic and anxious personality types, performance is impaired by noise because of a "reduced availability of attentional resources or working memory, due to diversion of attention to processing internal worries".

In conclusion, people with a more neurotic disposition are overly concerned with the source of the unwanted sound and respond to it more negatively, resulting in stress.

5.1.2 Openness, conscientiousness and agreeableness

Franklin *et al* (2013) examined the relationship between acceptable noise level and personality. The analysis revealed a correlation between acceptable noise and openness or conscientious personality dimensions. They suggest that people who are more open to new experiences may accept more noise while those who are of the more conscientious personality type, who generally desire fewer distractions when focusing on a task, accept less background noise. No effects on agreeableness were reported.

5.2 Noise sensitivity and personality traits

Much research has been done on noise sensitivity, and some researchers have proposed that it is a core personality factor to be considered when reducing noise distraction. In 1978 Weinstein developed his noise sensitivity scale and found that noise sensitivity is not strongly correlated with objective sound level, because some people are simply more sensitive to the same sound levels. However, noise annoyance and noise sensitivity are different. According to Stansfeld (1992) while annoyance is related to sound level, sensitivity is not and noise sensitive individuals are likely to be more annoyed by noise than non-noise sensitive individuals at all sound levels.

Although noise sensitivity is an important factor, we do not believe it is necessarily a personality trait *per se*. Noise sensitivity is determined by Wenstein's scale of emotional response to noise, so it is not surprising that those who rate themselves as noise sensitive are then more annoyed than others by what they perceive as noise. Stansfeld (1992) notes that noise sensitivity is considered a self-perceived indicator of vulnerability and it is linked to perception of environmental threat and lack of environmental control combined with a tendency to negative affectivity. Stansfield's description is very similar to the personality trait of neuroticism.

Indeed, researchers have found that noise sensitivity is associated with neuroticism (Belojevic and Jakovljevic, 2001; Job, 1988; Levy-Leboyer, Vedrenne and Veyssiere, 1976; Goldstein and Dejoy, 1980; Stansfeld 1992). Luz (2005) reports that "An association between noise sensitivity and neuroticism has been reported from England, Sweden, and Serbia … the statistical connection between noise sensitivity and neuroticism could be used to isolate and ignore the noise sensitive population". In their own research, Belojevic, Jakovljevic and Slepcevic (2003) found that neuroticism was the best individual predictor of reported noise sensitivity.

Weinstein (1978) previously questioned whether the reported "link between introversion and noise sensitivity is due to direct arousing effect of noise on the central nervous system, or to the fact that noise frequently has interpersonal significance and is seen as an intrusion by those who are ill at ease in social settings and prize privacy (psychosocial effect)". Belojevic, Jakovljevic and Slepcevic (2003) concur that age, education level and introversion were not significantly related to noise sensitivity. They conclude that "Noise sensitivity appears to be a complex, multidimensional personal characteristic but subject to situationally determined (and therefore considerably variable) cognitive and affective factors involving meaning, attitudes, motivation and so on".

As underpinning personality traits tend to be quite stable, noise sensitivity is more likely to be an attribute of a core personality factor, such as neuroticism, than an independent stand-alone personality factor. Noise sensitivity could be related to evolutionary psychology, as discussed in Section 3.3. Luz (2005) proposes that people who are noise sensitive have a very active orienting response (OR), explaining "For our ancestral hunter-gatherers living in natural quiet, an active OR was essential for survival. It helped the hunter keep food on the table and the gatherer to avoid predators. However, in a world filled with roars, buzzes and bangs, an active OR can be a disadvantage, especially for people whose nervous systems have difficulty 'turning off' the OR. The process of 'turning off' the OR is called 'habituation,' and noise sensitive subjects have a harder time habituating to a repeated sound."

5.3 Music and distraction

Listening to music in the workplace is becoming more common; usually people listen through headphones but occasionally music is played in the background. There are increasing concerns that the volume of music played through personal music players could damage hearing.

Music is often considered to be a form of exterior arousal. For example, electrodermal measurement of arousal showed that playing simple tunes can significantly alter the base-rate and performance of extroverts and introverts (Smith, Wilson and Davidson, 1984). Our concern here is whether music has a beneficial or detrimental effect on worker performance.

In an early experiment, Daoussis and McKelvie (1986) found that extroverts reported working with music twice as much as introverts, but both groups played background music very softly. Daoussis and McKelvie administered a reading retention test to the two personality types under quiet conditions and with background music. The performance of the extroverts was not affected under the two conditions but the performance of the introverts decreased with background music.

Adrian Furnham and his colleagues at University College London (UCL) have carried out many studies on the impact of music on performance for different personality types. Furnham and Bradley (1997) investigated the effect of pop music during a memory test with immediate and delayed recall. They found that introverts listening to music had a significantly lower recall than the extroverts in the same condition and the introverts who had completed the test in silence. Furnham and Bradley also found that introverts who completed a reading comprehension task when music was being played performed significantly less well than extroverts. Furnham and Bradley concluded that "There seems little evidence that the presence of background distraction (television, music, talk) actually facilitates performance in complex cognitive tasks, even for extroverts, though it seems clear that it nearly always impairs the performance of introverts".

Furnham, Trew and Sneade (1999) conducted a similar study examining the effect of vocal and instrumental music on reading comprehension and logic-problem tasks. They found that vocal music was more distracting than instrumental music, which is in line with the research on intelligible speech reported earlier. They also found that the performance of the introverts was impaired by the introduction of music whereas that of extroverts was enhanced. In a more recent study, Furnham and Strbac (2002) examined whether background office noise would be as distracting as music. They exposed the participants to silence, background garage music and office noise while the participants carried out a reading comprehension task, a prose recall task and a mental arithmetic task. Furnham and Strbac found that introverts performed less well on the reading comprehension task than extroverts in the presence of music and noise. They also confirmed that, in general, performance was worse in the presence of music and noise than in silence.

Cassidy and MacDonald (2007) reported that introverts were more detrimentally affected by the presence of high-arousal music compared with extroverts. Chamorro-Premuzic *et al* (2009) examined the effects of different types of background auditory stimuli on the abilities of introverts and extroverts to perform cognitive and creative tasks. Results showed no significant effects of background auditory stimuli and personality on either cognitive task performance. However, there was a significant effect on creative performance, with extroverts performing better in the presence of music than introverts. Chamorro-Premuzic *et al* concluded that background music may have a more detrimental effect on the creative task performance of introverts compared with extroverts.

As well as music, Furnham and colleagues studied the impact of the presence of an operating television on introverts and extroverts (Furnham, Gunter and Peterson, 1994), and found introverts and extroverts performed equally well at reading comprehension tasks with the television switched off. However, the extroverts performed better than the introverts when the television was on.

Various other studies have examined the distracting effects of television on cognitive processing. Significant performance decrements have been reported for several measures, including spatial problem solving, mental flexibility and reading comprehension as a function of television (Armstrong and Greenberg, 1990; Armstrong, Boiarsky and Mares, 1991). These results are consistent with the idea that background television influences performance by causing over-stimulation when people are performing complex tasks.

5.4 Control of noise and performance

Quite a few research studies have focused on how the perceived control of noise affects performance. The seminal piece of research in this area is that of Glass and Singer (1972), described above (see Section 3.3.1), where people in a noisy environment were asked to perform a proofreading task and told either that they could control noise or that they had no control over intermittent noise bursts. The subjects performed equally well during experiment. However, when both groups were tested on a task after being exposed to noise, the performance of the group who had been given control, even if they did not use it, was significantly better. Glass and Singer suggested that this may have been a consequence of increased tolerance for frustration in conditions in which noise bursts were signalled and could be anticipated. All individuals were exposed to identical circumstances, yet those with the perception that they could alter their circumstances, if they chose to do so, experienced less stress. Another significant finding is that stress from noise continued to affect performance of the subjects longer after they were exposed to the noise.

Rather than focus on noise, Carton and Aiello (2009) examined the effects on task performance of control over social interruptions. They defined an interruption as "any disruptive event that impedes progress toward accomplishing organizational tasks … Social interruptions are those that are initiated by human actors". They showed that participants who were able to anticipate social interruptions performed significantly better than did those who could not anticipate them.

Furthermore, participants who had the opportunity to prevent interruptions reported significantly less stress than those who could not. Carton and Aiello argue that individuals with knowledge that they may be exposed to interruptions have the ability to use preventive coping tactics to minimise disruption and frustration when the interruptions occur. More importantly, from an office perspective, they conclude that individuals need not actually prevent interruptions from happening in order to be benefit – simply believing they can prevent interruptions has an effect.

Other researchers have noted that some individuals appear better able than others to cope with the excessive stimulation inherent to the open-plan office environment. Mehrabian (1977) proposed that such individual differences in coping are due to an innate ability to "screen". He distinguishes between screeners, who effectively reduce over-stimulation by attending to information on a priority basis, and non-screeners, who cannot apply this strategy and tend to become over-stimulated.

6.0 Design implications for offices

6.1 Using the physical as a means of noise control

We have determined, from a physical perspective, that adequate amounts of absorption are necessary to control sound propagation and aide speech privacy in open-plan office environments. The use of sound-absorbing ceilings, screens, carpeting, soft materials and materials for diffusion (such as plants and trees) are all necessary design criteria. As well as the material choices within the space, an activity-based approach allows freedom of the individual to physically go to the appropriate space based on the activity and need for privacy, disturbance reduction and so on. Adequate acoustic boundaries should also be created between quiet zones for concentration and those where speech may be elevated, such as collaboration spaces. Dedicated "quiet booths" can be used as an effective solution when space is limited, provided they are not located near vocally intensive areas.

Space	Considerations	Physical solution
Informal meeting areas	Keep sound levels low; reduce sound propagation	Locate away from concentration areas; use partitions or screens, plants, absorbing of wall and ceilings
Open-plan office work area, individual desks	To keep speech and other sounds from spreading and to minimise the disturbance of co-workers	A sound-absorbing ceiling with good absorption qualities at speech frequencies (400–2,000 Hz) and sound-absorbing screens dividing people into groups
Semi-open meeting areas	Prevent sound from spreading; prevent sound levels from escalating; and avoid the need for people to raise their voices. The team should have local speech clarity so they can talk normally	Sound-absorbing ceilings with good absorption qualities at speech frequencies; and if people in adjacent areas can be disturbed, use sound-absorbing screens
Project rooms	Hinder wall-to-wall echoes and support communication (speech clarity). The room should also be properly sound-insulated to keep sound from entering or leaving the space	Sound insulation, a sound-absorbing ceiling and flooring with good absorption qualities at low frequencies, and wall absorbers
Phone-intensive	Speech flows in all directions, resulting in escalating sound levels and impaired speech clarity over the phone, and noise disturbance to other areas	A sound-absorbing ceiling with the best absorption qualities at all frequencies, sound-absorbing screens dividing people into groups and wall absorbers on every possible wall space.

Table 4. Examples of specific areas and suggested physical design criteria

Considerations for the type of space is a first step, and includes: i) the size of the room; ii) the location in relation to other spaces; and iii) whether the materials in the space are made of particularly hard surfaces such as concrete (these and other smooth/hard surfaces are like a mirror from the acoustic perspective).

Unless there is a need to project sound, accommodation should be designed to limit the sound reflections through absorption and aid sound propagation with barriers capable of absorbing at the speech frequencies. Diffusion (spreading the sound energy) is of importance and will occur due to the furniture and other objects in the room; but trees and extensive planting can also be good for the acoustic environment. Consideration should also be given to the type of equipment in the space; fans, projectors or other mechanical or electrical sound sources should be located away from concentration areas.

6.2 Beyond the physical – new practical guidance

Our literature review establishes that noise is subjective and is as much a psychological as a physical problem. In particular, distraction from noise results in loss of concentration/focus and memory/recall, which in turn results in loss of office worker performance.

Interpretation of sound as a noise depends upon a range of factors as described in Section 3.2. To summarise, noise distraction is related to:

- Task and work activity,
- Personality and mood,
- Perceived control and predictability,
- Context and attitude.

But as shown earlier in this report, different office workers will react differently to the same acoustic conditions in their workplace. Therefore actions to resolve noise distraction need to account for individual differences and not assume that a single physical acoustic solution will be work for all office occupants. A psychoacoustic approach to understanding noise distraction indicates that other, people-centred, solutions are also required. Such solutions are more behavioural, educational, managerial and organisational rather than physical.

We will now consider possible solutions that address the four key factors highlighted above. These solutions will be tested and built upon in our next phase of research (see Section 7).

6.2.1 Task and work activity

Individuals and teams typically conduct a range of work activities throughout the day. For example, part of the day may involve meeting colleagues or clients and some of the working day may be spent solo, carrying out processing or analysis. Such activities are better performed in different work environments which are specifically designed to support the activities, for example a meeting space is quite different to the space required for focused work. A core principle of "activity-based working" (or "agile working") is that employees are provided with choice of a range of work-settings that support their different work activities.

Activity-based working environments typically include:

- Meeting and teleconference rooms that have good acoustic properties to reduce sound transference, offering acoustic privacy and also reducing noise distraction to and from outside the room.
- Focus rooms or pods – places for staff to go if they wish to carry out work that requires concentration, or a confidential call, and to be free of distraction from their colleagues.

Some activity-based working environments provide phone booths to allow staff to make personal and confidential calls away from the open-plan desks and their colleagues. Small teleconference rooms allow several staff to join a call without distracting colleagues in the open-plan office.

Rather than offer rooms for focused work, some organisations are now creating larger quiet zones as part of the activity-based working options. Such zones tend not to have desk phones and prohibit impromptu meetings. Part of the agile working approach is to allow occasional remote working, including home-working, where employees can more easily control the level of distraction.

Although activities may vary throughout the day, different teams will usually have core work activities that take up the majority of their day. For example, a sales team is likely to spend more time on the phone than a team of analysts. The working environment for the team can therefore usually be planned around their core work activities, and teams conducting similar activities could be placed together. Generally, those involved in complex or detailed tasks, task requiring memory and recall, or people who are multi-tasking are likely to require a quieter environment than those involved in simple single tasks. Obviously, it is preferable to avoid locating more vocally active teams who prefer buzzy environments next to those requiring quiet for concentration.

We acknowledge that many organisations are looking to break down team silos and facilitate interaction between teams. Nevertheless, if the primary work activity of the team is heads-down work, then the space should be designed to support that, and additional work-settings away from the main open-plan workspace should be provided for interaction and collaboration.

Creativity and innovation is an increasingly important attribute of any business. Stimulating spaces are required to promote creativity, but it should also be acknowledged that much of the creative process takes place in solitude away from distraction (Oseland *et al*, 2011).

6.2.2 Personality and mood

The research literature shows that some personality types are better at coping with noise distraction than others, in particular people who are predominantly extroverted compared to those who are more introverted. Research into collaboration has shown that the most productive teams are those with a rich mix of personality types but the design of many workplaces is often more suited to extroverts (Oseland, 2012).

Psychological profiling is often used to determine whether a person has the relevant personality and attitude for joining an organisation. However, they may then be placed in a workspace designed with other personality types in mind. We propose that personality profiling should also be used to cluster people who prefer and function better in similar acoustic environments. Thus people who are primarily categorised as introvert, neurotic and conscientious personality types could be accommodated together in spaces that facilitate quiet work. In contrast, those who are primarily extrovert and more open personality types could be allocated space in stimulating (loud) environments. Better still, the different personality types could be offered choice over where they wish to work and select their preferred location.

Personality	Task	Quiet	Loud
Introvert	Simple	😐	☹
	Complex	☺	☹☹
Extrovert	Simple	☹☹	☺
	Complex	☹	😐

Table 5. Preference of sound level depending on task and personality

There is an interaction between personality type and task, as shown in Table 5. Introverts generally require quieter spaces to compensate for their innate higher level of arousal, but complex tasks increase arousal, so introverts cope the least well with complex tasks in loud stimulating environments. They perform slightly better at simple tasks in loud environments. In contrast, extroverts prefer loud stimulating environments to counter their innate low level of arousal. Simple tasks in quiet environments do not sufficiently stimulate the extroverts so they perform least well under these conditions. Complex task increase arousal such that the extroverts cope better with these under quieter conditions.

Mood affects our willingness to help other people under noisy conditions, and perception of noise can affect mood. In organisations seeking to enhance collaboration, it is important that noise annoyance is not increased due to perceived unnecessary noises.

6.2.3 Perceived control and predictability

Lack of control and predictability of noise decreases performance, but there is also research evidence to show that the degradation of performance continues after the noise has ceased. The research also indicates that it is *perceived control* rather than actual control of noise that has alleviating effects. It is not always practical to give full control over noise, particularly in open-plan environments, but there are other solutions.

Offering a choice of work-settings (e.g. by implementing activity-based working) gives employees the option of moving to a quiet zone or room and thus distancing themselves from the noise source. In this solution, it is important that the people affected fully understand that they have options, and they are given full choice.

Another approach is to introduce some form of "office etiquette" around noise. Quite often the people who find loud telephone conversations or nearby discussions distracting believe they cannot alleviate such problems. These people tend to be the ones who carry out work requiring quiet and also tend to be of the personality types that avoid unnecessary confrontation. Having office protocols, which is a type of charter or policy document, can be particularly helpful to those personality types. The office etiquette should set out acceptable behaviour and acknowledged that unacceptable behaviour can be challenged by all. It can be presented in written format and posted online, similar to office sustainability and other environmental guidelines.

For example, the etiquette document could cover:

- What the team member can do when disturbed by unanswered phones, loud teleconference calls, unnecessary chatting, local meetings
- Guidelines on acceptable use of mobile phones (e.g. set to voice mail after four rings or put on silence when in the office) and that it is acceptable to switch off unanswered phones
- Protocols that suggest lengthy discussion are continued away from the desks.

The agreed protocols would need to be backed up with alternative work-settings. The important point is that each team needs to agree on the preferred behaviour and team members must feel they have some control over unnecessary noise.

Finally, it is important to provide methods of controlling interruption from colleagues. Some organisations use visual cues to indicate when a person is busy, such as small "busy" flags on the desk. There are mixed views over such techniques but if a team likes the idea then it is worth incorporating into the office etiquette. A similar option is to use PC presence indicators, such as Microsoft Lync or Cisco Unified Presence, which can be set to "busy" or "available", so that colleagues refer to the status set by a person before approaching them, or they would ping an instant message to see if they are free. Another visual "do not disturb" cue often used is headphones; they also act as a form of sound masking and can improve the performance of some personality types. Again there are mixed views on the use of headphones and whether they lead to isolation from the rest of the team. At minimum we should be cognisant of when a colleague is in "mid-flow" before approaching them.

6.2.4 Context and attitude

Perception of noise is affected by attitudes towards the source of the noise. If people feel that a sound source is justified (e.g. an important announcement) or they are more familiar with those generating the sound (such as close team mates) they will be more tolerant of the distracting noise. So grouping teams together such that background speech may be of value to them rather than a distraction can be helpful. Management should clearly explain to new members of the team whether it is a noisy or quiet team and what the norm is. If it is a noisy team then the manager should justify the business reasons for it and explain the benefits.

It has been demonstrated that relevant speech is more likely to be distracting to a team member than speech that is interpreted as irrelevant, so if a task requires complete focus and concentration, removing noisy team distractions may be preferable (e.g. by working elsewhere).

The facilities management team should announce any unusual planned noises in the workplace (e.g. building works). If they explain the reasoning behind the noise, the resulting benefits and the timescales, then the occupants are likely to be more tolerant of the noise.

6.3 Generic solutions

The solution to noise distraction is as much to do with the management of the space and guidance on behaviour as it is about the design and acoustic properties. A choice of different types of space with different acoustic properties and agreed behaviours is essential for reducing noise distraction.

People-centred acoustic solutions can be summarised as follows:

- Displace – Displace the noise distraction by providing easy access to informal meeting areas, breakout and brainstorming rooms. Provide quiet areas for the staff to retreat to, including quiet booths, phone-free desk areas or a library-type space plus the option to work from home occasionally. Good design and visual cues can be used to indicate how people should behave in a space and the expected noise levels (e.g. consider the layout and design of a library compared with a café).
- Avoid – Avoid generating noise distraction (e.g. do not provide hands-free speaker phones in open-plan offices or meeting tables in the middle of workstations where people are carrying out work requiring concentration). Locate noisy teams together and away from the quieter teams. Co-locate team members, because people are more tolerant of noise from their own team. Consider the personality of the staff and perhaps separate the extroverts who thrive in noisy environments from the introverts who prefer quiet.
- Reduce – Reduce the noise distraction by controlling the desk size and density (high-density environments with people closer to each other generates more noise distraction). Consider allowing people who are conducting repetitive tasks requiring concentration to use headphones. Use good acoustic design to reduce speech intelligibility across open-plan areas and noise transference between rooms. If sound masking is to be used, consider using more natural soundscapes rather than white or pink noise.
- Educate – Introduce some form of office etiquette which reinforces consideration towards colleagues. Etiquette should cover phone use, loud conversations, music, headphones, managing interruptions, how different work-settings are used and so on. It may also include “do not disturb” signals. Explain to staff how the office layout works, the facilities available to them and how they can control noise disruption. If required, explain and justify why there is a noisy environment.

7.0 Next steps

7.1 Hypotheses based on literature review

Our literature review indicates some new hypotheses that require testing:

1. Extroverted office workers can cope better with noisy environments whereas introverts will perform better under quieter conditions.
2. Co-locating introverts and separating them from extroverts will help manage noise distraction.
3. Co-locating teams will help manage noise distraction from meaningful speech.
4. Perceived control over noise will reduce the problem of poorer performance caused by noise distraction.
5. Offering choice over alternative work-settings in the office will reduce noise distraction and improve performance.
6. Occasional working from home reduces noise distraction and will improve performance.
7. Educating employees in how to behave in open-plan environments and introducing office etiquette around noise will reduce noise distraction.
8. Activity-based, acoustically sensitive designed spaces create better environments for both introverts and extroverts.
9. Applying a combined approach of worker psychology mapping and acoustic design will improve worker performance.

7.2 Research proposal

Our intention is to conduct an intervention study in a real office with real office workers to test some, if not all, of the above hypotheses.

The study will involve measuring satisfaction with noise, determining an appropriate (embedded) performance metric and conducting personality profiling. Based on the survey results, appropriate changes will be made in the office. This will include organisational and behavioural change as well standard acoustical physical ones.

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