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Acoustics And Well-Being

Norman Varney

In this last series of articles about acoustics, we have covered "Prioritizing Audio for Optimized Performance," where we learned about how you must have the basic elements in place before varying degrees of fine-tuning can be effective. We then looked into "Understanding Noise and Vibration" and correlated laboratory measurements to perception, and revealed a game plan for mitigating airborne and structure-borne noise. And we discovered how acoustics can control and trigger emotional responses in the last article, "Acoustics vs. Emotion." With the basic understanding of what the acoustical hierarchy is, how to control sound energy, and how it impacts us emotionally, let's talk about acoustic well-being.

Everyone I know wants to be happy. To me, being generally happy is about attitude, and attitude is a choice we have control over. We can decide whether to be grateful and appreciative for what we have and be happy, or to become ungrateful and be miserable. Sure, we all have our ups and downs, but when I'm down I think of those who have much less to be thankful for and yet are genuinely happy. It doesn't matter where we are on the circumstantial ladder at any given time, a positive attitude will always bring us up. This is well known in the medical fields. Those with "the will to live" have a better chance of recovery. It is their emotional hope and desire that causes chemical changes that cause the body to heal.

Being happy certainly means being physically comfortable, and by that I mean lack of physical pain and having a clear mind. It turns out that the acoustics around us can have a positive or negative impact on our physiological and psychological well-being and that there are various areas of study we can look at to learn this. It's not only about preventing hearing loss, cardiovascular effects, stress, and annoyance but also about improving cognitive development, creativity, productivity, and general health. In simple terms, uncontrolled acoustics is bad for our well-being and controlled acoustics is good.

Education/Communication

It is well understood that acoustics controls our cognitive efficiency. Decades of research in education systems throughout the world have detailed learning cause and effects due to acoustics. The results rely on two main factors: noise and reverberation. Both affect how well speech is understood, and noise can interfere with concentration. There are several characteristics that play a factor in causing errors in communication. These causes vary from masking syllables ensuing misunderstandings, to distraction and annoyance causing lack of mental focus. These interferences can include the following:

1. Noise intrusion—noise coming from outside the building: air traffic, street traffic, weather, etc.
2. Background noise—noise in the building: HVAC, equipment noise, etc.
3. People noise—footfalls, talking, moving things around, etc.

The above establishes the noise floor and the causes for distractions and/or annoyances. In addition to these, we may have a reverberant room that amplifies and exacerbates these noises. Other than maybe cave dwellers, this has not been a problem for mankind until recently. In hard-surfaced buildings, excess reverberation times can also reduce speech intelligibility because the sound continues to reflect around the room while the next word is being spoken. In such rooms, distinguishing between words like bad, bath, bat, bag, and ban can be difficult and confounding, leading to incorrect interpretations and conclusions (see Figure 1). The loudspeaker's (or recording of) articulation, and the signal to noise (distance and amplitude) also play important roles in understanding what is being said, along with several other variables.

Much of the research relating to the issue of noise in education has been produced by studies focused on relating noise levels to particular outcomes. These findings show that noisy conditions have direct negative effects on learning, particularly language and reading development, as well as causing indirect problems to learners by distracting and/or annoying them. Laboratory-based cognitive psychology experiments have shown that noise affects performance in problem solving and memory tasks, an effect which is at least partly explained by noise interfering with language processing. This suggests that it might be problematic to live in a generally noisy place, and real world research into the effects of chronic noise, experienced by people living near airports or busy roads, confirms this. There are community environmental laws in place to limit allowable noise levels by time of day and location. A smart

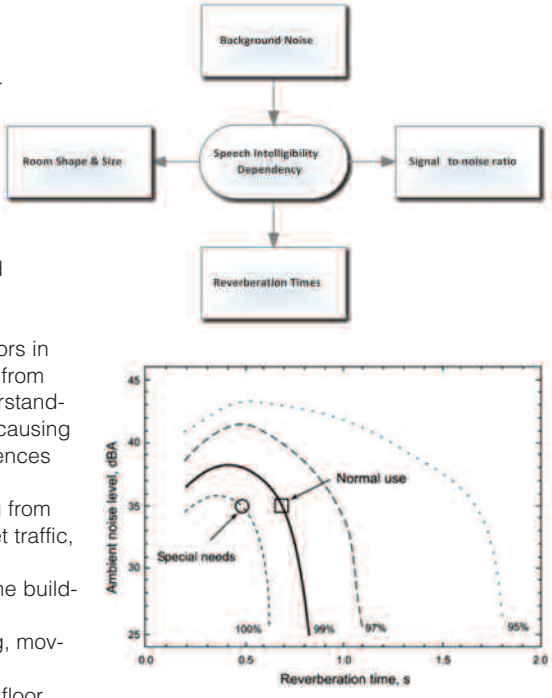

Figure 1: Equal speech recognition score plots relative to the noise floor/reverberation environment. Higher noise floors and longer reverberation times mean poorer intelligibility. Special needs can mean for hearing impaired or for recording, teleconferencing, etc. Note: Reverberation times are for the speech frequencies 500 Hz to 2 kHz only.

phone, a free dBA meter app, and a call to your City Council for the policy, may let you know if your zone is not in compliance. While you're at it, show the restaurant manager how loud and annoying the dining din is. It surprises me how many managers think this is good for business—maybe for a bar scene, but it's certainly not conducive for clients conducting business or romance. They will go elsewhere. I think restaurant owners don't realize how much business they are losing or how quickly acoustic treatment would pay for itself.

Stress/Healing

Noise can cause stress. I think most everyone has experienced it. Stress controls oxytocin levels, blood circulation, serum cortisol, and lactic acid in the muscles, etc. At the recent "Care for Sound" symposium in Sweden, Per Thorgaard, Chief Physician of Aalborg University Hospital in Denmark, said "If the acoustics are bad, even the right sounds would be bad." His lecture focused on the ethical need in modern medicine for comfortable sound environments, especially for critical illness patients. Studies indicate that the "right" sounds, meaning healing sounds, are whispering wind, murmuring water, singing birds, and for many, including myself, music. These sounds can bring about comfort, calmness and even uplift us when we are down. However, even these sounds can become annoying noise in places that contain many loud and reverberant sounds.

A study by researchers at Johns Hopkins University reveals that hospital sound-pressure noise levels around the world have increased steadily over the past 50 years, from 57 decibels to 72, with nighttime levels escalating from 42 dB to 60. In fact, it is among the top complaints of both patients and hospital staff members. Errors in communication occur due to the high reverberation times of the O.R. In addition, sudden noise distractions can startle surgeons while operating. Communication failures have been identified as the root cause of the majority of both medical malpractice claims and major patient safety violations, including errors resulting in patient death.

The ambient noise floor is the level of continuous sound that characterizes an area at any given time. Other sounds, to be perceived, must rise above this floor. If a sound rises 30 dB above the noise floor, it can cause a startle response. However, if the ambient sound level is too quiet, conversations can be overheard and unavoidable sounds can become distractions (think of a dripping faucet driving you crazy). When the noise floor becomes too loud, stress and errors increase. Therefore, when health care goals are set, both the optimum continuous volume level and the maximum level for incidental sounds must be taken into account. The World Health Organization (WHO) recommends that for good sleep, background sound levels should not exceed 30 dBA, with individual peak sounds no greater than 40 dBA. Intermittent noise can be more disruptive to patients' sleep than continuous noise. Though these levels may be idealistic for a residence, it seems a bit unrealistic for a hospital. In any case, we're far from that goal.

"Virtually no hospital meets [WHO] guidelines or recommended standards for either continuous noise levels or peaks, whether at daytime or nighttime conditions," says Dr. Roger S. Ulrich, Professor of Architecture and Director of the Center for Health Systems and Design at Texas A&M University, College Station. "A portable X-ray machine typically measures in at 90 dB," says Ulrich. Many alarms are in the range of 85 to 90 dB. Paging systems range from 75 to 80 dB. A team studying noise levels at the Mayo Clinic-affiliated Saint Mary's Hospital in Rochester, Minn., measured a nighttime peak of 113 dB during a shift change in a large surgical care unit.

Ideally, patients rest and recover from illnesses or medical treatments in places that are quiet and peaceful. Unfortunately, in the typical hospital the sounds of pages, alarms, machines, footfalls, HVAC, and conversations dominate the noise floor.

In its efforts to provide empirical standards and at the same time address the ambiguity of this issue, the EPA defines noise as "any sound that may produce an undesired physiological or psychological effect in an individual or group." This definition accompanies a decibel scale. Therefore, there are two tests to determine whether and to what degree noise is an issue. Based on the fact that noise is evaluated by patient satisfaction measures, the EPA verbal definition supersedes the decibel level standards, as amplitude alone does not necessarily indicate noise.

The noise of equipment, plus the noise of the hustle and bustle of a busy hospital has a serious impact on patients and staff alike. To name only a few common problems that patients in poorly acoustically designed healthcare facilities experience, are:

- Elevated blood-pressure levels
- Sleep disruption
- Decreased oxygen saturation
- Heartburn
- Require more pain medication
- Longer recovery duration
- Higher incidences of re-hospitalization
- Neonatal intensive care patients have increased heart and respiration rates

This is supposed to be a healing environment. It should be acoustically designed to be so. Noisy hospitals are contradictory to well-being environments.

There is a considerable body of research documenting the effects of noise on patient outcomes. For example, exposure to sudden noises, such as a dropped tray or slammed door, may cause a "startle reflex" in people, resulting in physiological reactions (in less than 1/100 of a second) such as muscular flexion, increased blood pressure, higher respiratory rate, increased heart rate, and vasoconstriction, which has been proven to have a negative influence on patient recovery times. It is interesting to note that you can startle from touch, balance, and sound but not by vision, taste, or smell. People exposed to continuous extraneous noise can also experience altered memory, increased agitation, less tolerance for pain, and feelings of isolation. These environmentally generated symptoms are often medicated or otherwise treated in ways unrelated to their cause.

Chronically high levels of sound, on the other hand, tend to increase blood pressure levels; a new study by University of Michigan researchers found a direct correlation between overall decibel levels and blood-pressure levels.

Higher blood pressure leads to a higher risk of cardiac problems, and a team of European researchers, in a study of 4,115 patients in 32 Berlin hospitals, found that chronic noise increased the risk of heart attacks by 50 percent for men and 75 percent for women. In a hospital environment, where people are already ill and psychologically stressed, unnecessary noise can be very harmful.

When a person's acuity is high, their adaptive capacity is low, resulting in a greater sensitivity to these kinds of environmental stressors, often resulting in medication. Research shows that a noisy environment causes emotional exhaustion.

Miscommunication is a frequent and serious problem among staff in the ER, during surgery, between staff and their patients and/or loved ones. Interfering and distracting sounds have been shown to contribute to medical and nursing errors. JCAHO mentions noise as a potential risk factor related to medical and nursing errors, stating that the ambient sound environments should not exceed the level that would prohibit clinicians from clearly understanding each other. As indicated, this needed goal is far from the typical hospital environments of today.

Creativity/Productivity Loss

It is not hard for anyone to relate to the frustration that noise causes when we are trying to concentrate on our jobs. Trying to work with noise means increased errors and slower productivity. Even when noise may not necessarily affect the performance of the staff, research shows that workers in a noisy environment will have to concentrate harder and exert more effort to be able to perform their function properly, which leads to them being more fatigued.

Once interrupted, it can take 23 minutes for a typical worker to return to the original task, says Gloria Mark, a professor of informatics at the University of California, Irvine. If that's true, we have a serious problem, considering how often we get interrupted. I think it takes me only 1 or 2 minutes to get back in the zone. Still, once interrupted, I may never regain what was going through my head at the time. Interruptions, of any kind, are a form of pollution, much of which we have control over. We might turn off our cell phone, close the office door, or wear noise-cancelling headphones when we need to concentrate hard on a task.

Well-Being Spaces

There are places we go and things we do to clear our heads, ponder about problems, and organize our thoughts. The best way to do this is in a quiet place of solitude. This is where we have the least distractions and can focus optimally. Our brain isn't fighting or anticipating bombardment. Periods of serenity help us to cope with conflicts and then we feel reinvigorated, accomplished, and confident. Many of the homes today are full of hard reflective surfaces, which are very uncomfortable. The noise never really settles down. This aggravates the brain and the body. I imagine a lot of the people who live in such homes don't realize how much more relaxing it could be for them if they introduced some absorption into the space.

We have established that a low noise floor is a good thing for our well-being. We have also acknowledged that long reverberation times are our foe. However, there are times when long reverberation times can be our friend. A good example is listening to choral or organ music in a big cathedral. This can be both calming and exhilarating. The right type of music performed in the right venue (appropriate reverberation times for the music) will support themselves and envelope the listener. Halls that offer reverberant sounds that reach the listener after 80 msec from all directions is enveloping. In some halls it washes over you from front to back. The longer the reverberation, the slower the music needs to be. Less percussion, less staccato. The hall and the music enhance each other and fuse to become one. Every venue is unique in how it transfers music to the listener. The size, shape, and construction relate to what we hear. Qualities such as timbre, dynamics range, clarity, and even pitch are heavily influenced by the space. These qualities translate into how we perceive spaciousness, loudness, intimacy, envelopment, etc.

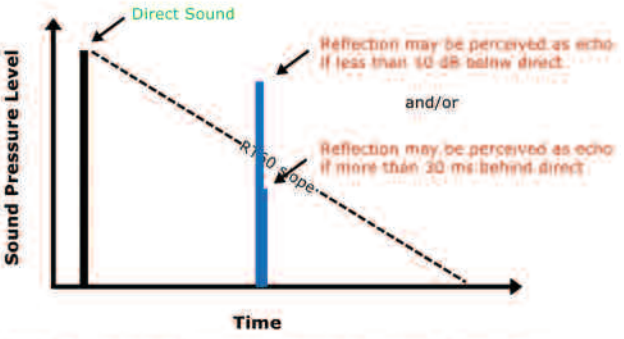

Fig 2. Depicts first order reflection targets to mitigate audible echos. Note: Timber and spatial distortions may occur at lower thresholds.

For centuries large, reverberant cathedrals have been acoustically designed to support chants, choir, and organ music to uplift the soul, while at the same time necessitate reverence when holding conversations.

Reverberant sound effects can be reproduced accurately in a controlled home-playback environment. However, when we don't control the acoustics, the sound is chaotic and not as planned by the artist. We hear some of the intended reverberation cues along with our room's own reverberation, and much information is lost. This distortion means we are never completely convinced by the illusion.

When the acoustics are under control, you can be transported to wherever you want to go. This is truly a remarkable experience! This has much more emotional impact than going from SD to HD, and how many of you could go back to SD?

How great is it for your well-being to be able to recuperate from a tough day at work by laying it aside with the immersive experience of a live concert DVD, action movie, or comedy relief? Studies are not in yet, but I suspect that potentially many lives will be saved and lengthened. Want a short vacation across the globe, to listen to Schubert in Vienna, walk in outer space, race a Formula One car, dive to the greatest depths of the sea, or climb Mount Everest? Good acoustics will take you there.

Thanks to technology and neurobiological research, we understand how much slower the cognitive brain is than the emotional brain. We appreciate how and why the perception of sound causes so much brain activity. We also recognize some general guidelines towards controlling and balancing our well-being acoustically:

- Good sleep—30 dBA or less continuous noise floor, with no more than 45 dBA limited peak events
- Waking hours—not more than 65 to 70 dBA continuous, and observe OSHA guidelines to prevent hearing loss
- Schedule quiet times, listen to music, listen to birds singing (but not crows or magpies), the gentle breeze, a babbling brook, either for real or recorded
- Create an acoustic playback environment that permits complete engagement and use it as a health aid:
  - o Target the ambient noise floor for around RC 20N
  - o Properly set up and calibrate the playback system
  - o Absorb or diffuse loudspeaker 1st reflection points so they are more than 10 dB below, and less than 30 milliseconds. behind the direct signal (see Figure 2)
  - o Shoot for room-reverberation times that are linear and between 0.25 to 0.40 seconds. Allow slightly longer delays below about 125 Hz.

Hearing is likely the most important of our senses. Our auditory system is many thousand times faster than the others and is used 100 percent of the time. It has the strongest ties to our emotions and reactions. Wherever there is matter, energy, and a receiver, there is sound. It is in our best interest to take a little more control of it. **WSR**

Norman Varney is the Acoustical Product Development Manager for Kinetics Noise Control in Dublin, Ohio. Having been in the noise control and sound quality industries for decades, he has earned many awards for acoustical products, room designs, etc. while working for A/V RoomService, Owens Corning Science & Technology Center, and MIT. Mr. Varney has written many articles on acoustics for numerous publications over the years, as well as participated in seminars and panel discussions. He is an active member of ASTM (Committee E-33 on Environmental Acoustics), Acoustic Society of America, Institute of Noise Control Engineering, AES, NAMM, CEDIA, etc.