CONSTRUCTION CANADA

June 2015 Vol. 57 No. 5

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Understanding acoustic privacy within the built environment

By Niklas Moeller

Typing the word 'privacy' into any search engine yields a virtually endless stream of entries describing the ways in which it can be violated. There are reports of hackers acquiring credit card information, law enforcement agencies mining social networking sites, and members of the public using drones to take aerial photographs. More recent headlines indicate voice-activated televisions can even eavesdrop on owners.

The preoccupation with vulnerabilities exposed by the Internet and electronic products is understandable given their relatively rapid spread into almost every aspect of everyday life. However, privacy can still be violated in 'traditional' ways. In fact, it can even be lost to those who do not intend to infringe upon it. People are often exposed to sensitive information simply by being within audible range of a conversation.

Current privacy legislation tends to focus on securing access to information stored on computers or within filing cabinets, but attention also needs to be paid to the built environment. When examined in this context, privacy has both an acoustic and a visual component. (This article primarily focuses on the former, except insofar as it is affected by the latter.)

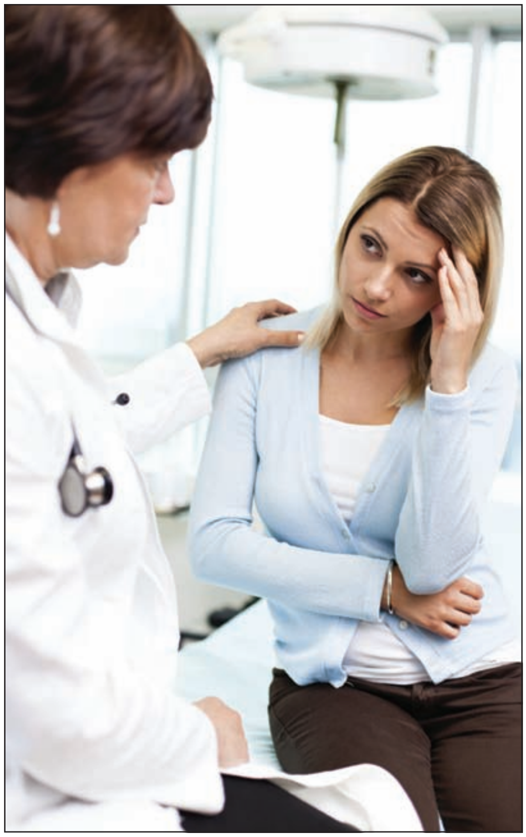
What is acoustic privacy?

Many people immediately equate acoustic privacy with speech privacy, but there is more to this concept than the ability to clearly hear what another person is saying.

For example, if the conversation taking place in a room next to an occupant is unintelligible, one may still be able to identify the speaker's tone and determine whether they are happy, sad, or angry. This type of information can be considered private under certain circumstances, such as when coming from behind the closed door of a human resources manager's office—the same can be said for non-verbal noises like those overheard from an adjacent hotel room.

How much of a conversation is understood also depends on whether or not the speaker can be seen. This effect—known as visual cues—has been quantified by various studies.[1] Generally speaking, if one can only understand 20 per cent of someone's conversation when not looking at them, the ability to see their lips increases that amount to nearly 55 per cent. If you start at 50 per cent, visual cues increase it to almost 90. In other words, there is also a visual component to acoustic privacy, which is important to bear in mind when designing a space.

Further, acoustic privacy should not only be considered from the speaker's perspective, but also that of the listeners. The reasons will become clear as this article explores the various impacts of a lack of privacy.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When people can unintentionally overhear a conversation, they often feel annoyed or even the sensation their own privacy is being violated. It can also make one insecure about the level of speech privacy, compromising an ability to freely communicate.

Where is it needed?

A lack of acoustic privacy carries real risk, particularly in facilities where there is a perceived need for it or an expectation on the part of its users. Examples include hospitals, bank branches, law offices, government, and military facilities. However, other types of spaces—such as commercial offices, call centres, and hotels—have privacy needs as well. The degree required typically depends on the type of activities the space hosts.

Why is it needed?

It is easy to understand the need for acoustic privacy—or even acoustic security—from a speaker's perspective, particularly in environments where medical information, financial planning, personal relationships, trade secrets, or matters of national security are being discussed. However, a lack of acoustic privacy can have impacts beyond divulging sensitive information to unintended parties. This fact becomes clear when perspective shifts from the person talking to the involuntary listener.

When a noise or voice enters an occupant's 'space,' some degree of annoyance is typical, but it can also make one feel as though one's privacy—or sense of physical separation—is being invaded. Perhaps the most relatable examples of this sensation are when the guest in a neighbouring hotel room turns up the television's volume or the patient at the other end of a waiting area starts speaking loudly into his or her cell phone.

If conversations can be inadvertently overheard, occupants can also become self-conscious about their own level of privacy. In some contexts, it can create a sense of unease, which in turn impacts the ability to freely communicate. For instance, if a patient can hear what is happening in the adjacent examination room at a medical clinic, he or she might be less inclined to disclose information to the nurse or doctor, out of fear of being overheard.

The degree of acoustic privacy afforded by the built environment can even impact an organization's brand image. People want to be in control of personal information when meeting with a financial or legal advisor, for example, and a positive acoustic experience can reinforce confidence in a firm. This level of protection is also indispensable for staff to effectively negotiate the terms of various agreements.

In some countries, the protection of verbal communication within particular types of facilities is actually mandated by law. The *Health Insurance Portability and Accountability Act* (*HIPAA*) introduced by the U.S. Department of Health and Human Services in 1996 is a good example. It requires healthcare entities to take "reasonable safeguards" to ensure there is speech privacy during both in-person and telephone conversations with patients and between employees.

Acoustic privacy is also vital to employees' overall satisfaction with their workplace. A worldwide, decade-

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Voices cause vibrations in windows, doors, pipes, and walls, which can be picked up by audio surveillance equipment and translated into intelligible speech. Sound masking can be applied to these structures in order to help protect privacy.

long survey of more than 65,000 people run by the Center for the Built Environment (CBE) at University of California, Berkeley, found lack of speech privacy is the top complaint in offices.[2] Participants expressed irritation at being able to overhear in-person and telephone communications, as well as concern for their own level of privacy.

What about the open plan?

The topic of workplace satisfaction also emphasizes the need to consider those occupying spaces other than closed rooms. Though some may dismiss the importance of acoustic privacy when designing an open plan, studies show it has a significant impact on productivity.

For instance, research conducted by Finland's Institute of Occupational Health shows unwilling listeners demonstrate a five to 10 per cent decline in performance when undertaking tasks such as reading, writing, and other forms of creative work. Simply hearing someone is speaking can disturb concentration, but this problem is greatly magnified when one can clearly understand what is being said because, if a conversation can be followed, it is much harder to ignore it.

Though an organization might not consider privacy a goal within an open plan, it is impossible to justify increasing disruptions. Taking the steps required to lower speech intelligibility within this type of space increases occupants' output and reduces error rates.

Assessing speech intelligibility

The subject of speech intelligibility cannot be discussed without getting into the concept of degrees because every word of a conversation does not need to be understood for privacy to be violated. Due to the redundancies and patterns in speech, building occupants can follow much of what is said even if only half of it is overheard—particularly if they have previously been part of a similar conversation. Further, private details can be exposed even when a small part of the discussion is overheard.

Further, it is difficult to subjectively assess degrees of speech intelligibility. For example, a listener would have a hard time indicating with any precision whether they can understand 40, 55, or 70 per cent of what someone else is saying.

Fortunately, there are ways to measure and quantify the degree of privacy afforded by the built environment. The Articulation Index (AI) remains the most widely used method. It was developed at Bell Labs in 1921 by Harvey Fletcher as he sought to quantify speech comprehension over telephone lines. During the 1950s, those that were involved in the speech privacy sciences adopted his invention as a measure of exactly the opposite: how much one could not understand.

To calculate AI, one uses a test signal including the frequencies known to specifically impact speech comprehension. This signal is measured at 1 m (3.2 ft) from the 'source' and again at the 'listener' location. The background sound level is also measured at the 'listener' location in order to quantify how loud the test signal is relative to it—a value known as the signal-to-noise ratio (SNR). This value is critical, because the lower the SNR, the less the intelligibility and the greater the speech privacy.

For AI, SNR is measured in each of 15 frequency ranges (from 200 to 5000 Hz). Each of these ranges is weighted according to the degree to which it contributes to speech comprehension. The final AI value ranges from 0 (where conversation is completely unintelligible) to 1 (where everything is heard and understood). The human voice varies from person to person, depending on factors such as sex and age.

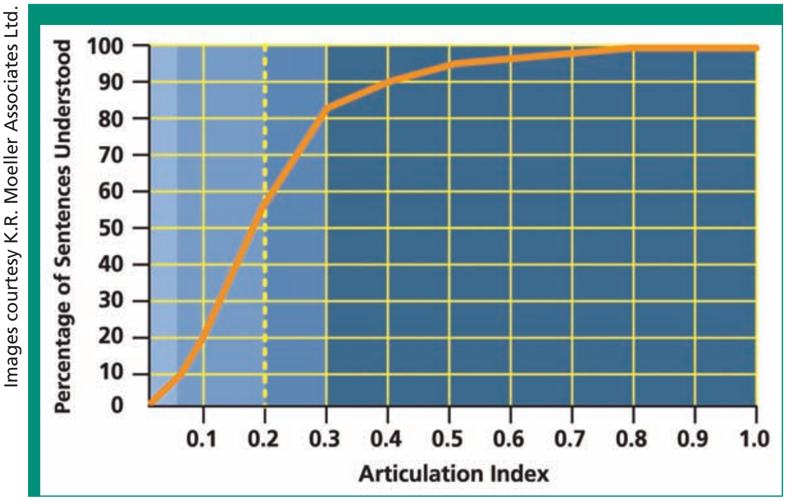
AI ratings are challenging to interpret in a meaningful way, so studies have been done to correlate them to subjective 'privacy' categories. However, the value of these groupings is somewhat diluted by the wide range of comprehension within each one:

- 'confidential' privacy ranges from 0 to 0.1;
- "normal' from 0.1 to 0.2; and
- "marginal' from 0.2 to 0.3.

If AI is above 0.3, there is effectively no privacy.

As shown in Figure 1, the relationship between AI and actual comprehension is not linear. On a 0 to 1.0 scale, many would expect a value of 0.5 to mean listeners would understand 50 per cent of a conversation, but—as is clear from the graph—they

Figure 1



The relationship between Articulation Index (AI) and intelligibility is not linear—for example, a value of 0.5 means a listener can understand approximately 95 per cent of a conversation, not 50 per cent. A very low AI value is, therefore, required for true privacy.

would actually understand approximately 95 per cent. The shaded areas along the left of the graph show the confidential, normal, and marginal privacy ranges, indicating just how low an AI is required for true privacy.

A more recent arrival on the acoustical scene is a metric called the Privacy Index (PI). PI is based on AI, in that it is calculated as 1.0 minus the AI value, multiplied by 100, and expressed as a percentage; in other words:

$$1 - AI \times 100 = PI\ (\%)$$

However, PI can be misleading. Part of the problem likely stems from its use of the word 'privacy,' which can cause users to come to the wrong conclusion about the rating's meaning. The fact it is expressed as a percentage creates even more potential for confusion. For example, with an AI of 0.3, there is a PI of 70 per cent.

Figure 1 demonstrates the reason to avoid this metric. When told the PI is 70 per cent, most would assume they would only understand 30 per cent of what is being said. In reality, nearly 85 per cent would be understood. Thus, building professionals should be cautious when investigating acoustical solutions and interpreting related PI statements.

How sound travels

To design the built environment for acoustic privacy, it is also important to understand the three ways sound (*e.g.* voice) travels to a listener.

Sound follows a direct path when it travels uninterrupted from the source to the listener or penetrates a barrier between them, such as a wall. This transmission path contributes the most to high levels of speech reaching the listener. In this context, high levels refer to more intelligible words at a relatively high volume. However, it can also travel on a reflected path. This type of transmission occurs when sound bounces off the various surfaces within the space, such as floors, ceilings, walls, and furnishings. Finally, it should be noted that sound can travel in a diffracted path—that is, it can bend around obstacles. This pathway is generally less significant than the first two.

Since speech travels in these various ways, it can be difficult to contain. Several methods must be employed because no single technique can sufficiently address all transmission pathways.

Designing for acoustic privacy

Of course, the louder a person speaks, the more likely he or she is to be heard. Building occupants should always try to be mindful of their voice level, but proper etiquette is only effective to a point. The remainder of the acoustical burden has to be borne by the design using a three-tiered approach called the 'ABC Rule,' which stands for absorb, block, and cover. Acoustic privacy is achieved by using a well-designed combination of these tactics. (The brief outline in this article touches on the interior fit-out and furnishings, not the shell of a building.)

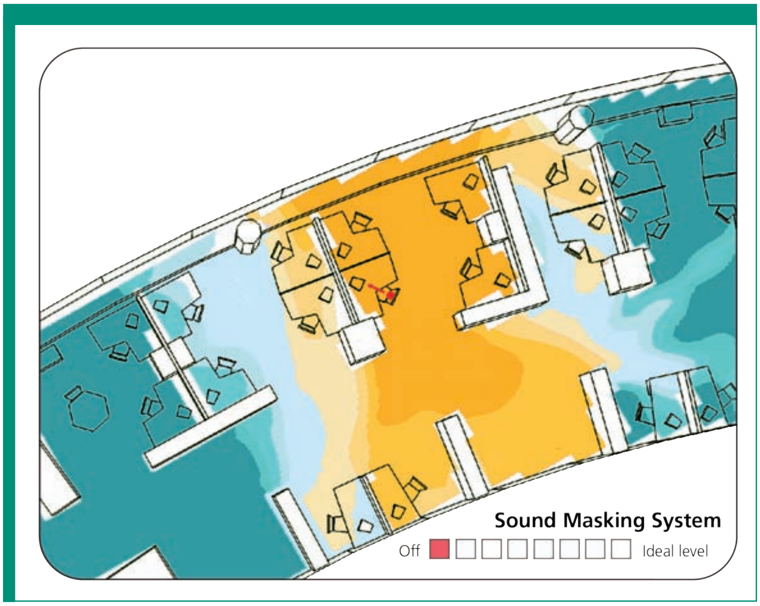
Absorb

The 'A' in 'ABC' stands for adding absorption. As speech sounds hit various surfaces within a facility, they are reflected back into the space. If those surfaces comprise hard materials such as concrete, glass, and metal, the reflected sound energy remains high and the overall volumes will rise.

A high percentage of hard surfaces also increases reverberation (*i.e.* echo) within the space, making it uncomfortable. Additionally, it can lower intelligibility due to the presence of more persistent sounds in the space, often referred to as the 'cafeteria effect.' However, it can also increase intelligibility—particularly in situations where there are not a lot of competing voices—because voice travels a longer distance and, hence, conversations can be heard from further away.

To control this type of transmission, absorptive materials must be applied to the ceiling, walls, and workstation partitions. As the ceiling is usually the largest unimpeded surface within a facility, organizations should invest in the best acoustic tiles or panels they can afford and ensure consistent coverage throughout their space.

Figure 2



As depicted above, the area of intelligibility around a speaker is not circular. Its shape is determined by numerous factors, including the orientation of the person speaking, as well as the physical barriers and absorptive/reflective materials that are used within the space.

Figure 3

When sound masking is applied, the area of intelligibility shrinks.

Block

The 'B' stands for blocking speech transmission using walls, windows, doors, and other physical structures. This method is most obviously used in the construction of enclosed rooms, but it is also extremely useful within the open plan. If there are no barriers between occupants in these spaces, speech travels more easily and the ability to see (and be seen) further reduces privacy due to the natural capacity for lip-reading. Again, though some might argue privacy is not expected within an open plan, understandable speech disrupts occupants' concentration. For this reason, workstation partitions should be no lower than seated head height—that is, 1524 to 1651 mm (60 to 65 in.). Even the direction in which people face will often have an effect on their voices' volume within the neighbouring workspace. Therefore, occupants should be seated facing away from each other on either side of partitions.

Today, there are numerous pressures to reduce the height of workstations or eliminate them altogether. This trend has had a dramatic impact on the acoustical performance of open plans because though other treatments can reduce overall volume levels and deal with noises generated from farther away, they have no effect over very short distances. When barriers are eliminated, local noise sources remain highly intelligible and disruptive.

Cover

'C' stands for covering, which can involve installing a sound masking system. This technology consists of a series of electronic components and loudspeakers typically installed above the suspended ceiling, which distribute a comfortable background sound throughout the facility. Though most people compare the output of a well-designed and professionally tuned masking system to that of softly blowing air, it has been specifically engineered to cover the range of frequencies in human speech. This sound also covers up incidental noises arising from general workplace activities or minimizes their disruptive impact on occupants by reducing the change between baseline and peak volume levels within the space.

The impact of background sound levels

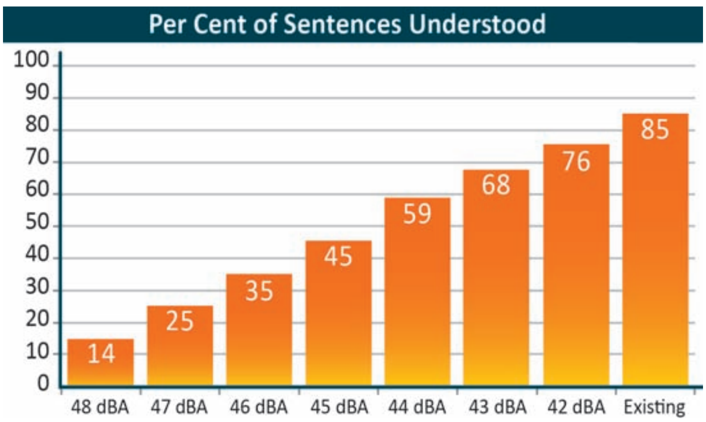
Most people are familiar with using walls, doors, workstations, and a well-planned layout to physically block voices and noises, as well as the benefits of installing ceiling tiles, wall panels, and soft flooring to absorb them. Fewer understand the role sound masking plays in achieving acoustic privacy.

As shown in Figure 2 (page 24) the area of intelligibility around an individual is not a simple circle. Rather it is a complex shape determined by numerous factors including the speaker's orientation, physical barriers, and absorption/

Figure 4

Articulation Index tests were conducted between these two workstations to determine how much of an impact sound masking has on speech intelligibility, even within an otherwise acoustically well-designed space.

Figure 5



The results of the AI tests show despite using absorption and blocking strategies, speech comprehension remains nearly 85 per cent until sound masking is applied. Comprehension drops by an average of 10 per cent for each decibel of increase in the masking volume.

reflection of the voice by the various interior finishings, furniture, and other items within the space.

In any space, voices and noises diminish in volume over distance. However, background sound levels are often so low in indoor environments speech carries intelligibly over 9 to 15 m (30 to 50 ft) or more in open space. By increasing the background sound level, sound masking reduces the signal-to-noise ratio. As shown in Figure 3 (page 24), any voices will disappear below the new level after a much shorter distance.

The exact length is, of course, a function of the space's entire acoustic design. However, as illustrated by the AI measurements conducted between the two workstations shown in Figure 4, sound masking plays an integral role.

This open-plan area's acoustical design was suitably planned. The partitions are 1650 mm (65 in.) tall and perform well in terms of both absorption and isolation. The ceiling tiles are highly absorptive (*i.e.* 0.95 NRC). The lighting system is indirect so as to not reflect too much voice/noise back down into neighbouring work areas. A sound masking system is installed above the suspended ceiling.

Figure 5 shows the results of the AI tests conducted between the two workstations. Despite the high-performance acoustical design elements, speech comprehension is nearly 85 per cent when the sound masking system is off, because the existing background sound level is only 40.6 dBA. When the system is turned on, comprehension quickly declines. In fact, for each decibel of increase in masking volume, comprehension drops by an average of 10 per cent.

When adding sound masking, it is important to ensure the system is both designed and tuned so as to provide consistent coverage throughout the space. Outdated specifications might allow for a wide tolerance (*e.g.* up to 4 dBA), but as indicated by Figure 6 (page 28), such variations in masking levels permit a swing of 40 per cent or more in performance. Modern, well-tuned sound masking systems are able to keep variations to just 1 dBA or less, providing dependable coverage throughout the installation.

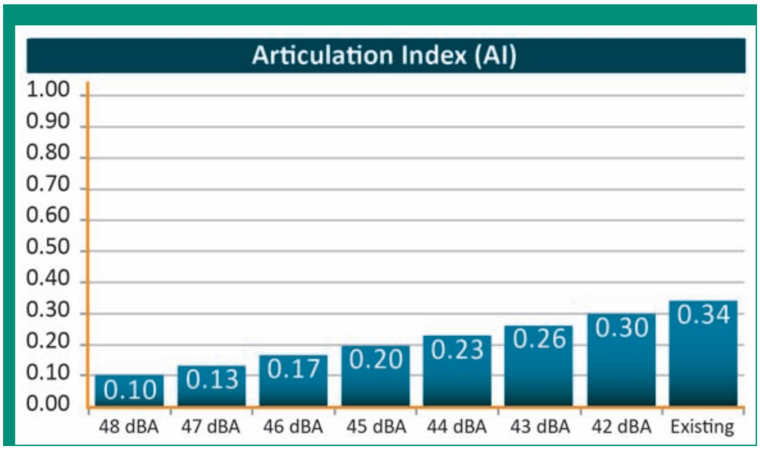
The masking sound must be tuned to meet a sound masking spectrum or curve, which is specified by an acoustician or provided by an independent party such as the National Research Council of Canada (NRC). The specified tolerance indicates by how much the sound is allowed to deviate from that curve. The introduction of decentralized-networked technologies over the last decade has made it possible to keep variations to just ±0.5 dBA, providing a much higher level of consistency in the masking sound across a facility.

Considerations for closed rooms

Maintaining an adequate background sound level is also important in closed rooms. Generally speaking, an occupant's expectation of privacy is higher in this type of space than within an open plan; however, doors and even deck-to-deck walls are often not enough to provide it.

Walls, windows, doors, ceiling tiles, and flooring reduce the volume of voice coming through the room's physical structure,

Figure 6



*AI tests also reveal the importance of properly tuning the sound masking in order to prevent large (*i.e. *greater than 1 dBA) variations in coverage.*

but even minor penetrations can seriously compromise its acoustic performance by allowing sounds to transmit into adjoining spaces. If the background sound level in those spaces is lower than the speech passing through the wall, it will still be possible to hear and understand a conversation. In other words, the degree of speech privacy experienced in closed rooms is still largely determined by the signal-to-noise ratio. While masking levels should be set to achieve between 45 and 48 dBA within an open plan, closed rooms should typically be lower at 40 to 45 dBA.

The doorway is a major challenge for a closed space. Even when closed, the door usually presents the weakest link, but when it is open, it does not matter how well the walls have been constructed, the level of sound isolation dramatically drops. For example, the effective rating of a 50 STC wall drops to 7 when the door to a typical 3-m (10-ft) wide office is opened. Most organizations do not want the doors to private offices to be closed at all times. Sound masking, absorptive materials, and layout (*e.g.* staggering doorways along a corridor) should be used in order to continue to provide some degree of acoustic privacy when they are open.

Speech security

Of course, eavesdropping can also be intentional, and handled in a much more sophisticated manner than leaning one's ear against a glass and putting it up to the wall.

Though this article focuses on acoustic privacy rather than acoustic security—such as what may be required by military facilities, corporate boardrooms, or laboratories—it is important to know without the proper treatment windows, doors, ducts, pipes, floors, ceilings, and walls present opportunities for electronic forms of eavesdropping. Speech causes vibrations on these structures, which can be picked up by probes or microphones and translated into intelligible speech. Further, these types of listening devices are difficult to detect because they can be used at a considerable distance from the target facility.

If an organization suspects it might be subject to such a threat, a sound masking system can be connected to transducers, which transfer the masking sound to the aforementioned physical structures, impeding the use of audio surveillance equipment. In this case, it is key to ensure the system produces a truly random masking sound (*i.e.* rather than on a loop) so it cannot be filtered out of recordings.

Conclusion

Attention must be paid to the topic of acoustic privacy within the built environment. Though this conclusion is obvious to organizations consistently dealing with sensitive information, the methods they use to achieve it are the same as those needed to accomplish other valuable acoustic goals—the only difference is how one sees the benefit: that is, from the perspective of the person talking or that of the group listening.

Building occupants working in an acoustically comfortable environment have an easier time concentrating on their tasks, and also suffer less stress and fatigue. An organization may decide it is more motivated by the need for a high-performance workplace than acoustic privacy, but taking the steps required to lower speech intelligibility allows them to reap both rewards.

Notes

[1] For more information, see the study "Methods and Applications of the Audibility Index in Hearing Aid Selection and Fitting" by Amyn M. Amlani, MS, Jerry L. Punch, PhD, and Teresa Y. C. Ching, PhD. Visit www.ncbi.nlm.nih.gov/pmc/articles/PMC4168961.

[2] For more info, visit www.cbe.berkeley.edu/research/briefs-survey.htm.

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