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Wind Turbine Syndrome for Non-Clinicians

Abstract

I interviewed 10 families living near large (1.5 to 3 MW) wind turbines, all of which were built since 2004. This gave me 38 people, from infants to age 75. Their symptoms formed a cluster (see Glossary for clinical terms):



- 1) sleep disturbance
- 2) headache
- 3) tinnitus (pronounced “tin’-ah-tus”: ringing or buzzing in the ears)
- 4) ear pressure
- 5) dizziness (a general term that includes vertigo, lightheadedness, sensation of almost fainting, etc.)
- 6) vertigo (clinically, vertigo refers to the sensation of spinning, or the room moving)
- 7) nausea
- 8) visual blurring
- 9) tachycardia (rapid heart rate)
- 10) irritability
- 11) problems with concentration and memory
- 12) panic episodes associated with sensations of internal pulsation or quivering, which arise while awake or asleep

The families not only lived near turbines and developed new symptoms; they moved away from the turbines (because they were so troubled, often abandoning their homes) and the symptoms, significantly, went away.

Hence, the definitive result of my report is that wind turbines cause the symptoms of Wind Turbine Syndrome (WTS).

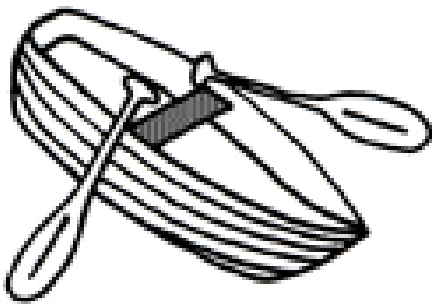
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Let's clarify something immediately. Not everyone living near turbines gets these symptoms. As a solo, unfunded researcher I could not get the samples needed to figure out what percentages of people at what distances get the symptoms. This needs to be done next. But I could (and did) look at the question of why some people are susceptible and others not, plus who is susceptible, and I used these patterns to explore the pathophysiology of Wind Turbine Syndrome: what's going on inside people to cause these specific symptoms.

I would like readers to be able to look at this study—including the detailed accounts I provide of people's experiences around turbines and their health backgrounds—and be able to make their own decisions about whether they should be exposed to these machines.

That said, I was able to prove mathematically that people with pre-existing migraines, motion sensitivity (such as car-sickness or seasickness), or inner ear damage are especially vulnerable to these symptoms. Equally as interesting, I was able to demonstrate that people with anxiety or other preexisting mental health problems are not especially susceptible to these symptoms.

This contradicts wind industry literature, which argues that people who worry about or otherwise dislike turbines ringing their homes are the ones getting ill. I show this to be complete nonsense.



Here is what's going on, as I put together the evidence. *Low frequency noise tricks the body's balance system into thinking it's moving.* Like seasickness.

(It's vital to understand that the human balance system is a complex brain system receiving nerve signals from the inner ear, eyes, muscles and joints, and inside the chest and abdomen. Because the eyes are involved, visual disturbance from the blades' shadow flicker adds to the balance disturbance.)

Let me repeat this, because its significance is huge. *Low frequency noise from turbines appears to deceive the body into thinking it's moving.* So what, you say? Not so fast! Research within the last 10 years has demonstrated conclusively that *the way our bodies register balance and motion directly affects an astonishing array of brain functions.*

How? By direct neurologic linkages connecting the organs of balance to various, seemingly unrelated brain functions.

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I'll rephrase this, since it's critical to the argument of this report. *The way our bodies perceive balance and motion in turn influences a host of brain functions which at first glance might appear to be entirely unrelated to balance and motion.* As I said, this is what the latest "balance" research tells us—more accurately, balance research combined with psychiatric, neurologic and cognitive research.

Incidentally, the people specializing in this kind of research are called *neuro-otologists*—from *neuro* for brain, and *oto* for ear.

And what are these seemingly unrelated brain functions affected by our perception of balance and motion?

- a) *Alerting and awakening*
- b) *Memory*
- c) *Spatial processing.* Spatial processing is defined as the ability to 1) picture things, 2) remember where things are, 3) remember how to get somewhere, 4) understand how things work, 5) figure out how to put something together or fix it, 6) figure out the most efficient order and timing of something (such as work around the kitchen, farm, fishing boat, property, or a series of errands), 7) remember what you're looking for when you get someplace (such as errands in town), 8) understand math concepts, 9) along with a host of other critical thinking functions.
- d) *The physiologic manifestations of fear.* This means increased heart rate and blood pressure, sweating, nausea, and hyper-alertness.
- e) *Aversive learning.* This is when something bad happens and as a result of the experience you now know to avoid the situation in future. The classic illustration in both animals and people comes from vomiting after you eat something. You avoid that food afterwards for a long time. (Remember that experience as a child?) Aversive learning is so imprinted on mammals (we are mammals) that even the environment associated with this experience can trigger the feelings of nausea—to continue the nausea illustration. Merely smelling that particular food, or being in the same restaurant, or just thinking about that particular food, or seeing the food—makes you queasy. Aversive learning is potent and, clearly, an evolutionarily old reflex in mammals.

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Okay. *Alerting and awakening, memory, spatial processing, the physiological manifestations of fear, and aversive learning.* All five brain functions are profoundly affected by our sense of balance and motion. All five get messed up when our sense of balance and motion is thrown off.

Back to wind turbines. Open any online newspaper article discussing Wind Turbine Syndrome and you almost invariably discover that someone has posted a comment ridiculing the whole idea for the obvious reason that there's no conceivable way such a disparate range of health problems—memory deficits, spatial processing deficits, anxiety and fear and panic, and aversive learning—could possibly be triggered by a wind turbine, of all things. Clearly, continues our brilliant curbside commentator, people who live near turbines and report these symptoms are making them up (probably because they don't like the darn things), and just as clearly the doctor who takes these seriously (that would be me) is a fake.

To which I respond: Clearly the authors of these brilliant gems of logic (forgive my cynicism) are neither neurobiologists nor clinicians—nor are they experiencing the symptoms which are clearly, unambiguously reported by many people living in the shadow (as it were) of industrial wind turbines.

Back to real medicine. Wind Turbine Syndrome symptoms, outlined above, occur together *because humans are hardwired to exhibit these precise symptoms when their balance and motion sensors are dis-regulated*—as happens to many people living near wind turbines.

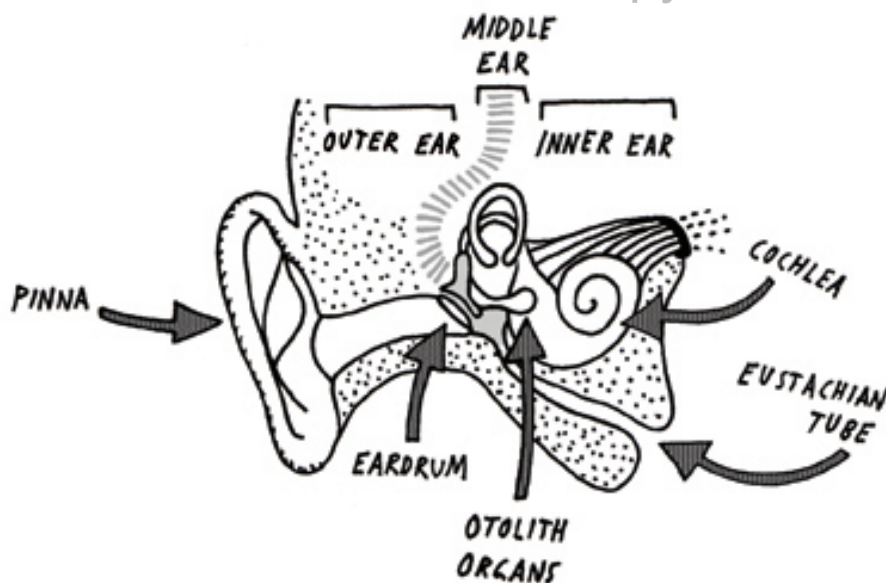
It's important to emphasize these symptoms are not psychological (as if people are fabricating them); they are neurological. People have no control whatsoever over their response to the turbines. It happens automatically. One can't turn on and turn off these symptoms.

We can be emphatic about this because *balance signals* (called *vestibular signals*) *are the one kind of sensory signal we simply cannot tune out.* You can tune out (ignore) what you see and hear—but not what comes in from your sense of balance. Call it a law of nature, if you like.

And what provides our sense of balance? Balance comes from a combination of signals. I'll rephrase this: balance comes from *clusters of signals from different body organs.* One source being, of course, the inner ear.

Stop. We need to review the anatomy of the inner ear, since it's essential to understanding Wind Turbine Syndrome.

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Start with the weird flap of skin on the side of your head, necessary for holding up your glasses and, naturally, earrings. This is not the outer ear; it's the pinna. (Boxers get cabbage pinna.) The outer ear is where you put Q-Tips, and where your two-year old stores beads and other treasures, where earwax lives, and where water gets lodged when you shower—and you have to shake it out. The outer ear is a blind pouch ending at the eardrum, sealing off the pouch at the inner end.

Then comes the middle ear: the place between the eardrum and what's called the oval window. This is the part of the ear that gets infected in little kids. (Moms, remember all those times you took Johnny to the doctor and she said, "Yup, Johnny has an ear infection." This is after Johnny woke up screaming in the night, after having a cold for three days.) The middle ear is open to the air, through the Eustachian (pronounced "U-station") tube from the back of the throat (up behind the nose). And the middle ear houses those wonderful three little bones, incus ("ink-us"), malleus ("mal-ee-us"), and stapes ("stay-peas"), that are linked in a chain. Incus, malleus, and stapes transmit the energy of the vibrating eardrum to the inner ear.

This brings us to our destination in this mini-lesson: the inner ear. The inner ear consists of the semicircular canals (which you remember from high school biology) and the so-called otolith organs (which you probably don't remember from high school biology). The otolith organs are one of the keys to understanding Wind Turbine Syndrome. They consist of two little membranous sacs which are attached to the cochlea ("coke-leah") (the spiral-shaped, membranous organ that transduces the mechanical energy of sound into neural signals) and to the semicircular canals (membranous organs

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which make a semi-circle in each of the three planes of movement—vertical forward, vertical sideways, and horizontal—and transduce angular acceleration: if you nod or turn your head, they detect it).

Bear with me a moment longer; we're almost there. Embedded in the two otolith organs are—believe it or not—rocks. (Remember when your teacher accused you having rocks in your head?) Well, not really rocks; they're tiny. In fact they're microscopic stones made of calcium carbonate (yes, chalk, or clam shells). The weight of these stones allows us to detect gravity and linear acceleration, by sending signals to the brain via minute neural (nerve) hair cells.

In people predisposed to Wind Turbine Syndrome the otolith organs (utricle and saccule) are (I propose) being rocked abnormally, thus sending aberrant motion signals to the brain. Either this, or their inner ear organs in general—which are all interconnected as a “membranous labyrinth”—may be hyper-sensitive to pressure changes, such as those produced by turbines.

We're in the presence, here, of a truly ancient anatomical structure. Many millions of years old. Biologists call it the macule (“mack-ewell”), which just means the “spot.” The macule is critical in fish and us, and everything in between.

The macule: the membranous structure with hair cells embedded in the membrane and the otoliths fixed on top in a protein matrix. Mother Nature loved the macule so much that she conserved it through eons of evolution. Fish use these organs to figure out, instantaneously, which way is up, just like us. Fish use the macule for detecting pressure shifts in the water, such as the waves made by nearby predators or prey, or the low frequency noise traveling over long distances from waves breaking on shorelines, thus helping them navigate during migration.

Otoliths. The macule. Very ancient. Ancient and fundamental organs of balance and motion that appear to be thrown out of whack by wind turbines, with consequences I have called Wind Turbine Syndrome.

Back, now, to what provides us with our sense of balance. I said balance comes from a combination of signals, and I just explained how some of them originate in the inner ear. Besides the inner ear, the eyes also send motion and position signals to the brain. So, too, do muscles and joints all over the body, involving what are called “stretch” receptors, telling us where we are in space.

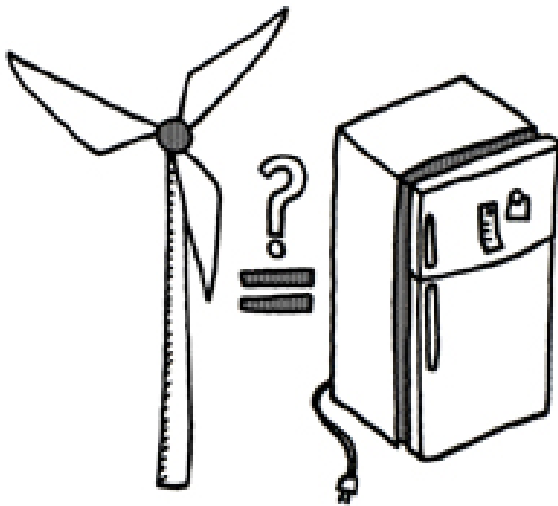
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And lastly, we maintain our balance by newly discovered stretch and pressure receptors in the chest and abdomen. These tiny receptors rely on various organs, including blood vessels and blood itself, as weights to detect the body's orientation to gravity and other forms of acceleration.

All this is the proper context for studying people's health complaints from wind turbines. Health complaints that are routinely dismissed by the wind industry as nonsense. (Not unlike the tobacco industry dismissing health issues from smoking.) The wind industry, however, is not made up of clinicians, nor is it made up of people suffering from wind turbines.

In time, I hope, researchers will be able to measure and correlate wind turbine noise (audible and sub-audible) and vibration with the symptoms people experience in real time—that is, while they're actually experiencing the symptoms. Until that happens, I offer this report as a pilot study.

Introduction and Background



Developers say turbines are quiet. No louder than a household refrigerator. With this (false) claim, they easily convince local governments it's okay to erect turbines mere hundreds of feet from people's homes. Nearly in their backyards, in many instances.

Wind turbine setbacks, in other words, are wind-industry-driven. Virtually no government regulation.

This is where my phone (and email) starts ringing. People from around the world contacting me to say, often with great emotion in their voice, they haven't slept well (if at all) since the turbines were installed 1500 feet (and more) from their back door. Not just insomnia, but a host of health issues, again, since the turbines in the neighbor's field began operation.

For over four years I've been listening to their complaints. Describing symptoms that are remarkably consistent, person to person. Consistent and, often, debilitating. Symptoms, I began realizing, that suggest people's balance systems are getting messed up.

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I realized what's needed is a clinical definition of the way people are getting sick when they live near wind turbines. If we can nail down the pathophysiology of their illness, we're in a better position to figure out,

- a) precisely what's causing it
- b) how many people are getting it
- c) who is susceptible
- d) how to control or prevent it.

This became my goal: figure out the pathophysiology of the illness cluster they all describe.

So let's begin. Except immediately there's a problem. Which is, developers focus on noise. They hire an acoustician to measure noise levels (incidentally, there are many ways to slice and dice noise measurements), who then writes a report saying, in effect,

- a) the turbines are emitting this (whatever) dB of noise
- b) the conventional acoustical wisdom about this range of dB says it doesn't create health problems
- c) hence, we conclude these people are faking their symptoms
- d) end of story

I turn the above sequence inside out. We need to begin with c) *symptoms*, not a) *noise levels*. The symptoms are consistent person to person, no matter if it's England or Canada or what have you. Furthermore, the symptom cluster fits with known clinical mechanisms. There is no mystery here.

Hence, the symptom cluster becomes—must become—the chief reference point.

When one measures noise, one must refine noise measurements so as to answer what it is about the noise spectrum *at this moment, when people are actually getting symptoms*, versus that other moment when they're not getting symptoms. *This* is the value of noise measurements.

Other published reports on health and wind turbines, by the way, find the identical set of symptoms to what I found. In my report I review papers by Dr. Amanda Harry, Barbara Frey and Peter Hadden, and Prof. Robyn Phipps.

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- a) Harry found all the same problems, and, interestingly, her group of patients was shifted toward older folks. Moreover, she sampled the same way I did: she talked to people who were bothered.
- b) Frey and Hadden document the same symptoms in people's own narratives.
- c) Phipps mailed questionnaires to everyone living within 9.3 miles of turbines. She got affirmative responses about unpleasant physical symptoms from people living at least 1.24 miles from turbines, on up to 2.2 miles. Some even further. Phipps got even more detail about what they were experiencing because (almost) 7% were so distressed, they telephoned her to describe more specifically their problems from turbine noise and vibration—almost all of them exhibiting disturbed sleep.

My own subjects make it clear their problems are caused by noise and vibration and, in some instances, moving blade shadows. What's more, my subjects notice that symptoms came and went with the wind's direction and strength, turbine spinning speed, which way the turbines were facing, and particular sounds coming from the turbines. In other words, they see their symptoms going up and down depending on what the turbines are doing. They also know that the quality of noise is strange and bothersome even compared to other loud noises, like nearby trains or cars. A few people were specifically bothered by the shadow flicker in rooms or blade shadows sweeping the landscape.



Above all, the symptoms went away when they left home and the turbines, and symptoms returned when they came back home.

Again, the only rational way to study the problem is *symptoms first, noise measurements second*, not the reverse.

Noise. You, dear reader, need to understand what noise is before we go further. If you're confident your grasp of noise is sophisticated, then skip the next few paragraphs. Otherwise, here we go.

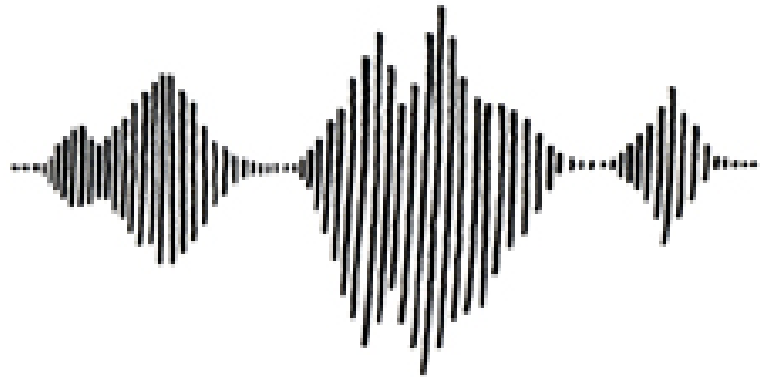
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Wind turbines indisputably make noise from infrasonic (below what you hear), through the range you can hear (audible, in other words), to ultrasonic (above what you hear). This is well established. By "above" and "below" we mean "pitch." "Frequency" means "pitch." Hence, low frequency noise (LFN) means "low-pitched," like the low notes on a piano. High frequency means high-pitched, like the "s" sounds in human speech.

Noise also has a quality of intensity or power which, if the sound is within the hearing range, we call "loudness." Loudness or intensity is measured as "decibels" or "sound pressure level." These are both measures of how much energy, or power, is in the sound wave, and is also called "amplitude."

Next definition: wavelength. A high frequency wave means a short wavelength (as with ocean waves: when the waves arrive in rapid succession the distance between the wave peaks is short). Low frequency means a long wavelength: peaks further apart, although the waves travel at the same speed.

Now things get interesting. *A sound wave in the air is a sequence of pressure changes.* A sound wave in a solid is more like a vibration. (In fact the word "vibration" is technically used to refer only to what happens in solids.)



(As an aside, I will often talk about noise and vibration together because I'm talking about a continuum of energy as it passes through different substances. For instance, a sound wave coming through the air, hitting a building, can make the walls vibrate, which in turn sets up sound waves inside the room.)

When symptoms of the sort we're dealing with, here, have been medically studied, they are typically associated with lower sound frequency ranges—below hearing range or in the lower part of the hearing range. With further research into Wind Turbine Syndrome it may turn out that some of the turbine noise

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in the higher frequencies is also causing symptoms; however, the chief noise culprit, from past clinical studies, appears to be low frequency noise.

Loudness, or intensity, also matters. How loud does a low frequency noise have to be to trigger health effects? Acousticians are taught, "*If you can't hear it, it can't hurt you!*" This, however, is an oversimplification of how the body works. Noise health standards focus on protecting people's ears from loud noise that could damage their hearing. *What these standards ignore is pressure detection by the balance mechanism or pressure or vibration effects on other parts of the body.*

There's the rub.

When we decide to look at symptoms first, the noise issue becomes very simple. People's symptoms come and go. Acousticians need to measure noise levels when symptoms are present and compare these to noise levels when symptoms are absent. In this manner they can find out exactly *what frequencies* at *what intensities* are causing symptoms.

In the *Discussion* section of my clinical report, I give two examples of published accounts by German noise control engineers correlating symptoms with their noise measurements. In each case the symptoms (very similar to Wind Turbine Syndrome, incidentally) were due to very low frequency noise. In one case the noise was identified but not the noise source; in the other case the source was a large building ventilator fan.

Back to my crash course on noise. (Yes, the pun is intended.) Resonance. Resonance is what happens inside the body of a guitar or violin after a string is plucked or disturbed by a bow. It's like an echo inside a space. Thus certain wavelengths bounce back and forth very efficiently, given the size of that space. The walls of the space tend to vibrate at particular frequencies, and if the natural vibration frequency of the wall is the same as the incoming sound frequency, the wall itself (guitar wall, violin wall) can give an added "punch" to the sound, making it louder.

This is a lot like pumping a swing. (We all did this as children.) Swinging is a kind of wave function, like sound, with frequency and amplitude. The frequency of the swing is how many times per minute it's going back and forth. Frequency depends on the length of the ropes—a short swing swings faster. Amplitude is how high the child is swinging. Resonance is a child who knows how to pump (add some

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energy to the swinging) at exactly the right time to increase the amplitude (swing higher). The frequency stays the same, but, as the child pumps, she swings higher and higher.

The child pumping is like the wall of a resonant chamber; it provides a little push to the "wave" at exactly the right time.

Okay, course on noise is over. Now let's apply it to Wind Turbine Syndrome.

Resonances occur inside body spaces and in solid but flexible or elastic parts of the body, such as along the spine. Different parts of the body have different resonant frequencies. Many of these are in the low frequency range. When a sound wave or vibration hits the body, it's more likely to set up vibrations in a body part with a matching resonant frequency.

In Wind Turbine Syndrome, an important body resonance is the resonance of the chest and abdominal space. The chest wall is made of elastic muscles, bones, cartilage, tendons, and ligaments, giving the chest a natural recoil we use in breathing. We use energy to expand the chest to breathe in, but much of the force to push the air back out comes from the elastic recoil of the chest.

One of the important parts of the breathing mechanism is the diaphragm muscle at the bottom of the chest. It's dome-shaped, like the top of an egg. When you take a breath, the diaphragm flattens. As it flattens, it pulls down, thus expanding the chest space and pushing on the abdominal space. The abdominal space is very soft and flexible, the front being thin sheets of muscle, skin, and other soft tissues, without bone or cartilage. So when you breathe in, your stomach sticks out. When you relax the diaphragm muscle, it springs back to its dome shape and it pushes air out. Natural elasticity at work.

Hence, when air pressure waves enter the lung, it takes very little energy in the air pressure waves to set this very mobile system vibrating. At frequencies between 4 and 8 times per second, the diaphragm will vibrate. Frequencies 4-8 times/second are low frequency noise or infrasound, below hearing range.

Not only the diaphragm vibrates, but the entire mass of internal organs in the abdomen swing up and down with diaphragm movements. One of the largest abdominal organs, the liver, is attached to the underside of the diaphragm.

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There are other places in the body with resonance, including the eyes (globes with bone around them and less dense material inside) and the brain case. Even the spine (backbone) has a resonance frequency. The spine is elastic. If it's vibrated at a particular frequency it can set up a vertical vibration along the spine.

Even very small body parts, like blood vessels inside the brain, have resonances that influence the damage caused by air pressure waves from a nearby blast, for example.

In sum, what we casually call *noise* can have a powerful impact on numerous internal structures and cavities. We will see the significance of all this in the Discussion, below.

Before moving on to the Methods section, a few words about measuring sound power and what's called "A-weighting" and "C-weighting." It's difficult to measure the loudness, or energy, of sound in consistent, reproducible ways, especially at low frequencies. A-weighted and C-weighted "networks" in sound-measuring equipment screen sound energy (i.e., loudness) according to frequency. A-weighting screens out most of the low frequency and high frequency sounds; it's biased toward what the human ear hears best. C-weighting includes more of the low frequency sounds, but not the very lowest frequencies.

It's easy to obtain standardized measuring equipment with these two weighting networks (A and C), but measuring the power of the lowest frequency sound requires expensive and specialized equipment that's not standardized among models. Nevertheless, if we are to fully understand Wind Turbine Syndrome, it's at this lowest of low frequencies that measurements must be made.

Methods

I used what's called a *case series* as my research protocol. (Remember my definition of a case series from the Preface: "*A descriptive account of a series of individuals with the same new medical problem.*")

In medical research, *case series* don't usually have control (comparison) groups. However, I added a new wrinkle to my study, based on my training in field ecology: despite not having a formal control (comparison) group, I chose subjects and arranged the way I collected information so I could create comparisons.

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First, to call this a wind-turbine-associated problem at all, I compared how people were *during exposure* to how they were when *not exposed*, and I specified that “not exposed” meant both *before* and *after* living near turbines. *All my subjects saw their problems start soon after turbines went on-line near their homes, and all saw their problems go away when they were away from the turbines.*

Second, to discover medical risk factors, I compared subjects who exhibited particular symptoms more intensely, to those who did not. Then I looked at whether these differences were influenced by age, underlying health conditions, etc.

There was a third type of implicit comparison going on—to the population at large. For example, both I and Dr. Harry sampled in the same way—we interviewed affected adults—and we both wound up with samples shifted toward people in their 50’s or older. This suggests that older people are more often affected, since older people are over-represented in our samples. (This makes medical sense, and also corresponds to patterns of noise complaints in other, non-wind-turbine settings).

Additionally, in my study there are more people with underlying migraine than in the general population, suggesting that people with migraine are, like older people, more susceptible.

Hence, the more elderly and migraineurs (people who get migraines) stand out in my investigations.

Now, let’s consider what a standard epidemiologic study of Wind Turbine Syndrome might look like, as distinct from my *case series* approach. When a scientist sets out to perform an epidemiologic study, he (she) begins by defining two identical groups to be studied. Notice, this is *before* either group is exposed to the (supposedly) disease-causing agent. One group being the *study group*, the other the *control group*. The study group, of course, is the so-called guinea pig: the individuals about to be exposed to the potential problem, in this case wind turbines. The control group is identical in every conceivable way to the study group: by age, by sex, and (in the case of wind turbines) similar rural areas with similar occupations, etc.

Then exposure starts. In this case, the turbines are built and turned on—though only, as I said, for the study group. The researchers monitor what happens to everybody in both groups—guinea pigs, non-guinea pigs—and make comparisons and draw conclusions.

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But there's a problem. A problem in what's called medical ethics. *It's unethical to design a study to expose people to something already suspected to be harmful.*

So another type of epidemiologic study, a case-control study, comes to the rescue. In a case-control study, people meeting the case definition for Wind Turbine Syndrome would be enrolled. For each case, two or three other similar people not living near turbines would also be enrolled. These are the controls. The researcher would collect the same types of data on all cases and controls, and make comparisons.

But to do this we need to know what a case is: *we need a case definition.* A case definition describes the symptoms and findings, proves there's consistency from person to person, and presents ideas or hypotheses about what causes the newly defined illness.

That is what my study has done—*created a case definition.* The next step is an epidemiologic study, *but the case definition comes first.*

Back to an epidemiologic study. A standard epidemiologic study would require several years of study, a huge research grant, and a small army of researchers. Besides this, as I explained in the Preface, the gag clauses found in wind leases and so-called Good Neighbor Agreements, plus the desire to sell one's home yet not reveal the noise toxicity and thus scuttle a potential sale, and the trickiness of community relationships—all these considerations would make an epidemiologic study highly difficult and perhaps doomed.

Nevertheless, epidemiologic studies should be undertaken. At least the attempt should be made.

My report should be seen as a necessary preliminary step to this much larger, more ambitious, more long term study. However, no government or private agency will undertake this Big Study without a preliminary project like mine—let's call it a pilot study—showing there is in fact something worth studying.

Back to my report. The problem in any clinical study is figuring out which new symptoms are due to a new exposure and which are not. In an epidemiologic study this is worked out by having parallel groups, with one group not getting exposed. Since I didn't have the resources to do such a study, I insisted that among my study subjects there be a post-exposure period—a time after exposure ended, during which the symptoms disappeared. *Wind Turbine Syndrome is defined only as those symptoms which came on*

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during exposure and abated only after exposure ended. It may not capture all the health effects of wind turbine exposure, because of the limitations built into my study design. But it certainly captured a significant set of symptoms.

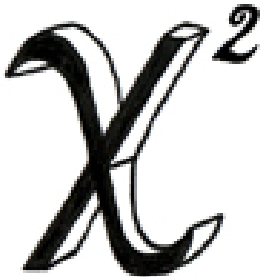
There's an additional way I generated a comparison group. I either interviewed every family member or, in the case of a 5-year-old and the elderly senile, I got information on these people. In this way I discovered that not everyone in the family was equally affected, despite living in the same house at the same distance from the turbines. I used comparisons between affected and non-affected people to figure out which parts of their pre-exposure medical history predicted which symptoms during exposure.

With this in mind, notice how I chose my study subjects:

- a) at least one family member was severely affected by living near turbines
- b) the family either had to have left the home or spent sufficient time away to experience relief from symptoms
- c) the people I interviewed had to be able to say clearly, consistently, and in detail what had happened to them, under what conditions and at what time
- d) they all live near turbines put into operation between 2004 and 2007
- e) if they had already moved out when interviewed, it was less than 6 weeks since they'd moved out
- f) they had to have taken serious action to protect themselves from the turbine exposure (generally identified as noise):
 - a. some moved out
 - b. some purchased a second home in anticipation of moving out
 - c. some left home for months
 - d. one family renovated the house in an effort to mitigate the noise
 - e. and one man took to sleeping in his root cellar

A final point. This squiggly symbol, χ^2 , is called "chi squared" (pronounced "key," as in "eye"). Don't panic! It's a simple statistical test. I'll illustrate with an example.

- 1) You have a group of people
- 2) You classify them as tall or short, with blue eyes or brown eyes



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- 3) A χ^2 statistic lets you say if blue eyes are associated with being tall or short in anything other than a random way
- 4) Since everyone knows that having blue or brown eyes has nothing to do with whether you're tall or short, if you do a χ^2 statistic on, say, 20 people, categorized for both of these qualities (eye color and height), it would come out to be non-significant
- 5) End of illustration. Now, that wasn't so hard, was it?

Notice, when you read my full report you encounter what are called p (probability) values in parentheses, together with χ^2 values. Again, don't panic. The p is the probability that the relationship between the two variables (eye color and height) is random. In other words, that being tall does not increase your probability of having blue eyes, or that height and eye color are totally unrelated.

P goes between 0 (zero) and 1 (one). Very low p values mean *there's a significant correlation between the two variables*. "Very low" would be less than 0.05. Less than 0.01 means there's an even stronger likelihood the two variables (eye color and height) occur together more than by chance.

Okay, you can breathe again; we're done with the math. This is precisely how I identify "risk factors" in my study. (Risk factor is something in your medical history or makeup that makes you susceptible, in this case, to Wind Turbine Syndrome when exposed to turbines.) I applied a χ^2 analysis. For instance, I look at whether a person has or does not have tinnitus when exposed to turbines. I compare that to whether they do or don't have a history of industrial noise exposure. I discovered, in this particular example, that a significant relationship does exist.

We'll come back to this in the Results section, below.

Results

My study demonstrated the following to be the core symptoms of Wind Turbine Syndrome.

- 1) First, *almost everyone had disturbed sleep*. Two particularly interesting patterns emerged in the disturbed sleep.

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- a. The first being what we might call “fear” patterns. This would be childhood night terrors and adults waking up alarmed and hyper-alert (i.e., felt they had to check and see if someone had broken into the home, even though they knew they had been awakened by turbine noise). At times adults woke up with a racing heart at night.
- b. The second was a tendency to urinate a lot at night. For adults this meant getting up frequently, and for one child it involved bed wetting (which resolved whenever she was away from the turbines).

I didn’t look for risk factors for sleep disturbance since virtually everyone interviewed had disturbed sleep.

- 2) *Headaches*. Slightly more than half the study group had headaches that were worse than what they normally experienced before and after turbine exposure. Headaches that lasted longer and were more severe, in other words.

Half of the people getting headaches were people with pre-existing migraine disorder (i.e., a hereditary tendency to get severe headaches, along with dizziness, nausea, visual changes, or strong avoidance of light and sound during these headache episodes). All the children who got headaches during turbine exposure either had migraine disorder themselves or their parents had migraine disorder.

About half the adults who got headaches during exposure had no risk factors for headache which I could identify. This means that anyone can get severe headaches when exposed to turbines.

- 3) *Ear symptoms*. Tinnitus was a dominant symptom during exposure. Tinnitus: ringing, buzzing, a waterfall noise, or even a buzzing that seems to be inside the head. Risk factors for tinnitus during exposure were:
 - a. having some tinnitus before exposure
 - b. having some hearing loss before exposure
 - c. a previous industrial noise exposure

All these suggest previous damage to the inner ear, which could come from noise exposure, chemotherapy, certain antibiotics, head injury, or even whiplash injury.

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People also experienced pain and popping and a feeling of pressure in their ears.

- 4) The fourth core symptom I am calling VVVD. *Visceral Vibratory Vestibular Disturbance*. This is a new symptom to medicine, I believe. Before reading further, you should study the VVVD symptom accounts in the Results section (page xxx), so you have a mental picture of what people say they're experiencing.

Once you've looked over those accounts we can move on to consider how the symptoms of VVVD can occur together. The symptoms being:

- a. A feeling of internal pulsation, quivering or vibration. For some, breathing feels controlled or restricted.
- b. Nervousness or jitteriness. Fear. The urge to flee. The urge to check the house for safety.
- c. Shaking
- d. Rapid heartbeat
- e. Nausea

VVVD is essentially the *symptoms of a panic attack associated with feelings of movement inside the chest in people who have never had panic attacks before* (none of my subjects had).

Because VVVD is so similar to panic attacks, I looked for a correlation between VVVD and a history of any other kind of anxiety or depression or mental health disorder. I found there is no relationship. However *there was a highly significant correlation between VVVD and pre-existing motion sensitivity* (i.e., people who get car-sick, seasick, or had a history of repeated episodes of vertigo).

Out of the 21 adults (age 22 and up) in the study, 14 had VVVD. The two toddlers in the study looked like they had something similar. Though we don't know exactly what they felt, they woke up screaming several times per night, and were inconsolable and hard to get back to bed or to sleep. The two 5-year-olds in the study also awoke fearful in the night.

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- 5) *Concentration and memory.* Almost everyone in the study had some kind of problem with concentration and memory. The more severe concentration problems were linked with a general loss of energy and motivation. What's noteworthy, among many of my subjects, was the degree to which they lost basic skills they had prior to turbine exposure, and the way teachers noticed new problems with kids' schoolwork and sent notes home. (Here, you should read the Concentration and Memory symptom accounts in the Results section, on page xxx, and the accounts of recovery from these symptoms on page xxx.)

For some people, these problems with thinking resolved as soon as they got away from the turbines, or even if the turbines turned in another direction. For others, they did not resolve immediately, but improved gradually over time. To me this suggests that the memory and concentration difficulties were not solely due to sleep disturbance.

I see the cognitive problems as the most worrisome of the whole constellation of Wind Turbine Syndrome symptoms. Somehow the brain seems to be conditioned into new patterns, as though thinking patterns have changed with the distorted vestibular input or prolonged disturbance of sleep. More about this later.

- 6) The remaining core symptoms were *irritability and anger*, which occurred in most of my subjects, including the children. Often it was the children's behavior and school problems, their irritability and loss of social coping skills, that drove families to move out of their homes and away from the turbines.
- 7) Most subjects had *fatigue* – sometimes a distinctly leaden feeling – *and loss of enjoyment and motivation for usual activities*. For most this cleared up soon after they got away from the turbines.
- 8) Finally, I listed clusters of symptoms that subjects told me about, but would require other modes of study (including physical exams or lab tests or x-rays, and a case-control format) to find out if they are connected to turbines. These symptoms occurred in low numbers in my study. They included *lower respiratory infections* (bronchitis, pneumonia, pleurisy) that were unusual for the people who got them, *worsened asthma*, *unusual middle ear fluid or infections*, and *ocular stroke*.

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Though my study cannot prove a connection, I think they are worth attention in a large-scale study of wind turbine health effects.

Discussion

This section is about how I think Wind Turbine Syndrome works, and the ideas I got from the medical literature and my referees. This is the most interesting section of the report—where we join the dots.

I recognized the symptoms of Wind Turbine Syndrome as being something coherent, something that hangs together, because I already knew about what's called *migrainous vertigo* or *migraine-anxiety associated dizziness*.

Migraine is not just a bad headache. It has many other peculiar symptoms associated with it. My husband has had migraines since he was a teen, but he never gets headaches. He gets dizziness, tiredness, and patches where he can't see (scotoma). He has to lie down till it goes away. Some years ago he had a terrible episode of nauseating vertigo (a spinning kind of dizziness), tinnitus, and anxiety that developed into depression. The person who figured out what was wrong with him was the otolaryngologist to whom this book is dedicated, Dr. Dudley Weider.

Dr. Weider taught me how migraine, vertigo, tinnitus, and anxiety are neurologically related—and he treated my husband successfully. I might add that my husband has always been motion sensitive. And I learned that this commonly goes along with migraine.

When I started hearing about the symptoms in Wind Turbine Syndrome, I recognized it as a related complex of symptoms. I had hoped to share this report with Dr. Weider, but, alas, he had passed away. Instead I had the pleasure of sharing it with a group of his former colleagues in otolaryngology. Read through the list of referees and readers of this report, and you will discover it's a Dudley Weider reunion. They taught me many other important matters regarding balance and the inner ear, which I've incorporated into this report.

First, Drs. Lehrer and Black recognized the symptom complex of Wind Turbine Syndrome as similar to the symptom complex of an inner ear problem called endolymphatic hydrops (EH). In the case of EH the

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symptoms are continuous or vary for unknown reasons. In Wind Turbine Syndrome these symptoms come and go depending on whether people are near or far from the turbines. Or whether the turbines are making a particular kind of noise, or facing in certain directions.

EH, which includes Meniere's Disease (pronounced "Man-ears") and perilymphatic fistula (where the fluid is leaking from the inner ear into the middle ear), involves distorted pressure relationships between the two fluid compartments in the inner ear: the endolymph and perilymph. This causes erratic and distorted balance and (often) hearing signals to be sent to the brain.

This brings us to the balance system and how it works. It's a complex system that penetrates many areas of the brain and draws sensory signals from all over the body. Other senses have only one kind of sensory input, whereas the balance system has four.

By balance system I mean a) *how the body maintains its upright posture* and also b) *everything to do with motion and position awareness*. For example, the balance system is highly active during the turns and twists of diving or gymnastics, even though a person is not staying upright.

Why all this focus on the balance system? Because I think that *people susceptible to imbalance are especially susceptible to Wind Turbine Syndrome*. So I need to explain the different ways people become imbalanced, and how the air pressure variations, or sound, from wind turbines may be triggering an abnormal sense of motion in susceptible people.

As I mentioned before, *motion* and *position* signals come from four discrete body systems and are integrated by balance centers in the brain:

- 1) eyes (the visual center)
- 2) dedicated motion and position sensing organs in the inner ear (the vestibular center)
- 3) stretch receptors from muscles and joints all over the body, and touch receptors in the skin (the somato-sensory center)
- 4) stretch and pressure receptors associated with organs in the chest and abdomen

The balance system requires that at least two of the first three channels, that we will call visual, vestibular, and somato-sensory, be working every moment if we are to maintain balance. Hang onto this point; it's extremely important. We might call it the Law of Balance.

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For example, the vestibular organs in the inner ear tend not to work so well in older folks. If the inner ear is not sending correct signals, people are more dependent on what they can see and on what their feet and legs are feeling, to keep their balance.

Since two channels have to be sending signals for balance to work, these people are in trouble in the dark.

If you have good balance, try this experiment: stand on one foot and feel all the little corrective movements your foot and ankle are making to keep you upright. People with normal balance can stand on one foot indefinitely.

Now, close your eyes. See how long before you have to put your other foot down to keep from falling over.

You can't keep your balance in this situation because you've deprived yourself of both vision and adequate somato-sensory input from the legs—and one system, the vestibular input from the inner ear, is not enough. (If you don't have good balance, keep both feet on the floor when you close your eyes, and you still may notice a difference.)

Variations in balance function seem to fall into four broad categories.

- 1) *The first is very young age.* Little children fall down a lot. As kids get older and improve their balance, they can do more complex things without falling. At very young ages, children are mapping their entire sensory system onto the world. For example, an infant figures out how far he has to reach his arm to touch something, and what that looks and feels like. This gives him a sense of distance, mapping that concept of distance onto his visual sensors and the coordinated stretch receptors of his arm and shoulder.

This process of learning where the parts of the body are in space, through increasingly complex activities, continues through childhood. In its early stages, children are more susceptible to balance disturbance.

- 2) *A second origin of balance variation is differences in the central (brain) processing of balance and motion-related signals.* People who are motion sensitive, which includes many people with

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migraine disorder as well as other people, have difficulty successfully integrating the signals from the different sensory channels of balance. Their brains tend to over-emphasize or under-emphasize certain channels.

For example, in a person with migrainous vertigo and tinnitus—like my husband—the signals from the inner ear may be turned up too loud. So, centrally, the brain has to turn these down. It has to deal with the over-intensity of one signal. Or it may not be that they're too loud, but distorted, in which case there's an even greater need for the brain to down-weight the signals from that channel.

When we turn down the signals from the inner ear, we become more dependent on the visual channel or the somato-sensory channel. People who are visually dependent for balance often have trouble with heights, like being high up in a building or on a cliff. (Witness my husband.) This is because, when everything is far away, there's less visual position information that can be drawn from what one sees (less retinal slip and parallax changes as one moves, for example).

Someone who is surface dependent, on the other hand, may be in more trouble when the surface is slippery, because he relies more on the position information coming from his muscles and joints. These signals are distorted by the slippery surface.

- 3) *The third source of balance variation or dysfunction is inner ear damage, or congenital or developmental malformations of the inner ear.* Damage may come from loud noise or blast exposures, head or neck injury (including minor ones like whiplash or a concussion), complications of repeated or chronic middle ear infections in childhood, or exposure to certain chemicals (aminoglycoside antibiotics or certain kinds of chemotherapy). There is also endolymphatic hydrops, an inner ear pathology (described above) that includes Meniere's disease and perilymphatic fistula. Autoimmune disorders like lupus can also cause endolymphatic hydrops.
- 4) *The fourth source of balance variation or dysfunction is older age.* There seems to be deterioration of inner ear function after about age 50, varying among people, of course.

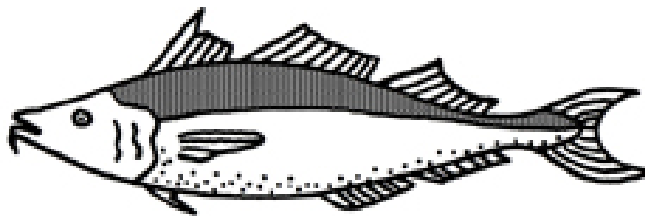
This brings us to *compensated vs. uncompensated balance dysfunction*. If you happen to have a balance dysfunction and yet are able to compensate for it, you feel fine: you keep your balance. On the other

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hand, if there's an additional challenge, or distortion from another channel, then you're off balance—you feel unsteady or dizzy, or have vertigo or motion sickness. This is *uncompensated balance dysfunction*. Because of what's called “the system's redundancy” (the “system” in this case being the brain) brain balance centers can ignore or down-weight anomalous (false) signals from one channel, *but they can't for two channels*.

People who suffer from Wind Turbine Syndrome have, I believe, a compensated balance problem at baseline, in one of the four ways described above. By *baseline* I mean: they had a compensated balance problem before they were exposed to wind turbines. *Exposure to wind turbines pushes them over the edge, since, as I said above, the brain can't ignore disorienting signals from two channels*. (Remember, one set of false signals is now coming from the turbines. The other set of disorienting signals is coming from any of the four categories described immediately above.)

How, you ask, might sound pulsations (coming from wind turbines) be disrupting human balance signals?



Good question. Let's start with fish. The otolith organs of the vestibular system are highly conserved through evolution. Meaning, they're similar in fish and all other vertebrates—amphibians, reptiles, mammals, and birds—that evolved from fish. In fish these organs detect upright position (a fish's version of balance), and also low frequency noise and pressure variations in the water.

This detection of pressure variations and noise, including low frequency noise, is important for detecting the movements of other animals to escape being eaten, catch prey, and navigate through the oceans using the low frequency sound from distant waves breaking on shores. (“No, Virginia, they don't use Google maps or GPS locators.”)

Thus the otoliths have a long evolutionary history of being sensitive both to gravity and noise/pressure variations. It makes sense that a system with a critical role in escaping predation would be hardwired into the brain's networks for fear and alerting, for fast escapes. Think too about all those stories about animals

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detecting and fleeing earthquakes, tsunamis, incipient volcanoes, and ice breakup—things that rumble or make low frequency noise and vibration—long before human beings become aware of them.

Detection of this kind of signal is tied to fear responses: the animals flee. Animals apparently pick up this kind of signal through the ground, but there is also evidence that animals, including us, are sensitive to air pressure changes which are not sound. Weather changes influence mood and energy in many people, with higher barometric pressure associated with better mood and more energy. Birds sense big snowstorms coming, and feed like crazy before the storm rolls in.

What about that fourth balance channel, the stretch and pressure receptors in the internal organs? This fourth one, called *visceral graviceptors* and discovered relatively recently (in the 1990s, by a German researcher), is especially fascinating. (This is the balance channel many physicians are unaware of, since we were all taught in medical school that only three senses feed into balance.)

Visceral graviceptors are based on stretch and pressure receptors in and around internal organs. These receptors can let you know you're upside-down because there's more blood in the chest, making the blood vessels weigh more. Or they let you know by increasing the pressure of blood inside organs or blood vessels. This is thought to be a reason why astronauts hurling through outer space can have the sensation they're upside down, because gravity is no longer pulling so much blood into the legs and more of it is in the organs and vessels of the chest.

There are suggestions in the balance literature that visceral graviceptors play an important role in car-sickness and seasickness, by being the detectors for unusual up-and-down motions at odds with what the rest of the balance system is saying. It helps in seasickness, for instance, to stand up and look out at the horizon. This brings information from the eyes and stretch receptors in legs in line with the vestibular and visceral motion signals.

The point being that anomalous (unusual) signals, including from the newly discovered visceral graviceptors, disturb the balance system.

The VVVD story also involves understanding how the chest is a receptor for air pressure fluctuations. (Every form of sound in air, from low frequency to high frequency, consists of strings of air pressure pulses.) Briefly, when we breathe, our airways and lungs, which fill most of the chest, are open to the air.

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Sound pressure waves can easily enter, and can set this elastic and mobile system moving with very little energy. (For a description of chest wall and diaphragm dynamics, see the explanation on page xxx.)

The internal graviceptors provide a potential link between the chest pressure fluctuations and the set of sensations and symptoms I call VVVD—the same set of neurologic symptoms seen in chronic inner ear disorders. The internal graviceptors may well provide the neural connection between chest pressure and weird discordances picked up by the balance system, producing similar sets of symptoms in these two situations. Or, as suggested by Dr. Owen Black (a balance and inner ear researcher), there may also be a relationship between pressure in the chest, the fluid around the brain, and the fluid in the inner ears in some people with particular inner ear problems.

Now consider how the balance system in the brain is neurologically tied in with fear and anxiety. Here we look to the work of Dr. Carey Balaban, a brain researcher. Balaban studies the neural networks linking balance with the brain centers controlling anxiety and fear, and with the autonomic responses and aversive learning that are also part of VVVD and Wind Turbine Syndrome. (The *autonomic nervous system* controls all the bodily functions that you don't have to think about and, in fact, you can't control. Such as blood pressure, heart rate, sweating, and digestion.) Disordered balance signals feed directly into fear and anxiety. *It's not because you start out scared or negative; it's because of a physiologic reaction to being off balance.* This is Balaban's point. He shows the actual nerve networks mediating these communications in the brain.



Balaban illustrates with a story. Imagine you're stopped in your car on a hill. Say, San Francisco. Out of the corner of your eye you see the truck next to you starting to inch forward. This immediately gives you impression you're starting to slip backwards! You panic! You jam your foot on the brake! The fear subsides as you realize you are in fact ... not moving.

Balaban's story underscores that when you sense you're not stable in space—you're going to fall, you're moving when you don't expect it—it grabs all your attention, immediately, with alerting and fear. He also points out that when the sense of moving unexpectedly goes on over a long time, as in vertigo, so does the sense of fear.

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Studies by psychiatrists and balance specialists show how the linkages between anxiety and balance problems play out clinically and in real life. A mild form of balance disorder is called *space and motion discomfort*, where people feel uncomfortable or dizzy in situations like looking up at tall buildings, closing their eyes in the shower, leaning far back in a chair, driving through tunnels, riding in an elevator, or reading in the car. These people also have abnormalities on balance testing. It's usually a central balance problem, meaning the brain has difficulty integrating all the different signals coming into the balance system, and deciding which ones to ignore if they don't match.

Space and motion discomfort is common in people with migraine disorders. So are dizziness, vertigo (spinning dizziness), and motion sickness. Balance testing is abnormal in people with migraine disorders compared to people who get other kinds of headaches, especially if the migraine patients tend to get dizziness or vertigo. The balance problems in migraine disorder, incidentally, can be inner ear or central (brain-based).

Anxiety problems are also associated with migraine, sharing a common thread in the serotonin systems of the brain. Space and motion discomfort is common in people with anxiety disorders. Balance testing shows that anxiety patients have higher vestibular (inner ear) sensitivity than people without anxiety problems. When balance testing is done in people diagnosed with panic attacks or agoraphobia (fear of leaving the house), a high number are found to have abnormalities of vestibular (inner ear) function—more than 80% in some studies. This is especially true if the people have episodes of dizziness between panic attacks.

In sum, *there is a robust clinical literature supporting the biological connection between balance problems and anxiety, and between balance problems and panic attacks, in particular. It makes eminent clinical sense that disturbing a person's balance system can lead to fear, alerting, and panic, including physical symptoms like fast heartbeat and shakiness.*

I've talked about how the visceral graviceptors in the chest might be stimulated and lead to balance disturbance, but not so much about the other channels of balance. In my study, two subjects, both adult women already prone to vertigo, were very sensitive to the visual channel. Both developed severe headaches when exposed to the moving shadows of turbine blades.

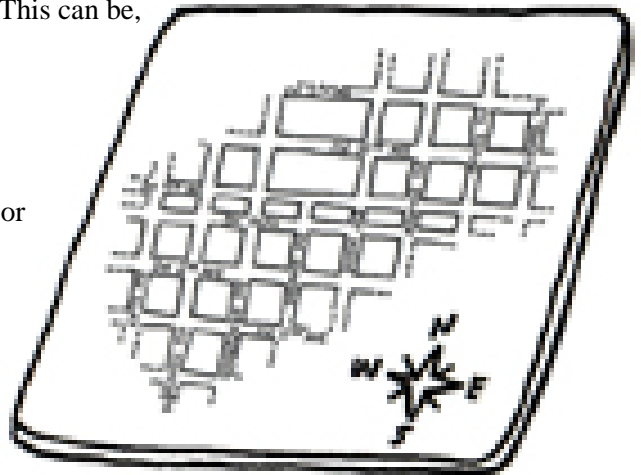
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Some subjects were able to feel vibrations from the ground in their lower legs, opening the possibility that the somatosensory channel (stretch receptors from the muscles and joints, and touch receptors from the skin) could be disturbed.

Many of my subjects had ear symptoms, including tinnitus, ear pressure, ear pain, or a physical feeling of noise inside the head. If the air pressure fluctuations from the turbines can produce these symptoms, which are all different from hearing the noise, might they also perturb the balance organs of the inner ear? The labyrinthine (inner ear) organs are delicate, interconnected membranous sacs with fluid inside and outside, sensitive to minute shifts in pressure and position. Audible sounds stimulate the cochlea, but certain sounds can also stimulate the saccule in humans (the otolith organ that tells us if we are upright). The otolith organs of certain fish, which are similar to ours, are known to detect low-frequency sound, aiding in navigation. This gives us reason to think, for both animals and humans, that certain types of noise may be able to stimulate the balance parts of the inner ear, especially the saccule, causing disturbance to motion and position sense.

The plot thickens. Thinking and memory: current research demonstrates that these, too, depend on coherent vestibular signaling. If you don't know which way is up, literally, at all times, your brain can't figure out a multitude of things related to position in space. This can be,

- a) *position in real space*, like
 - a. remembering how to get somewhere or
 - b. figuring out how to put something together, or
- b) *position in conceptual space*, like
 - a. the distance between two numbers or
 - b. the position of events in time or
 - c. the categorization of objects in memory



Research is supporting what doctors who treat balance problems have seen for years: *struggles with short-term memory, concentration, multi-tasking, arithmetic, and reading are common in patients with balance disorders.*

Neuroscientists have recently shown that nerves from the vestibular system follow a direct path to the hippocampus, a brain structure critical for memory in general and spatial learning in particular. People with no inner ear input to the brain at all (the nerves having been cut years before to remove tumors)

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cannot do experimental tasks involving navigation, and their hippocampi (plural of hippocampus) are smaller than normal. (Conversely, taxicab drivers in London have extra-large hippocampi, the size depending on how many years they have been driving and storing in their brains their personal map data of locations, shortcuts, and one-way streets.)

Functional MRI and PET scans (PET scans don't scan your pet, just as CAT scans don't scan your kitty; see Glossary) now allow researchers to see which parts of the brain are used for different tasks by awake humans while they are doing things. Stimulating the vestibular (inner ear balance) system lights up many areas in the brain, including those used for mental representations of space and mathematical thinking.

If the vestibular input is distorted (for example, by putting ice water in one ear), people make more mistakes in purely mental spatial tasks, like imagining a certain object in detail or imagining rotating it. These people were sitting still at the time, eyes closed, just thinking, not trying to keep their balance or having to judge where they were in space at all. Nonetheless, when signals came from one inner ear indicating movement—signals out of whack with all the other signals their balance centers were receiving—they remembered the objects less accurately and made mistakes when imagining them in different positions.

Disordered signaling from the inner ear at the time of spatial thinking, in other words, degrades both memory and concentration.

A cluster of brain centers that receive signals from the inner ear (meaning, they become active on functional MRI or PET studies when the vestibular organs are stimulated) is in the right parietal (“pair-eye-ital”) lobe of the brain, towards the upper middle on the right side. There can be some very weird outcomes if these centers are lost to a right parietal stroke. Called “hemineglect” (hemi-neglect: meaning neglect of half the body and half of space), these poor people can have so much unawareness of the left side of space that they can be unaware that their left arm is paralyzed or the left side of their body undressed. Vestibular stimulation, however, temporarily reverses the neglect, so that these people become aware of the left side again in a more normal way.

People with hemineglect have typical types of errors on visual search and visual memory tasks, with answers biased away from the left and towards the right sides of images. Left vestibular stimulation corrects or improves performance on these tasks.

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Other studies of people with hemineglect let us see what other kinds of mental tasks are “spatialized,” meaning, they require the spatial types of thinking done in these right parietal lobe centers linked to the vestibular system. Spatialized thinking includes mathematical operations like forming a mental image of a ruler (lower numbers on the left, higher on the right), and imagining the midpoint between two numbers. It also includes clock representations of time, and spelling at the beginning (left) and ending (right) of words. Studies of powerful thinkers also show how important spatial thinking is: great mathematicians think of math in spatial terms (which is efficient, because the actual neural representation of numbers is spatial), and outstanding memorizers use spatially oriented strategies.

The punchline being, when there’s a lack of input from the vestibular system, spatial thinking gets shut down. Whereas when the input from the vestibular system is confused (disordered), spatial thinking gets mixed up. Spatial thinking absolutely requires vestibular stimulation. Disordered vestibular information knocks it off balance, so to speak, rendering it less efficient and inaccurate.

Spatial thinking, it must be emphasized, is much of what we do with our brains.

Now, think about the specific tasks my study subjects had trouble with—what they spontaneously told me about themselves and their children, along the lines of,

- a) “I can’t believe I can’t manage something this simple anymore!”
- b) “He (my child) knew how to do this, and now he can’t do it at all and gets really mad and frustrated when I make him keep trying!”

The letter and number refers the person’s Family Tables. I put a description of the *spatial quality* of each task in italics:

A1 Remembering what he had come to get when he arrived at a store. *Spatial memory for the image of what he was searching for.*

B2 Remembering a series of errands and things to get in town. *Spatial memory for the objects and places to get them, spatial calculation of the most efficient path and order.*

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C1, D1, G3 Reading. *Conversion of spatial input (words on page) to language and then to concepts and imagery (which are also spatial). There is also direct vestibular control of eye movements.*

C2, G2 Multitasking in kitchen and household. *Having an internal map of the locations and timing of multiple things at once, inserting tasks and events into the map and not losing awareness of them when out of sight.*

C7 Math—lost skills and forgot math facts. *Spatial representation of numbers and number relationships.*

E2 Spelling, writing. *Putting letters in the right order so the word looks right; changing language into a visual representation.*

F2 Assembling furniture. *Being able to convert written instructions or diagrams to 3-dimensional mental representations of what she was supposed to do with the pieces.*

F2 Following the steps in a simple recipe. *Picturing and ordering the steps in mind from the written instructions.*

F2 Following the plot of a TV mystery. *Noticing, remembering, and putting together visual clues.*

F3 Did worse than in past on national exams. *Outstanding memorizers use spatial strategies, as described above.*

H3 Reading, spelling, math. *All these have significant spatial components.*

I1 Professional landscaping and gardening—loss of concentration. *Planning and arranging things in space, remembering where you put down a tool, judging if something you're building is*

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turning out right and how to fix it, planning steps of tasks efficiently in time and space, not forgetting steps.

J1 Paying bills. *Mathematics, memory for objects and services purchased, mental calculation of future needs.*

These are not all the tasks people said they were having trouble with, but they are the majority. Making sense? *Balance signals messed up, spatial thinking full of errors and inefficiencies, and people are enormously frustrated over normal, common sense things they suddenly can't do efficiently.* (“Common sense” has a big spatial thinking component, too.) Early school learning is thrown off, as well as reading and certain higher memory and problem-solving tasks in adults.

Interference of noise with reading and children's learning is not a new discovery; there is an extensive literature on it. In brief, environmental noise, like airport or traffic noise, makes children learn to read more slowly. In these studies, large numbers of children were studied in carefully controlled exposed and non-exposed groups, by choosing school districts at different locations relative to airports. Children were exposed to the extra noise both in school and at home.

In one study, a city closed an old airport and built a new one, and researchers had the opportunity to follow the reading skills of both sets of children over time. The ones living near the airport that closed showed improvements in their reading. The ones near the new airport showed slower learning after planes started flying in and out.

One study looked at children living in an apartment building next to a busy highway. Those on the higher floors, where it was quieter, had better reading scores and better ability to tell word sounds apart.

The effects of noise on reading ability go beyond the distracting effects of noise, and are linked to problems with language processing—like differentiating between sounds in noisy environments.

Noise can affect thinking in adults, too, at loudness levels nowhere near the levels that harm hearing. In one study, industrial workers worked on psychological tests while exposed to 50 dBA broadband noise (like white noise or machine noise) with or without low frequency components. The noise with low frequency components interfered with test performance more than the noise without the low frequencies, especially in individuals who rated themselves as sensitive to low frequency noise. Neither type of noise

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was considered more annoying than the other, nor did subjects become accustomed or sensitized to the noise.

Many environmental noise studies look at effects on sleep, stress hormone (adrenalin, cortisol) output, blood pressure, and cardiovascular risk factors in general. Noise at night can significantly disturb sleep even when the person does not remember waking up. Since the sorting and storage of daily memories occurs during sleep, especially dreaming or what's called REM sleep (rapid eye movement), sleep disturbance by noise, even without known awakening, interferes with memory and learning.

In children, nighttime low frequency (rumbling/vibrating) noise from trucks has been shown to produce more stress hormone at a time of night when it's not usually produced (i.e., the wrong time of night), than gets produced in the same children exposed to regular nighttime car traffic noise. *In other words, low frequency noise stimulates elevated stress hormone production in children during nighttime sleep.*

(Elevated cortisol levels are also known to harm memory and learning, reducing the survival of new hippocampal memory cells, as in chronically abused children.) High adrenalin or cortisol levels elevate blood sugar and increase blood pressure, increasing cardiovascular risk.

Interestingly, the levels of noise that disturb sleep are quite low. Noise events of 32 dBA cause people to move in sleep, showing a low level of arousal. Noise events of 35 dBA cause arousals that can be seen on a brain wave study (EEG). Conscious awakenings occur at 42 dBA. This is why the World Health Organization (WHO) recommends 30 dBA as an acceptable indoor nighttime noise level.

I don't present noise analyses in this paper—something that clearly needs to be done, but requires resources I didn't have—but I find that published descriptions of people's experiences in documented low frequency noise are very similar to what my study subjects noticed and described to me. If you haven't already done so, I recommend you read the section of clinical text called "Low-frequency noise" (pages xxx-xxx).

First, I quote Dr. Birgitta Berglund (the dean of community noise studies and lead editor of the 1999 World Health Organization *Guidelines for Community Noise*) on the reasons she thinks many of the adverse effects of noise in general are due to its low frequency components. She calls attention to how low frequency noise travels farther than other noise without losing its power, travels through walls and hearing protectors, rattles objects, sets up vibrations and resonances in the human body, and is linked to motion sickness even when vibration is not present. The lower frequencies can make it hard to

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distinguish sounds at higher frequencies, like speech. Noise with low frequency components is experienced as louder and more annoying than noise at the same dBA level without low frequency components. All this is discussed in the “Low frequency noise” section in the clinical text. Again, it’s well worth reading.

It’s important to remember that the term “annoyance” in community noise surveys is used as a shorthand for a variety of negative reactions. Some of them severe. “Apart from ‘annoyance,’” states the WHO, “people... exposed to community noise... report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion.”

In the clinical report, I quote as well several other small studies of situations wherein people were exposed to documented low frequency noise. For instance, the symptoms that healthy young men felt when exposed to high amplitude low frequency noise, for only 2-3 minutes, in a NASA test facility in the 1960s, included fatigue, reduced efficiency at performing tasks, tickling in the ear, chest vibrations, and a feeling of fullness in the throat—all symptoms I heard about from my study's participants.

Indeed a case report from Germany in 1996 may well be Wind Turbine Syndrome, since the source of the low frequency noise (actually infrasound, below 10 Hz) was never identified. It’s an especially interesting story. The couple’s symptoms and the intensity of noise below 10 Hz both varied with the wind and weather, and were worse in winter. Their symptoms were,

- a) sleep disturbance
- b) headache
- c) ear pressure
- d) not feeling well in a general way
- e) decreased ability/efficiency in doing things
- f) chest symptoms described as shortness of breath and a tingling/crawling sensation

Symptoms occurred when the sound pressure level at 1 Hz was 65 dB, well below the couple’s own hearing thresholds measured in a sound lab. All the frequencies responsible for the symptoms, which were all below 10 Hz, had sound pressure levels below 80 dB.

We now know that sound levels near turbines easily fall within these ranges, as measured by a Dutch physicist several years ago.

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The 1996 German case, above, and another series of cases, also by German noise control officials, both *emphasize how the symptoms and the degree to which the people were bothered increased over time after they moved into the home or apartment with low-frequency noise. They did not get used to the noise. In fact, the opposite: they became sensitized to it over time.* At first it wasn't so bad, but it grew worse and worse.

My study subjects said the same thing, as they compared turbine noise to other types of noise, like traffic, that they easily got used to. Many said that wind turbine noise would not sound loud to people who did not live with it, but several also mentioned visitors being bothered if they spent the night. When they moved away from their turbine-exposed homes, all the families moved into towns and villages with more traffic noise, but no risk of turbines being build next door.

Hence, glib claims that “you will get used to wind turbine noise,” are contradicted both by people who struggle to live with it, and by clinical evidence.

Both German case studies focused on the ability of low frequency noise, with its long wavelengths, to pass through walls and then reverberate or set up resonances inside rooms. The authors of the case series measured the difference in low frequency noise intensity near walls and away from walls, picking up nodes of higher intensity away from walls, like a standing wave in a stream.

In my study, Mr. and Mrs. G (G1 and G2) both identified a spot in one room where they got symptoms, a feeling of internal vibration for Mrs. G and the beginnings of nausea for her husband. They could not feel any vibrations with their hands if they touched walls or furniture. I think this was one of those places where the low frequency sound (air pressure) waves overlapped in such a way, as they bounced around the room, that they made a stable spot or standing wave of increased intensity.

Swedish researchers verified in a survey study of hundreds of households that the amount of noise needed for a wind turbine to cause severe annoyance was much lower than the amount of noise road traffic, airplanes, or trains would have to make to be severely annoying to as many people. “Amount of noise” was measured in dBA, which filters out the effect of any low-frequency components, and averaged over time. Fifteen percent of people were highly annoyed at 38 dBA of wind turbine noise, compared to 57 dBA for aircraft, 63 dBA for road traffic, and 70 dBA for trains. By the time the wind turbine noise level

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reached 41 dBA, 35% of people were highly annoyed. Sixteen percent reported sleep disturbance over 35 dBA of outdoor turbine noise.

When these researchers interviewed some of the people surveyed, they found the same sorts of problems I encountered in my study, including people who had moved out of their homes because of the noise or rebuilt their homes to try to exclude the noise. Some reported feeling invaded or violated by turbine noise, being sensitive to blade motion as well as noise, and the loss of their ability to rest and feel restored at home.

From this one can reasonably conclude that, for wind turbines, perhaps unlike other sources of noise, *community standards allowing 45-55 dBA outside neighboring homes are asking for trouble.*

George Kamperman and Rick James, two independent American noise control engineers with decades of experience working with industrial noise and communities, recommend a noise standard based on quietest background ambient noise and using C-weighted as well as A-weighted measurements, so that the low frequency components are also controlled. Their specific recommendations—for how the noise measurements should be done and how the procedures should be spelled out in a local ordinance—were presented at the annual conference of the Institute of Noise Control Engineering/USA in 2008 and are posted on the Wind Turbine Syndrome website at <http://www.windturbinesyndrome.com/?p=925>. An important part of Kamperman and James's method is that as turbines get larger, setbacks will have to be longer.

But the simple answer is: keep wind turbines at least 2 km (1¼ miles) away on the flat, and 3.2 km (2 miles) in mountains. These are minimum distances; Kamperman and James's methods will in all likelihood recommend longer setbacks, especially in rural areas that are very quiet at baseline.

Secondly, all wind turbine ordinances should hold developers responsible for a full price (pre-turbine) buy-out of any family whose lives are ruined by turbines—to prod developers to follow realistic health-based rules and prevent the extreme economic loss of home abandonment.